2010

Synthesis Report

ENERGY

Low Carbon Emissions Scenarios in Brazil

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THE WORLD BANK

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The Energy Sector Management Assistance Program (ESMAP) is a global knowledge and technical assistance program administered by the World Bank that assists low- and middle-income countries to increase know how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth.

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INDEX

TABLE

FIGURES

GRAPHS

ACRONYMS

ABAL - Associação Brasileira de Alumínio
ABC - Associação Brasileira de Cerâmica
ABCP- Associação Brasileira de Cimento Portland
ABIA - Associação Brasileira das Indústrias de Alimentos
ABIC - Associação Brasileira da Indústria de Café
ABICAB - Associação Brasileira da Indústria de Chocolates, Cacau, Amendoim, Balas e Derivados
ABICS - Associação Brasileira da Indústria de Café Solúvel
ABILUXA- Associação Brasileira da Indústria de Iluminação
ABIMA - Associação Brasileira das Indústrias de Massas Alimentícias
ABIP - Associação Brasileira da Indústria da Panificação e Confeitaria
ABIPECS - Associação Brasileira da Indústria Produtora e Exportadora de Carne Suína.
ABIQUIM - Associação Brasileira da Indústria Química
ABIT - Associação Brasileira da Indústria Têxtil e de Confecções
ABIVIDRO - Associação Brasileira das Indústrias de Vidro
ABM - Associação Brasileira de Metalurgia e Materiais
ABRABE - Associação Brasileira da Indústria de Bebidas
ACV - Análise de ciclo de vida
AIEA - Agência Internacional de Energia Atômica
AISI – American Iron and Steel Institute
AMS - Associação Mineira de Silvicultura
ANDA - Associação Nacional para a Difusão de Adubos
ANEEL – Agência Nacional de Energia Elétrica
ANFACER - Associação Nacional de Fabricantes de Cerâmica para Revestimentos
ANICER - Associação Nacional da Indústria Cerâmica
ANP - Agência Nacional do Petróleo, Gás Natural e Biocombustíveis
API – grau API – classificação do American Petroleum Institute, mais adotada atualmente, para classificar o petróleo de acordo com a sua densidade volumétrica, ou seja, de acordo com o seu grau API.
ATR - Açúcares Totais Recuperáveis
BB - Banco do Brasil
BEN- Balanço Energético Nacional
BEU - balanço de energia útil
BF - blast furnace
BM- Banco Mundial
BNB – Banco do Nordeste
BNDES - Banco Nacional de Desenvolvimento Econômico e Social
BOF - basic oxygen furnace
BP - British Petroleum
BRACELPA - Associação Brasileira de Celulose e Papel
Brix - Teor de sólidos dissolvidos
C - Carbono
C&T - Ciência e Tecnologia
C4 - Butano
CARB - Califórnia Air Resources Board
CB - Certificados Brancos

CBEE – Centro Brasileiro de Energia Eólica
CCAP - Center for Clean Air Policy.
CCF – cyclone conveter furnace process
CCS - Captura e Seqüestro de Carbono
CE - Ceará
CEF - Caixa Econômica Federal
CENEA- Centro de Energias Alternativas e Meio Ambiente
CEPED - Centro de Pesquisa e Desenvolvimento do Estado da Bahia
CEPEL – Centro de Pesquisas de Energia Elétrica
CEPI – Confederation of European Paper Industries
CNI - Confederação Nacional da Indústria
CO - Monóxido de carbono
CO2 – Dióxido de Carbono
CO2e - dióxido de carbono equivalente
COMPERJ - Complexo Petroquímico do Rio de Janeiro
CONPET – Programa Nacional de Racionalização do Uso dos Derivados de Petróleo e Gás Natural
COPPE/URRJ – Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa em Engenharia da Universidade Federal do Rio de Janeiro
COVs - Compostos orgânicos voláteis
CP - cimento Portland
CRESESB – Centro de Referência para Energia Solar e Eólica
CTENERG - fundo setorial de ciência e tecnologia para energia
CTPETRO - fundo setorial de ciência e tecnologia para petróleo e gás
CV - carvão vegetal
DA - Destilação Atmosférica
DCE – 1,2 dicloroetano
DIEESE – Departamento Intersindical de Estatística e Estudos Sócioeconômicos
DIOS – direct iron smelting reduction process
DNPM - Departamento Nacional de Produção Mineral
DRI - direct reduction iron
DV - Destilação a Vácuo
EAF - eleCtric arc furnace
EBAMM -ERG Biofuels Analysis Meta-Model
EC - Commission of the European Communities
EDELCA - Electrificación del Caroní
EE - Eficiência Energética
EGEE - Expert Group on Energy Efficiency
ELETROBRÁS - Centrais Elétricas Brasileiras S.A.
EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária
EPE - Empresa de Pesquisa Energética
EUA - Estados Unidos da América
FCC - Unidade de Craqueamento Catalítico
FFV - Veículos Flexíveis ao Combustível
FINAME – Programa de Financiamento de Máquinas e Equipamentos
FNDCT - Fundo Nacional de Desenvolvimento Científico e Tecnológico
FT - Fischer-Tropsch
gC - Grama de Carbono

GEDAE - UFPA – Grupo de Estudos e Desenvolvimento de Alternativas Energéticas da Universidade Federal do Pará
GEE - gases de efeito estufa
GLP - gás liquefeito de petróleo
GN - gás natural
GNC - gás natural comprimido
GNL - gás natural liquefeito
GoB - Governo do Brasil
GREET - Green House Gases Regulated Emissions and Energy use in Transportation
GTL – Gas-to-liquids
H2 - hidrogênio
H2S - ácido sulfídrico
ha - Hectare (10.000 m^2)
HCC - hidrocraqueamento
HDN hidrodesnitrogenação
HDO - hidrodeoxigenação
HDS - hidrodessulfurização
HDT- hidrotratamento
HISMELT – smelt reduction vessel process
IAA - Instituto do Açúcar e do Álcool
IAEA - International Atomic Energy Agency
IBGE - Instituto Brasileiro de Geografia e Estatística
IBS - Instituto Brasileiro de Siderurgia
Ícone - Instituto de Estudos do Comércio e Negociações Internacionais
IEA - International Energy Agency
IEDI - Instituto de Estudos para o Desenvolvimento Industrial
IFP - Instituto Francês de Petróleo
IGPM - Índice Geral de Preços de Mercado
IISI - International Iron and Steel Institute
INMETRO - Instituto Nacional de Metrologia, Normalização e Qualidade Industrial
INPE - Instituto Nacional de Pesquisas Espaciais
INT - Instituto Nacional de Tecnologia
IPCA - Índice Nacional de Preços ao Consumidor Amplo
IPCC - Intergovernmental Panel on Climate Change
IPI - imposto sobre produtos industrializados
ISR - Institute for Sustainable Resources
J - Joule
kg - quilograma
LCA - Life Cycle Analysis
LCCCS - Low Carbon Country Case Study
LFC - lâmpadas fluorescentes compactas
LI - Licença Ambiental de Instalação
LP - Licença Ambiental Prévia
LUBNOR - Lubrificantes do Nordeste
LULUCF - Land Use and Land Use Change and Forestry
MA - Estado do Maranhão
MCT - Ministério da Ciência e Tecnologia
MDIC - Ministério do Desenvolvimento, Indústria e Comércio Exterior

MDL – Mecanismo de Desenvolvimento Limpo
MELP - Modelo de Expansão de Longo Prazo
MG - Estado de Minas Gerais
Mha - Milhão de hectares
MIPE - Modelo Integrado de Planejamento Energético
MJ - Milhão de Joules
MJf - MJ do combustível
ML - Milhão de litros
MMA - Ministério do Meio Ambiente
MME - Ministério de Minas e Energia
M-Ref - Modelo de Estudo do Refino
MSR - Modelo de Projeção de Demanda Residencial de Energia
Mt - Milhão de toneladas
N2O - Óxido Nitroso
NH3 - Amônia
NIPE - Núcleo Interdisciplinar de Planejamento Energético
NOx - Óxido de Nitrogênio
NREL - National Renewable Energy Laboratory
O&M - Operação e Manutenção
O.C. - óleo combustível
ODP - Processo de Dessulfurização Oxidativa
OECD – Organiation for Economic Co-operation and Development
OHF - Open Hearth Furnace
ONG - Organização Não Governamental
NOS - Operador Nacional do Sistema Elétrico
P&D – Pesquisa e Desenvolvimento
PA - Estado do Pará
PAC – Programa de Aceleração do Crescimento
PBE - Programa Brasileiro de Etiquetagem
PCH – Pequenas Centrais Hidrelétricas
PDEE - Plano Decenal de Energia Elétrica
PDVSA - Petróleos de Venezuela SA
PE - Pernambuco
PET – politereftalato de etileno
PIB - produto interno bruto
PL - Programação Linear
PNE - Plano Nacional de Energia
PNMC – Plano Nacional das Mudanças do Clima
POAG - Plano de Otimização do Aproveitamento de Gás
ppm – Partes por milhão
PQZ - Plano de Queima Zero
PR - Progress Ratio
Proálcool - Programa Nacional do Álcool
PROCEL - Programa Nacional de Conservação de Energia Elétrica
PROEÓLICA - Programa Emergencial de Energia Eólica
PROESCO - Programa de Apoio a Projetos de Eficiência Energética
PROINFA - Programa de Incentivo às Fontes Alternativas de Energia Elétrica

PVC - policloreto de vinila
R$ - Moeda Brasileira Real
R.H. - recursos humanos
RECAP - Refinaria de Capuava
REDUC - Refinaria Duque de Caxias
REFAP - Refinaria Alberto Pasqualini
REGAP - Refinaria Gabriel Passos
REMAN - Refinaria de Manaus
RENEST - Refinaria Abreu e Lima
RENEST - Refinaria Abreu e Lima
REPAR - Presidente Getúlio Vargas
REPLAN - Refinaria de Paulínia
REVAP - Refinaria Henrique Lage
RGR-Reserva Global de Reversão
RJ - Estado do Rio de Janeiro
RLAM - Refinaria Landulpho Alves
RN Rio Grande do Norte
S - Sul
SBS - Sociedade Brasileira de Silvicultura
SE -Sudeste
SEBRAE - Serviço Brasileiro de Apoio as Micro e Pequenas Empresas
SEKAB - Svenska Etanol Kemie AB
SENAI Serviço Nacional de Aprendizagem Industrial
SIC - Serviço de Informação da Carne
SIDRA - Sistema IBGE de Recuperação Automática
SINDICERV - Sindicato Nacional da Indústria da Cerveja
SINDIFER – Sindicato das Indústrias do Ferro
SINDUSGESSO - Sindicato da Indústria do Gesso
SMR - Reforma a Vapor de Metano
SNIC - Sindicato Nacional da Indústria do cimento
SP - Estado de São Paulo
SRFT - Standard Refinery Fuel Tonne
SSP - simple superphosphate
t - tonelada métrica
tc - tonelada de cana
tCO2 - tonelada de dióxido de carbono
TIR - Taxa Interna de Retorno
TJLP -Taxa de Juro de Longo Prazo
TSP - triple superphosphate
UDA -Unidade de Destilação Atmosférica
UE - União Européia
UEE - uso eficiente de energia
ULSD - Ultra Low Sulphur Diesel
UNFCC - United Nations Framework Convention on Climate Change
ÚNICA- União Nacional da Indústria da Cana de Açúcar
UNICAMP - Universidade Estadual de Campinas
UPB - Unidade de Petroquímicos Básicos Refinaria Presidente Bernardes - RPBC

US$ - Dolares americanos
US/EPA - United States Environmental Protection Agency
US/OTA - United States Office of Technology Assessment
USDOE - Departamento de Energia do EUA
US - Universidade de São Paulo

VP - valor presente
WTO - Organização Mundial de Comércio

UNITS

BTU/h - British Thermal Unit/hour
EUR/GJ - Euro per gigajoule
Gj/t - Gigajoule per ton
Gt CO_2/yr -Gigaton of carbon dioxide per year
GW - Gigawatt
GWh - Gigawatt per hour
Kbpd - Kilos barrel per day
kg/s - Kilo per second
kg/t - Kilo per ton
kgCO_2e/l - Kilo of carbon dioxide equivalent by liter equivalent
kV - Kilovolt
kWh - Kilowatt hour
kWh/t - Kilowatt hours per ton
m3 - Cubic metre
m3/yr - Cubic metres per year
m3/day - Cubic metres per day
Mbpd - Millions of barrels per day
Mha - Millions of hectares
Ml - Millions of liters
MPa - Mega Pascal
Mt CO_2/yr - Millions of tons of carbon dioxide per year
Mt CO_2e - Millions of tons of carbon dioxide equivalent
Mt - Millions of tons
MW - Megawatt
ºC -Degrees Celsius
t - Ton
t/ha - Tons per hectare
tc - Ton of sugarcane
tCO_2 - Tons of carbon dioxide
tCO_2e/MWh - Tons of carbon dioxide equivalent per megawatt hour
TEP - Ton equivalent of petroleum
TEP/t - Ton equivalent of petroleum per ton
TJ - Terajoule
TWh - Terawatt hour
TWh/yr - Terawatt hours per year
US$/ MWh -US$ per megawatt hour
US$/bbl -US$ per barrel
W - Watt

Acknowledgments

This report synthesis the findings for the energy sector of a broader study, the Brazil Low Carbon Study, which was undertaken by the World Bank in its initiative to support Brazil's integrated effort towards reducing national and global emissions of greenhouse gases while promoting long term development. The study builds on the best available knowledge and to this effect the study team undertook a broad consultative process and surveyed the copious literature available to identify the need for incremental efforts and centers of excellences. It was prepared following consultations and discussions on the scope of the work with the Ministries of Foreign Affairs, Environment and Science and Technology. Several seminars were also organized to consult with representatives of Ministries of Finance, Planning Agriculture, Transport, Mines and Energy, Development, Industry and Trade. Several public agencies and research centers participated or were consulted including EMBRAPA, INT, EPE, CETESB, INPE, COPPE, UFMG, UNICAMP and USP.

The Brazil Low Carbon Study was prepared by a team lead by Christophe de Gouvello, the World Bank and covers four key areas with large potential for low-carbon options: (i) land use, land-use change, and forestry (LULUCF), including deforestation; (ii) transport systems; (iii) energy production and use, particularly electricity, oil and gas and bio-fuels; and (iv) solid and liquid urban waste. The present document is supported by more than 15 technical reports and four synthesis reports for the four main areas.

This study was supported by the World Bank through funds made available from the Sustainable Development Network for regional climate change activities and through support from the World Bank Energy Sector Management Assistance Program (ESMAP).

This synthesis report on Energy was prepared by a team coordinated by Roberto Schaeffer and Alexandre Sklo, COPPE-UFRJ and Christophe de Gouvello, The World Bank, and composed of Manoel Regis Lima Verde Leal, CENEA; João Eduardo A.R. Silva, Universidade de São Carlos; Fábio Marques, Rodrigo Ferreira, Luiz Goulart, and Thiago Mendes PLANTAR; Roberto Schaeffer (coordinator energy), Alexandre Szklo, Amaro Pereira, Bruno Soares Moreira Cesar Borba, André Frossard Pereira de Lucena , David Castelo Branco, and Antonio José Alves, COPPE-UFRJ; Maurício Henriques, Fabrício Dantas, Márcio Guimarães, Roberto S. E. Castro Tapia, Joaquim Augusto Rodrigues, Marcelo R. V. Schwob, Fernanda M. Bernardes, INT; Arnaldo Walter, Gilberto Jannuzzi, and Rodolfo Gomes, UNICAMP; Sérgio Pacca and Júlio Hato, USP.

The World Bank supervision team of the whole Low Carbon Study included Christophe de Gouvello, Jennifer Meihuy Chang, Govinda Timilsina, Paul Procee, Mark Lundell, Garo Batmanian, Adriana Moreira, Fowzia Hassan, Augusto Jucá, Barbara Farinelli, Rogerio Pinto, Francisco Sucre, Benoit Bosquet, Alexandre Kossoy, Flavio Chaves, Mauro Lopes de Azeredo, Fernanda Pacheco, Sebastien Pascual and Megan Hansen.

Executive Summary

The current challenge of global climate change requires proactive measures to be taken to reduce Greenhouse Gas Emissions (GHG). The key international agreement in this regard is the Kyoto Protocol which sets binding targets for certain countries for reducing GHG emissions by at least 5.2% over 1990 levels during the period 2008 to 2012.

Brazil, although not possessing its own emissions reduction targets within the Kyoto Protocol for this period, is nevertheless party to the discussions about the need for countries to reduce emissions. Brazil is one of the signatories of the United Nations Framework Convention on Climate Change (UNFCCC) which commits all signatories, regardless of their current or past responsibilities for emitting polluting gases, to stabilize GHG emissions.

A strong possibility exists within the context of the Kyoto Protocol that developing countries which are potential major emitters of GHG such as Brazil, China and India could, in the post-2012 climate change regime, be included in the group of countries committed to reducing emissions.

The fact that Brazil is deeply committed to the climate change question and increasingly concerned with reducing GHG emissions raises a number of important issues that need to be addressed by public and private sector decision makers and to involve the population as a whole.

By way of a contribution to combating the profound changes in the world's climate, the present study seeks to identify how it would be possible for Brazil to reduce GHG emissions in the energy sector over the next 20 years without restraining the country´s economic development.

Renewable sources are a major feature of Brazil's energy matrix, which means that emissions produced by the power sector are relatively low compared with those of highly industrialized countries. Nevertheless the growth foreseen in the country's energy sector could significantly increase emissions.

The main aim of the study is to examine the potential for abating GHG emissions in Brazil in the energy area and to assess the relative costs of doing so for the time frame 2010-2030. Basically the study seeks to demonstrate by how *much*, by *when* and at what *cost* Brazil could reduce its GHG energy sector emissions. Given its special features, the fuel use and emissions of greenhouse gases in the transportation sector are dealt with in another report of this project.

In addition the study aims to provide information for the Brazilian government to enable it to develop a long-term strategy (2030) for reducing carbon in the energy area (except the transport sector) and, more specifically, to provide the technical input needed for evaluating the potential for reducing greenhouse gas emissions produced by the key economic sectors.

In short, the study seeks to identify the different options and opportunities that could justify possible international resources being allocated to Brazil. The teams involved in the study needed first to focus on the proposed mitigation and carbon sequestering options and then, after identifying these proposals, to focus on existing barriers to the successful deployment of these options and suggest a set of public policies which could be mobilized to overcome them. The study also provides estimates of the scale of investments and operating costs likely to be involved, as well as a mitigation cost curve.

The study is based upon the four-stage approach developed by the World Bank, namely:

1. To establish a Reference Scenario with a view to anticipating the future evolution of GHG emissions in Brazil that is consistent with the Brazilian government's long-term goals.

2. To identify and quantify the lowest carbon-producing options for mitigating or sequestering GHG emissions.

3. To evaluate the costs relating to the carbon reduction options identified, to identify the main obstacles to the immediate adoption of these options and to explore possible ways of overcoming these obstacles.

4. To construct a Low Carbon Scenario to reflect the long-term objectives of the Brazilian government.

Using this approach, the study analyzes the macroeconomic impact of the change from a Reference Scenario to a Low Carbon Scenario and the accompanying financial implications.

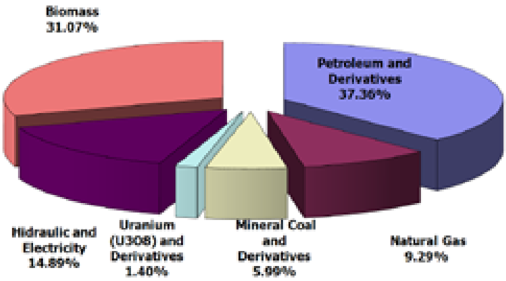
The study forms part of the final report prepared by the World Bank – *The Low Carbon Scenario for Brazil* - which includes sections covering:

- The reduction of emissions associated with land use, land use change and forestry (LULUCF) , including deforestation;
- The promotion of more efficient and less carbon-intensive mesures in transport systems; and
- The reduction or capture of GHG emissions produced by urban waste.

1. Introduction

Compared with international levels the quantity of greenhouse gas emissions (GHG) from the Brazilian energy sector is relatively low. This is due to the widespread use of renewable sources in the national power matrix. According to the annual National Energy Balance Report, 45.9% of Brazil´s domestic energy supply in 2007 was produced from renewable sources, while in 2006 the world average was 12.9% and in OECD countries only 6.7% (MME, 2008a). This is basically due to the use of hydropower (accounting for 74.3% of total internal supply of electricity) and energy produced by biomass (mainly alcohol, sugarcane bagasse and charcoal) in the energy matrix. Graph 1 below illustrates the structure of domestic primary energy supply.

Graph 1 – Internal Energy Supply in Brazil: Energy Sources (2007)



Source: MME, 2008a.

In 2005 the energy sector in Brazil (including transport sector), was responsible for 329 million tons equivalent of carbon dioxide [1] compared with a world total of around 27 billion tons, amounting to around 1.77 tCO_2 per year per inhabitant (Brazilian), compared to an average total worldwide of 4.2 tCO_2 and 11.02 tCO_2 *per capita* in OECD countries (IEA, 2007a).

These figures demonstrate that Brazil occupies 17th position in the ranking of GHG emitters in the energy area - a mere 1.2% of global emissions. In the electricity generation sector Brazil is in 65th position, accounting for under 0.5% of global emissions produced by the sector (Frischak, 2009).

In terms of global climate change (GCC) Brazil is thus well ahead of most other countries in the energy area, particularly in the electric power generation sector. The fact that Brazil draws much of its energy from renewable sources guarantees a low emission factor by reducing the country's potential for mitigating emissions produced by the energy sector. In short, Brazil's current situation in the energy sector looks extremely positive in terms of GCC.

If Brazil possessed an energy matrix in line with average world standards, emissions in the energy area would be almost 60% higher than at present, making this country the 9th biggest GHG emitter in the sector (just behind the USA, China, Russia, India, Japan, Germany, Canada and the United Kingdom), putting it almost on a par with the emissions produced by the British energy system. This comparison was arrived at by rearranging the data referring to three key

1 The situation is very different when the emissions produced by land use change are taken into account. The Brazilian case is atypical. At present 75% of the GHG emissions of Brazil are a consequence of emissions which have nothing to do with the energy sector (land use change, livestock rearing etc). This situation significantly affects Brazil's contribution to GHG global emissions. If land use and land use change are left out of the equation, Brazil is the world's eighth largest emitter of GHG, with 2.3% of global emissions. However, if land-use change is taken into account, Brazil rises to fourth position after the United States, Russia and China - with 5.3% of global emissions).

sectors in Brazil's energy system[2]:

1) *electricity generation*: assuming an emission factor from electricity production by the national grid equal to the world average of 522.5 gCO_2/kWh (WRI, 2009).

2) *transport*: assuming the use of C gasoline instead of hydrated ethyl alcohol (currently used in flexible fuel vehicles in Brazil).

3) *industry*: assuming the use of mineral coke instead of charcoal from renewable plantations - considered to be 50% of the total charcoal used by industry as a whole (AMS, 2008).

In the above hypothetical situation, emissions from the energy sector in Brazil in 2005 would have amounted to almost 200 $MtCO_2$ higher, as can be seen in Table 1 below. It is clear that the most substantial contribution to low carbon emissions in Brazil is the low emission factor of the national grid resulting from the use of hydroelectricity. Indeed only for the energy sector, the emissions of greenhouse gases increases by more than 6 times using the average emission factor of the world grid.

Table 1 – Increase of Brazilian emissions ($MtCO_2$)
assuming Brazil´s energy system similar to world average

	2000	2001	2002	2003	2004	2005	2006	2007
Electricity generation	154.8	143.4	152.4	161.1	169.9	177.1	183.7	195.7
Industry	9.7	8.8	9.2	10.9	12.9	12.7	12.3	12.7
Transport	16.7	15.4	17.5	16.6	18.5	20.0	18.4	24.7
Total	181.2	167.6	179.1	188.7	201.3	209.8	214.4	233.1

The expansion of electricity supplied from renewable sources in Brazil (by, for example, the major hydroelectric plants) neverthless faces a number of challenges, given that in due course a significant growth of energy supplied from carbon-emitting sources (as for example thermal plants fired by coal, combustible oil and natural gas) is expected, regardless of the fact that the government´s official studies do not yet reflect this development. This is the case of, for example, the National Energy Plan "PNE 2030" (EPE, 2007), which we have used as the baseline Reference Scenario in the present study.

A series of other developments could also cause the situation to deteriorate. For example, the possible increase in the use of petroleum derivatives (especially diesel) resulting from the growth of the agroindustry and freight transport sectors in Brazil, together with the possible increased consumption of metallurgical coal used by the country's steelmaking industry. In view of the potential impacts on climate change, Brazil has a responsibility to contribute actively to international efforts to stabilise GHG concentrations.

The above picture underscores the importance of studying the special features and peculiarities of the Brazilian energy system and to plan its development on the basis of scene-setting exercises focused on the emissions arising from the production and consumption of energy. In his way it will be possible to identify the potential for reducing emissions in the sector and the related costs of abatement. As highlighted before, the energy sector is analyzed excluding the case of the transport sector that is emphasized in another report.

2 These estimates are simplifications employed to give an overall idea of the degree of importance of renewable energy sources in Brazil. If the standards of the Brazilian energy matrix were similar to those common to the rest of the world, its industrial and transport profile would be somewhat different in local terms. The higher proportion of electricity-intensive industries in Brazil such as primary aluminum and sodium chloride manufacture can be justified by the low cost of electrical energy in the country, which basically depends for its electricity on hydro plants. Moreover, other factors are not taken into account which have an impact on the low emissions of the Brazilian energy sector such as the relatively high number of low powered passenger vehicles.

2. General Methodology of the Energy Sector Study

The aim of this study was to develop two carbon emissions scenarios associated with the supply and demand of energy up to 2030. In the event we were able to determine the potential for reducing greenhouse gas emissions as well as the respective costs of moving from a Reference Scenario to a Low Carbon Scenario in the Brazilian energy system.

The study adopted the "wedges" method to represent units of global carbon mitigation in the energy sector. The use of wedge diagrams, as proposed by Pacala and Socolow (2004), made it possible to identify the relative impact of alternatives for reducing emissions by evaluating future scenarios (showing time plotted along the abscissa and the quantity along the ordinate expressed in Gt CO_2/year).

The Reference Scenario considered by the study was the *2030 National Energy Plan* (PNE 2030) developed by Brazil´s Energy Research Company (EPE [3]). On the other hand the Low Carbon Scenario was prepared by analyzing the mitigation options produced by our study teams focused on different themes related to the energy system.

We chose to work with the PNE 2030 since it was the most recent publicly available official long-term plan for the Brazilian government's energy area. Since this plan was published by EPE in 2007 it obviously failed to take into account the effects of the recent global economic crisis in its macroeconomic analysis. A further downside to the PNE 2030 is that it predicted an increase in the use of Brazil´s still under-exploited hydro potential. This has not materialized in view of the many legal and environmental difficulties involved in getting the planned hydro plants constructed and operating. Meanwhile, the most recent energy "auctions" [4] would appear to indicate that more thermal electric power plants will be brought into use in due course.

Notwithstanding the above factors (which could possibly be considered as still marginal to the main energy debate) the PNE 2030, given its technical and economic consistency projected over the long-term, nevertheless proved to be a key tool for providing a succint picture of the Brazilian energy sector.

As for the Low Carbon Scenario, this study examined the mitigation options (which were not considered in the PNE 2030) presented by our work teams responsible for each of the 7 sectors addressed by our study. This made it possible to gauge the potential for reducing greenhouse gas emissions over the period 2010 - 2030, as well as the costs involved.

In the Low Carbon Scenario we sought to ensure technical consistency between all the sectors and mitigation options by avoiding calculating the possible effects of divergent or contradictory measures, thereby avoiding double-counting and/or inconsistencies. However, since not all the energy supply and demand sectors were covered in the study, an integrated optimization of the entire energy system was not possible.

3 The Energy Research Company is a public body linked to the Ministry of Mines and Energy. Its remit is to provide services in terms of studies and research to underpin the planning of the energy sector. Studies and research are undertaken on electric energy, oil, natural gas and derivatives, charcoal, renewable energy sources and the whole question of energy efficiency.

4 In an effort to contain this development the Brazilian government launched in April 2009 a Normative Directive obliging coal and oil thermal electric plants to mitigate their CO_2 emissions. The likely result of this is that the product of such plants will be more expensive and could undermine the competitive status that they currently enjoy. The new plants will have to compensate for a least one third of their emissions by planting "reforestation" trees in regulated plantations and the other two thirds would need to be mitigated by firms investing in renewable energy generation or taking other measures to promote energy efficiency. In this way, the measure could possibly re-direct the basic thrust in the Brazilian energy sector back towards the use of hydroelectricity.

The following sectors were addressed in the course of the study [5]

<u>Electricity</u>
Supply
Hydroelectricity [6]
Wind (aeolic) energy[7]
Cogeneration from biomass [8]
Demand
Energy efficiency in electricity consumption [9]

<u>Oil and gas</u>
Supply
Refining and GTL [10]
Demand
Emissions reductions from industrial use of fossil fuels [11]
Replacement by biomass
Ethanol [12]

The study did not address the increased generation of nuclear energy in the national electricity matrix as a mitigation option. The Low Carbon Scenario does not take into account the establishment of more nuclear plants in addition to those mentioned in the Reference Scenario, given the improbability of more than six new nuclear plants being constructed in Brazil over the next 20 years (the PNE Reference Scenario refers to between 4 and 6 new plants).

This is basically due to the need for lengthy advance planning, including the selection of the ideal location for new nuclear plants, licensing, acquisition of specific equipment (manufactured exclusively abroad), as well as the long construction period involved in new nuclear facilities, which could be anything between five to eight years. For example, in the United States and France it is reckoned that new nuclear plants being planned or under construction require a minimum of five years before going on stream.

Similarly, the study did not regard any increased use of hydro power for generating electricity as a mitigation option. Despite the fact that only around 30.9% of Brazil's hydroelectric potential has been exploited to date (EPE, 2008), it is expected that any expansion of electricity supply produced by large hydro plants is likely to run into difficulties, mainly in the environmental licensing field. As a result, a significant increase in electricity supply produced by carbon-emitting sources such as fuel oil and coal plants cannot be ruled out.

The prospect of limited further expansion of hydroelectric power risks giving the impression that the country is on the way to making its electrical energy generation matrix less 'climate friendly' than hitherto. However, it must be remembered that even with the structural changes expected in the electricity sector, the extra emissions produced by the sector will not be particularly significant over the longer term. According to Frischtak (2009) the increase in emissions following modifications to the electricity matrix are likely to account for only between 1% and 3% of the country's total emissions.

A further factor needs to be taken into account. Lucena *et al* (2009) argue that the national

5 This study also identified the potential for (and the costs of) reducing GHG emissions in the transport sector. This is described in a separate report (*Transport Report*).
6 Hydroelectricity: main author Sergio Pacca (University of São Paulo)
7 Wind Energy: main author Barbara Farinelli (World Bank)
8 Cogeneration of Biomass: main author Arnaldo Walter (UNICAMP)
9 Energy Efficiency: main author Gilberto Jannuzzi (UNICAMP
10 Refining and GTL: main author Alexandre Szklo (COPPE)
11 Industry: main author Mauricio Henrique (INT)
12 Ethanol: main author Manoel Regis L.V. Leal (CENEA)

energy system is vulnerable to climate change and that it is possible that hydro electricity could decline over the longer-term as a result of the lower water levels in the rivers, as predicted by the IPCC.

Finally, we considered a number of mitigation options which, despite their costs being incurred wholly within Brazil, would appear to hold out the prospect of preventing (or at least reducing) the negative impacts of greenhouse gas emissions in the wider world. One example would be for Brazil to increase its ethanol exports to displace gasoline in vehicle engines in other countries. It could even export Brazilian hydroelectricity to neighboring countries, which would have the effect of reducing emissions from their own grids. These additional considerations are addressed in the chapters below.

The analysis of mitigation alternatives considered by each study group made it possible to quantify the potential for reducing the greenhouse gas emissions of each energy sector. The estimates were based on the sum total of emissions avoided as the result of the mitigation options examined for each sector. In other words, the scale of the emissions that can be reduced in the energy area during the period 2010-2030 can be determined and set alongside the PNE 2030 Reference Scenario.

2.1 ***Economic Analysis***

In our study we estimated the marginal abatement costs for the 2010-2030 period of each mitigation option. These are presented in the form of marginal abatement curves. The study also identified the carbon price that would make the mitigation option analyzed for the 2030 time horizon economically viable (*Break Even Carbon Price*).

2.1.1 Marginal Abatement Cost Curves

The marginal abatement cost curves (MAC) of greenhouse gas emissions consist of graphs showing the economic attraction of mitigation options arising from their GHG mitigation potential. MAC have been widely used for analyzing GHG mitigation policies. To construct the marginal abatement curves, mitigation options are applied to the emission baseline of each economic or technical/activity or sectoral/program.

The marginal abatement cost curves at the technical/activity level call for simple techniques and models, such as a cost/benefit analysis, requiring fewer data and being easier to interpret and understand. This approach however deals only with technical /activity information and fails to capture the impacts of the activity on the various sectors of the economy. It follows that the technological options for mitigating GHG that could have an impact on the economy as a whole are not accurately identified by using this method.

The sectoral/program MAC are generated by comparing a portfolio of GHG mitigation options in a Low Carbon Scenario with the existing baseline options. Optimization tools (e.g. linear and dynamic programing) are normally used to create a baseline and emission reductions scenarios. This approach has been commonly used in the energy sector for planning purposes. The method addresses both the direct and indirect effects of a GHG mitigation option throughout the entire energy sector. It is more realistic than the technical method since it takes account of the sector-specific/sub-sectoral effects (but not the effects on the whole economy). Two disadvantages: (i) this method requires sectoral/subsectoral models based on a very substantial quantity of data and (ii) the inter-sectoral effects are not calculated.

The economic abatement curves are generated in the same way as by the sector-specific approach. The advantage of this method is that it calculates the abatement effects of technological options in other sectors of the economy. General equilibrium models are normally employed in this type of analysis. This approach takes account both of the direct and indirect effects of a GHG mitigation option on the entire economy. Although the abatement costs obtained with this modeling can be more realistic, modeling exercises of this kind are constrained by limited data. Interpretation of the findings can also prove difficult for those with no economic expertise.

Considering the advantages and disadvantages of each of these approaches, and taking into account data availability and the overall objective of this study, we decided to use the technical/activity approach. In this method the abatement cost curves are generated by making a peer-to-peer comparison between the technological options for GHG mitigation and the baseline technical options (in other words technologies that would have been used instead of mitigation options). In this approach the net present value of the baseline technological option is normally compared with the Low Carbon Scenario option. The aim of the study is however not only to compare *baseline* and *abatement* technologies in a static analysis but also to develop a reduction path for the emissions by considering possible scenarios for the penetration of the abatement technologies and measures. In this way annualized (or leveled) costs were used to calculate the abatement cost of each alternative. Assembling the alternatives and their respective potential for emissions reduction enabled construction of the abatement cost curves.

The marginal abatement cost of each mitigation option was determined on the basis of the incremental cost arising from the deployment of the measure compared with the baseline and annual avoided emissions, in accordance with the following equation:

$$CA^{opção} = \frac{CAL^{baixocarbono} - CAL^{base}}{EA^{base} - EA^{baixocarbono}}$$

Where "CA" represents the marginal abatement cost of a ton of CO_2 avoided of each mitigation option; "CAL" represent the annual net cost; and "EA" represents the annual emission in each scenario.

The net annual cost (CAL) represents the difference of the annualized investment cost and of the annual financial cost of implementing the option. This financial result is given by the total income and expenditure on the operation and maintenance resulting from implementation of the option.

$$CAL = \frac{INV.r.\frac{(1+r)^t}{(1+r)^t - 1} + OM + COMB - REC}{(1+r)^{(n-2009)}}$$

Where "CAL" represents the annual net cost of deploying the option; "REC" is the income; "OM" is the cost of operation and maintenance; "COMB" represents fuel costs; "INV" represents the investment cost; "r" is the discount rate; "t" is the estimated operating lifetime of the project; and "n" is the year of analysis.

This methodology serves to calculate the marginal cost abatement curves based on the comparison of alternatives according to the same discount rate - in this case the discount rate used in the PNE 2030 (8% per year).

2.1.2 Break Even Carbon Price

In order to provide another way of analyzing the viability of implementing the mitigation options the necessary incentives were also evaluated (carbon price) in order to obtain the

Internal Rate of Return (IRR) of the sectors. A level of incentive was estimated which could be offered to the economic players in the hope that the mitigation alternatives would be more attractive than the options considered in the Reference Scenario. The aim was to identify how a GHG reduction option could be attractive from the private sector´s point of view.

This incentive was calculated so that the Internal Rate of Return of the low carbon alternatives would be the same as the IRR desired by agents in the particular sector where the option would be implemented, as can be seen in Table 2 below. The incentive was expressed in terms of tons of carbon dioxide avoided (*Break Even Carbon Price*).

Table 2 – Sectoral IRR

Sector	IRR expected by sector agents
Industrial	15%
Cogeneration	18%
Wind	15%
Residential	79%
Commercial	15%
GTL	25%
Refining	15%

It was decided to undertake this analysis given that in practice investors are generally more interested in their rates of return when making decisions. Once investors have an idea of the different risk levels and different types of technologies, their expected rates of return vary accordingly. As observed, in the majority of the sectors the IRR is 15% a year. However for some measures the rates are different. For example, the rate in the case of GTL projects was 25% a year, while the IRR for cogeneration projects in sugarcane plants was 18% per year.

The GHG mitigation projects with a rate of return of less than the sectoral IRR would be incapable of attracting private financing without the introduction of additional incentives such as ‘carbon credits’. In this study the level of such incentives is interpreted as *break even* costs since they represent the size of the incentive needed to bring the benefits and costs up to the level of the sectoral IRR. If the *Break Even Carbon Price* for a GHG mitigation option is negative it follows that the application of this kind of measure is economically attractive.

On the other hand if the *Break Even Carbon Price* is positive the option is not attractive because it is unable to generate the sectoral IRR necessary in the absence of *break even* incentives.

Quantifying potential and financing requirements involved our study teams in evaluating the barriers to implementing the mitigation options and proposing a number of possible alternatives for overcoming such barriers.

2.2 Mitigation Options

‘Mitigation options’ represent the options considered for each subsector involved in this study. The options seek to prevent or reduce the quantity of greenhouse gas emissions in Brazil caused by the production and consumption of energy. These options were proposed in the PNE 2030, which forms the Reference Scenario for our study.

In this report the mitigation options of the areas listed below are set out in detail (a total of 25 options).

Energy Demand Side

- Energy efficiency in electricity consumption
- Emissions reductions from industrial use of fossil fuels

Energy Supply Side

- Cogeneration from biomass
- Wind energy
- Refining and Gas-to-Liquid (GTL)

Our study also considered mitigation options which, in spite of having a cost incurred within Brazil, also seek to prevent or reduce the negative impacts of carbon emissions on other countries, or simultaneously in Brazil and a neighboring country. This is the case for example of the increased production of ethanol for export as a substitute for gasoline and the case of the Brazilian hydroelectric plants on the right bank of the Amazon River linked to the Venezuelan hydro plants on the left. These additional options will be presented at the end of the study. The following options were also proposed:

Additional options:

- Ethanol
- Hydroelectricity

Of the 25 mitigation options considered, 4 are in the residential sector, one in the cogeneration sector, one in the commercial sector, 5 in the refinery sector, 13 in the industrial sector and one in the wind energy sector.

Our paper sets out the mitigation options related to the supply and consumption of electricity and to the supply and consumption of non-vehicle fossil fuels. The mitigation options related to the consumption of vehicle fuels are detailed in *The Low Carbon Scenario for Brazil* report under "Transport Sector ".

2.3 Potential for reducing emissions and Marginal Abatement Cost

This potential refers to reductions of carbon emissions arising from the change from a Reference Scenario to a Low Carbon Scenario, or in other words the maximum potential for abating greenhouse gases of each of the options considered in the energy sector over the timeframe 2010 - 2030.

2.4 Barriers against the implementation of low carbon options

In the previous section we estimated the marginal abatement cost of each mitigation option using two approaches: the first using the same social discount rate and the second the *Carbon Break Even Price*. Based on these results this section evaluates the market-related, technological and regulatory barriers to the implementation of the proposed options. It is important to emphasize that these are sector-specific barriers: barriers against one particular mitigation option for one specific sector do not necessarily apply to the whole of the energy sector.

2.5 Existing and proposed measures

Under this item we present the measures that already exist in Brazil which either favor or impede implementation of the proposed options. We also discuss the possible incremental, substitution, curtailment or adjustment measures that could be used to overcome the barriers discussed in the previous chapter.

3. Reference Scenario for the energy sector

The Reference Scenario represents a 'trend scenario' for the evolution of the energy sector in Brazil. This scenario presents market baseline features without major qualitative changes while retaining the natural ebb and flow of energy supply/demand and technological development/ evolution. This scenario therefore does not cover many options associated with the mitigation of greenhouse gas emissions.

In order to impart greater credibility to the study and hopefully to help contribute to Brazil's energy policies, we used as our Reference Scenario the most recent publication on the sector, the PNE 2030 published by the Energy Research Company (EPE). The PNE 2030 contains analyses and surveys aimed at providing information to assist the formulation of a strategy for expanding energy supply in response togrowth of demand. The PNE in effect provides a long-term view of the integrated and sustainable use of available energy resources in the country.

The study teams consulted the EPE frequently in order to confirm the EPE´s agreement in principle for them to use the PNE to assist with the establishment of the Reference Scenario and also as a way of gaining first hand access to the assumptions and hypotheses employed by the EPE in the PNE 2030. The basic goal was to ensure that our work was in line with this documentary source, especially with regard to the interfaces with other sectors included in the study (e.g. transport, agriculture, waste etc).

3.1. Methodology of the Reference Scenario (PNE 2030)

The PNE 2030 employed a parametric technical-economic model called the *Integrated Energy Planning Model* (MIPE) as the main instrument for simulating end-use consumption of energy in Brazil. This model was developed in the Postgraduate Engineering Programs Coordination Unit (COPPE) of the Federal University of Rio de Janeiro (UFRJ).

The PNE 2030 applied the *Model for Projecting Residential Energy Demand* (MSR) developed by the EPE, specifically to electrical energy consumption in the residential sector. The PNE 2030 also used the *bottom-up* [13] type model in which residential consumer demand can be obtained on the basis of numbers relating to the ownership and use of domestic electrical appliances. Calculation of the model was done on the basis of 'ownership and use' surveys produced by the National Electric Energy Conservation Program (PROCEL) coordinated by ELETROBRÁS. Application of the model enabled assumptions related to energy efficiency in this consumer segment to be incorporated.

On the supply side, two specific models were applied in order to evaluate the transformation of primary energy: the *Refinery Study Model* (M-Ref) developed in the PPE/COPPE and used for measuring growth of the oil refining sector in response to projected demand for petroleum derivatives, and the *Long-Term Expansion Model* (MELP) produced by the Electric Energy Research Center (CEPEL).

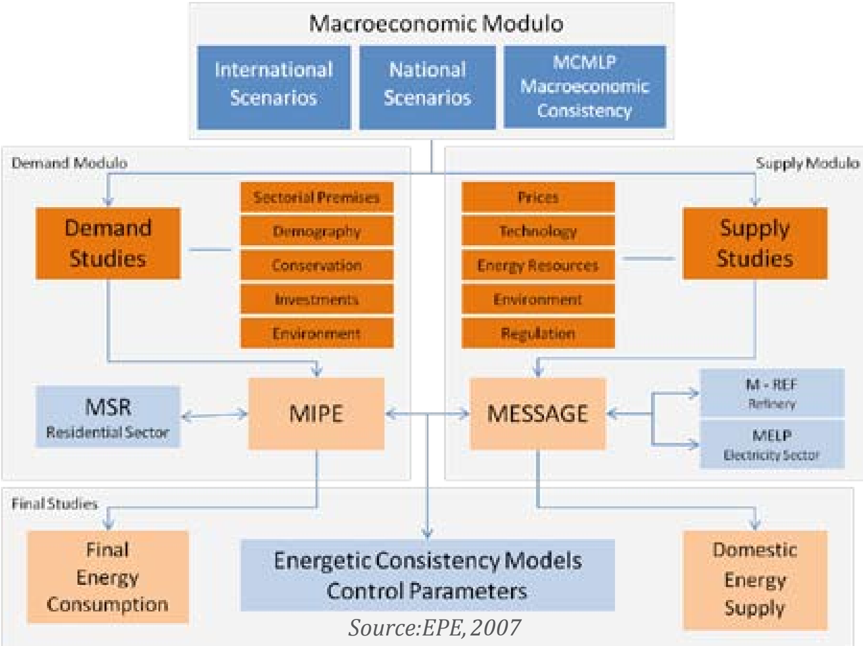
The MELP is an optimization model consisting of two versions (one which employs linear programing and the other mixed-integer programing). This model enables solutions to be found for expanding electrical energy supply while (i) minimizing the costs of expansion and operation and (ii) taking into account the investment costs involved in expanding inter-connections between subsystems. The MELP model is invaluable for dealing with the characteristics of Brazil's electricity system, particularly with regard to the location of potential hydro plants vis-à-vis major consuming centers.

13 A disaggregated model which involves modeling on the basis of demand vis-à-vis supply.

All the results obtained in the PNE 2030 supply and demand studies were assembled by applying the model known as *Message* formulated by the International Atomic Energy Agency (*Model of Energy Supply Systems and their General Environmental Impacts*). The *Message* model selects the means for energy production needed to meet demands for useful energy in such a way as to minimize the operation and maintenance costs for the entire energy system over the period under observation. It is a 'linear programing' model that can be applied to the energy system as a whole. The model analyzes the possible substitutions between energy sources in the different transformation centers by the level of end-consumption, subject to user-defined constraints imposed by available potential (reserves and electricity generation and transmission capacity) and the levels of environmental impact (e.g. maximum limits of atmospheric emissions etc).

In this way the PNE 2030 was able to provide a picture of the evolution of the composition of internal demand for energy and enable forward hypotheses to be formulated regarding the Brazilian Energy Matrix over the next 25 years. Figure 1 below illustrates this.

Figure 1 – PNE 2030: Calculation Models Used



Source:EPE, 2007

3.2 Describing the Reference Scenario (PNE 2030)

The PNE 2030 is the Brazilian government´s most recent long-term study on the country´s energy system. Although other official studies have been published since, none of these has possessed the wide coverage of the PNE 2030 in terms of consistent simulation of all the energy chains existing in Brazil. Sectoral studies for electricity, petroleum, gas and ethanol etc were incorporated in the present study based on PNE 2030 analyses.

For the purposes of our study, 'Scenario B1' of the PNE 2030 projection was employed given that it represents an "intermediate" baseline scenario i.e. based on an average economic growth rate for Brazil. The main macroeconomic data - GDP growth and population increase – relevant to this scenario are presented in the following table.

Table 3 – Basic parameters of the PNE 2030 – Macroeconomic

Parameters	2010	2020	2030
Population (000 inhabitants)	198,040	220,086	238,555
GDP (10^9US$ [2005])	955,8	1,377,4	2,133,2

Source: EPE, 2007

Brazil's average annual GDP growth is expected to be 4.1% per year, with the services and agriculture sectors growing at an average of 4.2% and the industrial sector at 3.7%. The main energy data recorded by the PNE 2030 are as follows:

Table 4 – Basic parameters of the PNE 2030 – Energy

Parameters	2010	2020	2030
Petroleum WTI (US$/bbl)	40	45	45
Emission factor of electricity (tCO_2e/MWh)	0.094	0.069	0.079
Average cost of expansion (US$/MWh)	56.9	56.4	55.9

Source: EPE, 2007

According to EPE (2007), the average emission factor of the Brazilian grid will increase from 0.094 tCO_2e/MWh in 2010 to 0.069 tCO_2e/MWh in 2020 and to 0.079 tCO_2e/MWh in 2030. In order to construct an annual analysis in the present study we have interpolated the average emission factor of the grid for the periods 2010 - 2020 and 2020 - 2030.

As already mentioned, the likelihood exists of more thermal electric plants being brought into operation in the Brazilian energy system. This development was not projected by the PNE 2030. If this situation materializes and continues over the long-term, the average emission factor of the Brazilian grid will be higher than that forecast by the EPE. Thus the low carbon analysis done in this study using the PNE 2030 as the Reference Scenario will turn out to be 'conservative' if the use of hydroelectricity, for example, in the Brazilian energy system is not as substantial as that projected by the EPE.

Even if the proportion of renewable sources increases in the energy matrix, the emissions level is likely to increase in the years up to 2030 according to EPE expectations. Total emissions of just over 970 million tons of CO_2 by 2030 are expected.

The transport [14] and industrial sectors are likely to be the largest contributors to emissions growth over the long-term. However electricity generation will produce the highest emissions increase over the 25-year period. This will amount to a year on year increase of around 7%, meaning that the electricity sector's share of total emissions will increase from 6% in 2005 to over 10% in 2030.

The increased emissions levels are a cause for concern in Brazil: an evident need exists to undertake measures and provide incentives for encouraging initiatives to be taken to reverse this trend. While on the one hand the country's development would appear to make it impossible to reverse the growth of emissions, on the other hand efforts need to be made to ensure that economic development can progress without increasing the specific volume of emissions.

The Reference Scenario employed (PNE 2030) is relatively carbon unintensive due to the expected share in energy production of nuclear and hydroelectric plants. However, as

14 This sector is not addressed in this report but in a separate document (*Transport Report*)

mentioned above, the PNE forecasts do not take into account the fact that these two energy sources face challenges in the environmental licensing area and lengthy construction times before they can be brought into operation. The ensuing delays could pave the way for more intensive use of thermal sources. Moreover, some of the low carbon measures included in the Reference Scenario are not yet assured, meaning that perhaps the levels of financing necessary to achieve the Low Carbon Scenario will be higher than those considered in this study with respect to the transition from the Reference to the Low Carbon Scenario. These doubts would seem to corroborate the conservative nature of the present study and probably indicate that the mitigation potential may turn out to be somewhat lower in Brazil´s case.

The next sections of this chapter deal with the Reference Scenario relating to the sectors involved in energy supply and end use on which our study has analyzed the alternatives for carbon emissions mitigation. Note that the details presented are derived from estimates of greenhouse gas emissions drawn up by our work groups on the basis of PNE 2030 data.

3.3 Reference Scenario - Energy Demand

3.3.1. Energy efficiency in electricity consumption

The Reference Scenario under consideration referred to the continuation of the use of conventional technologies in the three sectors under this heading: *residential*, *industrial* and *commercial*.

For the baseline year (2009) the emissions from end-use consumption by the *residential* sector considered in the present report amount to 394,000 tons of CO_2 equivalent, while electricity consumption, taking into account transmission and distribution losses, is 4.2 TWh (Table 5).

For the Reference Scenario relating to the residential sector for the end uses considered in this report the emissions in 2030 are 11 times higher than those for 2009. The consumption of electricity is 13 times higher. It was noted that domestic refrigerators alone are responsible for 60% of these increases. Tables 6 and 7 below give an idea of electricity consumption and emissions for year 2030 and the aggregated figures for consumer end uses considered here.

Table 5 –Estimate of emissions of CO_2 (in tCO_2)
and electricity consumption in 2009 (in MWh): Residential Sector

	Emissions (tCO_2)		Electricity consumption (MWh)	
End use appliances	2009	%	2009	%
Electric showers	23,320	6	248,170	6
Refrigerators	137,972	35	1,468,292	35
Air conditioning equipment	27,247	7	289,958	7
Lamps	205,565	52	2,187,610	52
TOTAL	394,104	100	4,194,030	100

Table 6 – Estimate of emissions of CO_2 for the period 2009-2030: Residential Sector

	Emissions (tCO_2)		Accumulated total 2010-2030
End use appliances	2009	2030	
Electric showers	23,320	435,028	3,970,674
Refrigerators	137,972	2,720,299	21,731,407
Air conditioning equipment	27,247	794,412	6,847,418
Lamps	205,565	190,769	3,905,099
TOTAL	394,104	4,140,507	36,454,599

Table 7 – Estimate of electricity consumption for the period 2009-2030: Residential Sector

	Consumption (MWh)		Accumulated total 2010-2030
End use appliances	2009	2030	
Electric showers	248,170	5,539,450	53,368,062
Refrigerators	1,468,292	34,639,079	295,351,862
Air conditioning equipment	289,958	10,115,689	93,552,036
Lamps	2,187,610	2,429,163	49,399,719
TOTAL	4,194,030	52,723,381	491,671,679

In the case of the *industrial* sector, in the base year (2009) total emissions for the end uses considered in this report amounted to 22.5 million tons of CO_2 equivalent and the consumption of electricity, taking account of transmission and distribution losses, amounted to 239.6 TWh (Table 8).

Table 8 –Estimate of emissions of CO_2 (in tCO_2) and electricity consumption in 2009 (in MWh): Industrial and Commercial Sector

	Emissions (tCO_2)		Electricity consumption (MWh)	
End use equipments	2009	%	2009	%
1 CV Motor	2,149,785	9.5	22,877,866	9.5
5 CV Motor	4,545,260	20.2	48,370,346	20.2
10 CV Motor	4,752,926	21.1	50,580,317	21.1
100 CV Motor	10,968,292	48.7	116,723,807	48.7
Total Motors 1-100 CV	22,416,263	99.5	238,552,336	99.5
Lighting	107,470	0.5	1,143,693	0.5
TOTAL	22,523,734	100	239,696,029	100

For the Reference Scenario of the industrial sector for the end-uses considered in the present report, emissions in 2030 of 'substituted' end-uses represent 42% of the emissions for 2009. Meanwhile, the consumption of electricity by the equipments substituted over the period up to 2030 represents 52% of the total consumption for 2009. Electric motors account for practically all of this (99.5%). Tables 9 and 10 contain figures on the emissions and electricity consumption in 2030 and the accumulated total for the end uses considered in the study.

The accumulated total *emissions* are 2.7 times higher when compared with the emissions for 2030, while the accumulated *consumption* is 3.4 times higher than total consumption for 2009.

Table 9 – Estimate of the emissions of CO_2 for the time frame 2009-2030: Industrial and Commercial Sector

	Emissions (tCO_2)		Accumulated total 2010-2030
End use equipments	2009	2030	
1 CV Motor	2,149,785	1,158,259	6,695,459
5 CV Motor	4,545,260	2,448,890	14,156,113
10 CV Motor	4,752,926	1,791,575	12,115,205
100 CV Motor	10,968,292	3,888,595	26,809,534
Total Motors 1-100 CV	22,416,263	9,287,319	59,776,311
Lighting	107,470	101,393	999,082
TOTAL	22,523,734	9,388,711	60,775,393

Table 10 – Estimate of electricity consumption for the time frame 2009-2030: Industrial and Commercial Sector

	Consumption (MWh)		Accumulated total 2010-2030
End use equipments	2009	2030	
1 CV Motor	22,877,866	14,748,754	90,748,082
5 CV Motor	48,370,346	31,183,080	191,867,373
10 CV Motor	50,580,317	22,813,125	164,502,818
100 CV Motor	116,723,807	49,515,644	364,097,308
Total Motors 1-100 CV	238,552,336	118,260,603	811,215,580
Lighting	1,143,693	1,291,091	13,639,140
TOTAL	239,696,029	119,551,694	824,854,721

In the *commercial* sector, in the base year (2009) total emissions for the end uses considered amounted to 295,000 tons of CO_2 equivalent (Table 11). Meanwhile electricity consumption, taking into account transmission and distribution losses, was 3.1 TWh (Table 12).

In the trend scenario for the commercial sector emissions in 2030 for 'substituted' equipments amount to 253,000 tons of CO_2 whereas the accumulated total over the period is 2.4 million tons of CO_2.

Consumption of electricity in 2030 is 3.2 TWh and the accumulated total for the entire period is 31.9 TWh.

Table 11 – Estimate of emissions from electricity consumption for the time frame 2009-2030 in the Trend Scenario: Commercial Sector

End use equipments	Emissions (tCO_2) 2009	Emissions (tCO_2) 2030	Accumulated total 2010-2030
Lighting system	295,467	253,262	2,338,462

Table 12 – Estimate of electricity consumption for the time frame 2009-2030 in the Trend Scenario: Commercial Sector

End use equipments	Consumption (MWh) 2009	Consumption (MWh) 2030	Accumulated total 2010-2030
Lighting system	3,144,343	3,224,925	31,881,547

3.3.2 Reduction of Emissions from Industrial Consumption of Fossil Fuels

CO_2 emissions caused by the burning of fuels go hand-in-hand with the increasing use of energy over the years. These emissions are derived partly from fossil fuels and partly from nonrenewable combustible materials such as nonrenewable biomass, particularly when these materials are extracted from natural stocks (interrupting their regrowth cycles). On the other hand, renewable sources such as sugarcane bagasse and black liquor complete their whole cycles, unlike vegetal coal (charcoal) and nonrenewable fuel wood which are partially extracted from native forests (AMS, 2008; Brito, 2008). Table 13 below shows figures relating to the 'renewability' factors for biomass (e.g. how much of the material used comes from plantations that are regularly 'renewed'). The fuel wood used in the paper and cellulose sectors example is wholly renewable, while that used in the ceramics industry is only 20% renewable.

Table 13– Renewability factors for combustible biomass (%)

	Wood	Sugarcane bagasse	Other renewables	Black liquor	Charcoal
Cement	-	-	100	-	50
Iron/steel	-	-	-	-	30
Ferroalloys	50	-	-	-	50
Mining/ granules	-	-	-	-	50
Nonferrous metals	-	-	-	-	50
Chemicals	90	-	100	-	90
Food/beverages.	50	100	-	-	-
Textiles	90	-	-	-	-
Paper/cellulose	100	-	100	100	-
Ceramics	20	-	100	-	-
Others	50	-	-	-	-

Note 1: Estimates based on AMS (2008), Brito (2008); Homma et al., 2006; INT (2005b) and sectoral information from industry associations.

Note 2: Other renewables include biomass waste such as wood bark, stalks, straw etc.

As can be seen in Table 14 below, CO_2 emissions reached 126.8 million tons in 2007, with the *iron and steel* sector responsible for 45.1% of the total. This sector was the main emitter of GHG in view of its very high consumption levels of both fossil fuels and nonrenewable biomass (in this case represented by nonrenewable charcoal originating from unsustainable extraction of materials from native forests). According to the Minas Gerais Silviculture Association (AMS, 2008) at least half of the charcoal is nonrenewable and is generally considered to be a net source of CO_2 emissions. The *chemical* sector comes in second place as regards total emissions (11.6%) mainly on account of the high consumption of natural gas by the industry. The *ceramics* industry comes in third place, accounting for 8.0% of emissions given that it uses large quantities of "deforested" timber. In fact the ceramics sector overtakes the *cement* sector where the use of petroleum coke ('petcoke') and other fossil fuels is widespread. On the other hand, the *food and beverages* sector and the *paper and cellulose* industry, while consuming large quantities of fuel, actually produce low emissions precisely because of the extensive use of sugarcane bagasse and black liquor respectively.

Table 14 – Estimate of emissions of CO_2 and 'renewability indices' for fuels in 2007 (in 000 tCO_2)

	Natural gas	Mineral coal and derivatives	Fuel wood	Sugarcane bagasse/ liquor/other renewables	Petroleum derivatives	Charcoal	Total	Proportion (%)
Industrial - total	17,939,9	47,714.2	11,590.0	-	36,759,0	12,815.7	126,818.8	100.0
Cement	39.8	514.8	-	-	7,119.8	504.8	8,179.1	6.4
Iron/steel	2.738,7	41,233.0	-	-	2,375.2	10,857.1	57,204.0	45.1
Ferroalloys	4.7	448.7	197.8	-	619.9	1,400.6	2,671.7	2.1
Mining/ granules	633.8	2,898.4	-	-	3,469.7	-	7,001.9	5.5
Nonferrous	1,246.5	1,149.3	-	-	5,687.4	20.5	8,103.7	6.4
Chemicals	5,137.7	236.9	20.4	-	9,255.4	7.7	14,658.1	11.6
Food/ beverages.	1,293.3	163.1	3,804.5	-	1,703.6	-	6,964.5	5.5
Textiles	764.8	-	38.4	-	377.6	-	1,180.7	0.9
Paper/cellulose	1,321.4	330.2	-	-	1,662.4	-	3,314.0	2.6
Ceramics	2.235,8	170.9	6.026,4	-	1,767.6	-	10,200.7	8.0
Other industries	2,523.5	568.9	1,502.6	-	2,720.4	25.0	7,340.4	5.8
Share (%)	14.1	37.6	9.1	-	29.0	10.1	100.0	

An analysis of fuels employed by industry reveals that the biggest emitters of GHG are the sectors burning mineral coal and its derivatives (37.6%), followed by petroleum derivatives (29.0%) and natural gas (14.1%).

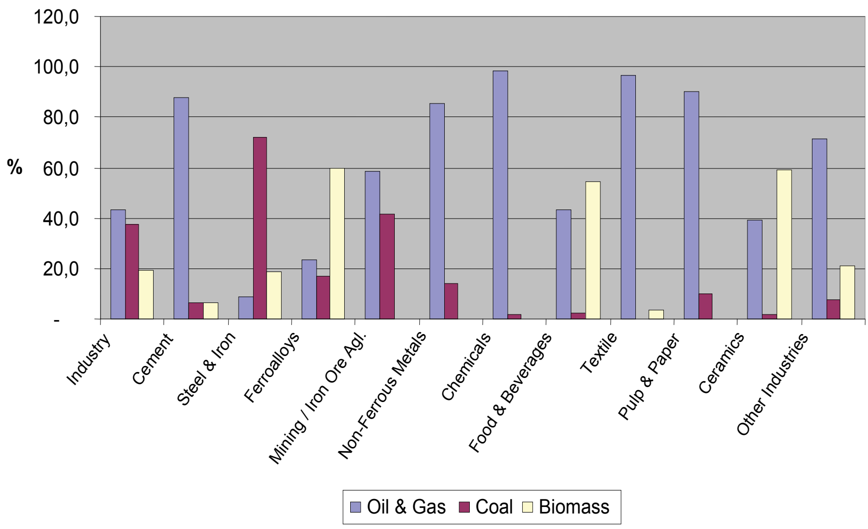
By aggregating the data into three major blocks of fuels - oil and gas, mineral coal and its derivatives, and biomasses, we conclude that 80.8% of emissions of CO_2 in the Brazilian industrial sector are caused by the burning of fossil fuels. The remaining 19.2% emissions arise from burning charcoal and fuel wood from deforested or other nonrenewable sources, as shown in Table 15 below.

Table 15 – Emissions of CO_2 in thousands of tons and percentages by groups of fuels and user sectors

	Petroleum and gas	%	Mineral coal and derivatives	%	Biomass	%	Total
Total industry	54,698.9	43.1	47,714.2	37.6	24,405.7	19.2	126,818.8
Cement	7,159.6	87.5	514.8	6.3	504.8	6.2	8,179.1
Pig iron/steel	5,113.9	8.9	41,233.0	72.1	10,857.1	19.0	57,204.0
Ferroalloys	624.6	23.4	448.7	16.8	1,598.4	59.8	2,671.7
Mining/granules	4,103.5	58.6	2,898.4	41.4	-	0.0	7,001.9
Nonferrous	6,934.0	85.6	1,149.3	14.2	20.5	0.3	8,103.7
Chemicals	14,393.1	98.2	236.9	1.6	28.1	0.2	14,658.1
Food/beverages.	2,996.9	43.0	163.1	2.3	3,804.5	54.6	6,964.5
Textiles	1,142.4	96.8	-	0.0	38.4	3.2	1,180.7
Paper/cellulose	2,983.8	90.0	330.2	10.0	-	0.0	3,314.0
Ceramics	4,003.4	39.2	170.9	1.7	6,026.4	59.1	10,200.7
Other industries	5,243.9	71.4	568.9	7.8	1,527.6	20.8	7,340.4

Graph 2 illustrates the variable behavior of specific sectors in the overall emissions rankings. Note that some sectors are in line with the average for industry as a whole, such as iron and steel, while others have completely different profiles as in the case of ferroalloys, food and beverages, paper and cellulose.

Graph 2 – Percentage share of energy sources in CO_2 emissions, by sector



In order to project the Reference Scenario we adopted the scenario involving increased energy consumption by industry as forecast in the PNE 2013 (EPE, 2007) - PNE *Scenario B1*, forecasting moderate growth (i.e. an annual growth rate of 3.7%). The growth of the specific industrial sectors was considered to be equal for all of them. Table 16 shows the evolution of emissions on a year-on-year basis in the Reference Scenario, with emissions rising to 291.7 million tons of CO_2 in 2030.

Table 16 – Projected emissions of CO_2 for the Reference Scenario 2007 - 2030 (in 000 tCO_2)

2007	2008	2009	2010	2011	2012	2013	2014
126,818.8	131,384.3	136,114.1	141,028.4	146,246.4	151,657.6	157,268.9	163,087.8
2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
169,122.1	175,379.6	181,868.6	188,597.8	195,575.9	202,812.2	210,316.3	218,098.0
2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
226,167.6	234,535.8	243,213.6	252,212.5	261,544.4	271,221.5	281,256.7	291,663.2

3.4 Reference Scenario- Energy Supply

3.4.1 Petroleum, gas and refined products sector: refining and GTL

Brazil's petroleum refining sector at present possesses 13 refineries mainly concentrated in the southeast region of the country, accounting for approximately 60% of total capacity. Refineries located in the south region account for around 20% of total capacity (Szklo & Uller 2008).

The number of refineries has not increased substantially over the past 30 years. PETROBRAS has however invested in extending its facilities and in increasing refining capacity since the inauguration of the Henrique Lage Refinery in 1980, from 1.1 million barrels to 1.9 million barrels a day (Petro & Química, 2008).

Brazil's Energy Research Company (ETE) argues in its *National Energy Plan 2030* (EPE, 2007) that the country needs at least seven more refineries by year 2030 in order to cope with domestic demand. Some speculation exists regarding the construction of refineries exclusively to be built for oil export purposes but only two refineries, the Abreu Lima Refinery (RENEST) in Pernambuco[15] and the Rio de Janeiro Petrochemical Complex (COMPERJ)[16] are actually under construction[17].

In our study we considered the refineries belonging to the PETROBRAS system and the Manguinhos refinery in 2007 [18]. The RENEST and COMPERJ will be considered as part of the calculation of emissions from the Brazilian refining sector exclusively for year 2015.

Finally, the sum total of emissions for each of the refineries operating in the years under consideration results in the total of emissions of the Brazilian refining sector for years 2007 and 2015. Table 17 below summarizes the results obtained for the emissions of the sector for years 2007 and 2015 in terms of $MtCO_2e$. Table 18 provides figures for the emissions over different time scales and for the total accumulated emissions in $MtCO_2e$ over the period under analysis.

Table 17 – Emissions from the Brazilian refinery sector for years 2007 and 2015 – Existing refineries and refineries under construction ($MtCO_2e$)

Emissions	2007	2015
$MtCO_2$/yr	13.8	25.5

Table 18 – Emissions from the Brazilian refinery sector in the Reference Scenario – existing refineries and refineries under construction ($MtCO_2e$)

Existing refineries	Accumulated total over the period	2010-2014	2015-2019	2020-2024	2025-2030
Emissions ($MtCO_2e$)	518.3	109.7	127.7	127.7	153.2

The building of seven new refineries is planned for between 2010 and 2030 to meet the demand for derivatives. The first of these, constructed by PETROBRAS, is almost completed and start-up is forecast for 2012. The remaining units are still at the planning stage, with two of them scheduled to begin operations between 2014 and 2020. The remaining two are expected to come on stream between 2020 and 2030 (EPE, 2007). It is worth noting that for these for refineries the preliminary feasibility studies include no calculations (yet) of greenhouse gas emissions.

15 The Abreu Lima plant will be built in partnership with PDVSA and is scheduled to come on stream in 2010, with a capacity of 200,000 barrels/day (*Petro & Química*, 2008)

16 The *Refinaria Petroquímica* (COMPERJ) will have a capacity of the 150,000 barrels/day. Start-up is planned for 2012 (*Petro & Química*, 2008)

17 The refineries proposed are the following: the Abreu Lima Refinery (PE), the Petroquímica Refinery (COMPERJ), the Premium I Refinery (MA), with a capacity of 600,000 barrels/day targeted at the export market; the Premium II Refinery (CE), with a capacity of 300,000 barrels/day also targeted at the export market; and the Premium II Refinery (RN) with a capacity of 300,000 barrels a day following upgrading works on the treatment plant (Petro & Química, 2008).

18 The Ipiranga S.A refinery was bought by PETROBRAS (Petro & Química , 2008).

The EPE (2007) study predicts in its 'most probable' scenario an increase in demand for petroleum derivatives in Brazil of 3.4% per annum between 2005 and 2030, particularly for diesel and aviation fuel, both of which are forecast to grow above average. On the other hand the study conducted by ABIQUIM (2007) indicates an even greater demand for petrochemical products by 2020.

Consumption of petrochemical products is growing rapidly, particularly for propane (7.2% per annum) and ethylene (5.7% per annum). A substantial increase has also been noted in aviation fuel (4.7% per annum), followed by low sulphur diesel (3.6% per annum). Aromatic hydrocarbons are forecast to grow at different rates but demand is expected to be met by 2020 following investment in a new petrochemical refinery planned to begin operations in 2012 in the state of Rio de Janeiro. Consumption of paraxilene will increase strongly due to new projects coming on stream that are expected to increase demand in Brazil by over 400%, while benzene and butadiene are likely to grow at around 5% per annum.

The main function of the refineries under study is to satisfy the growing demand for derivatives and petrochemicals, principally kerosene, diesel, propane and ethylene[19]. In addition to examining the Brazilian government´s plans for this sector, the present study assesses the impacts on the basic refinery scheme model of refinery-produced carbon emissions. The two approaches to the refinery sector in the model aim to satisfy the growing demands for fuels and/or for basic petrochemical products in Brazil. The medium and light distillates produced are required to meet future quality specifications for the Brazilian market (diesel and gasoline with 50 ppm sulphur). Petrochemical products produced in the event of petrochemical integration are ethylene, propane, C4 (butanes) and aromatics.

Table 19 shows the emissions for the new refineries by period and by accumulated total, while Table 20 shows the total emissions for existing and new refineries according to the Reference Scenario.

Table 19 – Emissions according to the Reference Scenario – new refineries (except those under construction)

New refinery	Total accumulated over the period	2010-2014	2015-2019	2020-2024	2025-2030
Emissions ($MtCO_2e$)	128.2	0	14.0	43.0	71.2

Table 20 – Total emissions of the refinery sector for the Reference Scenario in $MtCO_2e$

Reference Scenario	Total accumulated over the period	2010-2014	2015-2019	2020-2024	2025-2030
Existing and new refineries	646.6	109.7	141.7	170.7	224.5

The Reference Scenario for GTL considers that the volume of gas flared will not be reduced. In this case, diesel S50 will be obtained on the basis of investments in conventional hydrotreatment units in the refineries. The projected emissions for producing this amount of diesel from conventional refinery units, together with the emissions resulting from gas flaring, are summarized in Table 21.

19 *Per capita* consumption of petrochemicals in Brazil remains low. This explains the steep growth forecast for the next few years. While in the United States consumption *per capita* in 2007 was 108 kg, in Spain 87 kg *per capita*, and in Argentina 29 kg *per capita*, in Brazil it was still under 26 kg (ABIQUIM 2007).

Table 21 – Emissions for GTL in the Reference Scenario

Reference Scenario	Total accumulated over the period	2010-2014	2015-2019	2020-2024	2025-2030
GTL ($MtCO_2e$)	174.2	0	22.9	45.8	105.4

3.4.2 Electricity Productio n Sector: Cogeneration from Biomass

The Reference Scenario involves an adjustment of the PNE 2030[20]. The availability of biomass (bagasse from sugarcane production and 'recovery' straw) impacts directly on the potential for generating electricity by cogeneration. Another important aspect concerns the technologies used and their rates of penetration, given that in the Low Carbon Scenario the PNE 2030 hypotheses are more conservative than those adopted in this study.

For example, according to the Reference Scenario, throughout the 2008-2030 period a significant quantity of electricity (e.g. 82% in 2010, 67% in 2020 and 58% in 2030) is generated using cogeneration systems with counterpressure turbines producing electricity estimated at 50kWh per ton of cane. Also for the cogeneration systems with extraction and compensation turbines and for the BIGCC systems, the indices for electricity generation considered in the PNE 2030 are also conservative (e.g. 70 kWh/ton and 185 kWh/ton respectively for operation during the sugarcane harvest).

Thus the production of surplus electricity increases only slowly over the 2010-2030 timeframe, from 22 kWh per ton of cane in 2010 to 38.6 per ton in 2030.

Projections of avoided emissions

Since practically all Brazil's sugarcane processing plants are, and will continue to be, self-sufficient in terms of electric power during the 'safra' or sugar harvest period, the 'avoided' greenhouse gas emissions relate only to the production of surplus electricity. It is generally considered that generating electricity from sugarcane biomass residues produces no greenhouse gases (i.e. emissions avoided).

Using the set of hypotheses adopted, the avoided emissions of CO_2 due to the expansion of electricity generation based on cogeneration with sugarcane biomass residues would increase from 811.600 tons of CO_2 in 2010 to 3,855,000 tons of CO_2 in 2030. The accumulated reduction of emissions over this period would be 48.3 million tons of CO_2 while the average emissions reduction rate year-on-year would be 2.3 $MtCO_2$/yr.

The annual averages of avoided emissions of carbon dioxide between 2010 and 2030 are shown in Table 22.

Table 22 – Emissions of CO_2 avoided from the production of surplus electricity –Reference Scenario ($MtCO_2$/yr)

	2010-2015	2016-2020	2021-2025	2026-2030
Reference Scenario	1.5	2.2	2.5	3.2

20 It has already been mentioned that the production of sugarcane for the period 2009-2030 was corrected on the basis of the series of adjustments made which took into account real sugarcane production in the three years 2005/2008.

3.4.3 Electricity Production Sector: Wind Energy

At present 33 wind farms are an operation in Brazil with a total capacity of 415 MW (ANEEL, 2009). Compared with the total aeolic potential for producing electricity in Brazil of 143,500 MW (Cepel, 2001) the sector currently contributes relatively little, accounting for an input of only 0.37% into the Brazilian electrical energy matrix.

According to the PNE 2030 projections, the supply of wind energy will expand from 415 MW to 4,682 MW between 2010 and 2030. Using wind energy to complement electricity production throughout Brazil would be expected to satisfy only 1% of total demand for electricity in 2030.

Apart from being part of the effort to diversify Brazil's energy supply by expanding the use of renewable sources in the matrix, wind energy can also contribute to reducing CO_2 emissions in the atmosphere given that wind-powered generation of electricity produces no polluting gases. Table 23 shows the costs of expanding the installed capacity in wind energy (in US$/MW) for each of the years analyzed up to 2030. Note that the costs tend to decrease over time to reflect the technology "learning curve" factor.

Table 23 – Cost of installed capacity of eolic energy

Year	US$/MW	Year	US$/MW
2010	$ 1,200,000	2021	$ 852,123
2011	$ 1,062,073	2022	$ 846,974
2012	$ 1,008,564	2023	$ 842,618
2013	$ 969,706	2024	$ 839,339
2014	$ 935,465	2025	$ 836,052
2015	$ 912,344	2026	$ 833,062
2016	$ 897,376	2027	$ 830,723
2017	$ 886,156	2028	$ 827,554
2018	$ 873,713	2029	$ 824,787
2019	$ 865,323	2030	$ 822,149
2020	$ 857,802		

A PNE 2030 survey identified an average annual investment cost over and above the baseline scenario for wind power generation of US $6.7 billion (PNE 2030: pp 266), corresponding to an additional average 30,058 GWh. This amounts to US $223 million per TWh. The total investment cost was obtained by calculating the difference between electricity generation of the Low Carbon and Reference Scenarios and multiplying it by the average investment in expansion of the electricity sector.

The fixed tariff for electricity produced by wind power established by the National Electrical Energy Agency (ANEEL) is 100 US$MWh. The emissions factors of the electricity sector were based on PNE 2030 values.

According to the results of the cost projections model the present total investment cost of a wind farm in the Reference Scenario is US $6.3 billion between 2010 and 2030, including the fixed operating and maintenance costs and employing a social discount rate of 8% a year. In the Reference Scenario, the mix of electricity generation sources, including wind power, would produce emissions of 19.3 million tons of CO_2 equivalent between 2010 and 2030 (Table 24).

Table 24 – General picture: Reference Scenario (accumulated values)

Reference Scenario	2010	2015	2020	2025	2030
Average cost of expansion per year (US$/MWh)	223	223	223	223	223
Installed capacity (MW)	405.5	1,260	2,282	3,410	4,682
Present cost (US$ million in 2009)	0,00	1,027	3,002	4,860	6,227
Electricity sales (GWh)	888	10,973	31,213	63,424	109,081
Present value of receipts (US$ million in 2009)	82	807	1,808	2,897	3,951
Emissions of CO_2 eq. (millions of tons of CO_2 eq.)	0.00	2.3	7.8	14.6	19.3

3.5 **Reference Scenario - Additional Options**

3.5.1 Substitution by Biomass: Ethanol

The Reference Scenario of this mitigation option is essentially *Scenario B1* of the 2030 National Energy Plan with regard to the sugar/alcohol sector. However, since the PNE 2030 scenario was produced using data up to and including 2005, a number of discrepancies can be noted in the harvests for the following three years (up to 2008) in terms of cane, sugar and ethanol production. Moreover certain agricultural indices were lower than those forecast by sector experts.

With regard to the hydrolysis of sugarcane residues, the hypotheses indicate an extremely rapid growth beginning in 2010 and declining rapidly from 2020 onwards, contrary to the expectations of area specialists and the IEA prognosis. On account of this the coordinators decided by common agreement to make certain adjustments in the PNE 2030 Reference Scenario in order to adapt the numbers to conform to the *Low Carbon Country Case Study*. The results are summarized in Table 25.

Table 25 –Reference Scenario for the sugar/alcohol sector

	2010	2015	2020	2025	2030
Cane for sugar (Mt)	277.3	301.6	315.2	337.5	362.2
Cane for ethanol (Mt)	373.5	489.5	583.9	654.3	720.6
Cane for ethanol/sugar (Mt)	650.8	791.1	899.2	991.8	1,082.7
Conventional ethanol (ML)	31,655	42,685	52,387	60,389	68,422
Ethanol from hydrolyzed cane (ML)	130	1,680	4,530	5,840	7,130
Total ethanol (ML)	31,785	44,365	56,917	66,229	75,552
Ethanol exported (ML)	7,889	13,055	18,220	15,664	13,108
Total sugar (Mt)	38,196	42,733	45,953	50,616	55,885
Cane productivity (t/ha)	81.8	86.5	91.3	95.9	100.3
Area under cane production for ethanol and sugar (Mha)	8.08	9.92	11.19	11.95	12.70

The supply scenario for sugarcane biomass was slightly modified with respect to the PNE 2030, with an increase in bagasse production from 135 kg/t of cane to 140 kg/t, (both dry basis) in order to take account of the methodology most widely accepted in the sector for estimating quantities of bagasse from cane fibre (considered to be 13.5%) and from bagasse brix. A further variation from the PNE 2030 scenario is the quantity of cane produced. The scenario is shown in Table 26.

Table 26 –Supply of biomass in the sugar/alcohol sector

	2010	2015	2020	2025	2030
Cane production (Mt)	661	858	1,022	1,146	1,273
Bagasse production (Mt, d.b.)	92.6	120.2	143.1	160.4	178.2
Straw availability	41.7	84.1	128.8	144.4	160.4
Total biomass available (Mt, d.b.)	134.3	204.3	271.9	304.8	338.6
Biomass used (%)[1]	0.4	3.6	7.6	8.0	8.3
Biomass for hydrolysis (1000t, d.b.)	0.6	7.4	20.7	25.2	28.1
Hydrolysis Yield (L/t, b.s.)[1]	210	240	255	265	275

b.s: dry basis [1] EPE, 2007

3.5.2 Electricity Production Sector: Hydroelectricity

Hydropower is one of the sources most widely employed in Brazil to produce electricity. The installed capacity of the country's major hydroelectric plants [21] is 74,936.91 MW, which corresponds to 74.67% of the total electricity generation capacity of just over 100,000 MW. The total energy generated by Brazil´s hydroelectric plants in 2007 was 322,630.3 GWh (ONS, 2008). In addition, Brazil imports energy from neighboring countries to guarantee internal supply. In 2007 an amount equal to 83,323.6 GWh of electricity was imported from the 'binational' plant at Itaipu which possessees an installed capacity of 14,000 MW (ONS, 2008). Around 4,078 MW of the 7,000 MW installed capacity belonging to Paraguay are used by Brazil (ONS, 2008).

Development of hydroelectricity in the past, mainly during the 1970s, was a vital key to Brazil's development. At present, despite a number of environmental and economic setbacks, expansion of the electric energy supply is still rooted in growth of the hydroelectric sector. In 2007 around 5,500 MW of hydroelectric capacity were under construction in Brazil, with about 33,000 MW at the planning stage (Hydropower & Dam, 2008).

Compared with other countries in Latin America, the untapped potential that could be exploited by building more hydroelectric plants in Brazil is considerable. However, faced by future demand for electricity and continuing problems of an environmental nature, this potential could well fall short of future requirements. The total potential available in Brazil for hydroelectric development amounts to around 251,490 MW - the biggest in Latin America. It is estimated that the technically usable potential of Brazil's hydroelectric resources could generate around 1,488 TWh/yr (EPE, 2007).

Only 30.9% of Brazil's hydroelectric potential has been exploited to date (Table 27). The amount of hydroelectric power produced by existing plants takes into account the potential production of plants under construction or of those granted the 'go-ahead' by the end of 2005 (EPE, 2007). In estimates of Brazil's hydroelectric potential it is common practice to include the 50% produced by the existing binational sources.

The inventoried potential of the hydroelectric sector in Brazil is around 126,000 MW, with around 70% located in the Amazon Region, namely the Amazon and Tocantins/Araguaia hydrographic basins, both of which present a number of difficulties that could impede future

21 Large hydroelectric plants with an installed capacity of over 30MW.

hydro development. Note that the figures for estimated potential are drawn from theoretical surveys that have not yet been confirmed. Decisions for example are still pending regarding the location of a number of major dams that will possibly need to be built (EPE, 2007).

Table 27 – Brazilian Hydroelectric Potential (MW)

River Drainage Basin	Used	Inventory	Estimated	TOTAL	%
Amazon	835	77,058	28,256	106,149	42.2%
Paraná	41,696	10,742	5,363	57,801	23.0%
Tocantins/Araguaia	12,198	11,297	4,540	28,035	11.1%
São Francisco	10,290	5,550	1,917	17,757	7.1%
South-East Atlantic	4,107	9,501	1,120	14,728	5.9%
Uruguay	5,182	6,482	1,152	12,816	5.1%
South Atlantic	1,637	1,734	2,066	5,437	2.2%
East Atlantic	1,100	1,950	1,037	4,087	1.6%
Paraguay	499	846	1,757	3,102	1.2%
Parnaíba	225	819	0	1,,044	0.4%
NE Atlantic (W)	0	58	318	376	0.1%
NE Atlantic (E)	8	127	23	158	0.1%
TOTAL	77,777	126,164	47,549	251,490	100%
%	30.9%	50.2%	18.9%	100.0%	

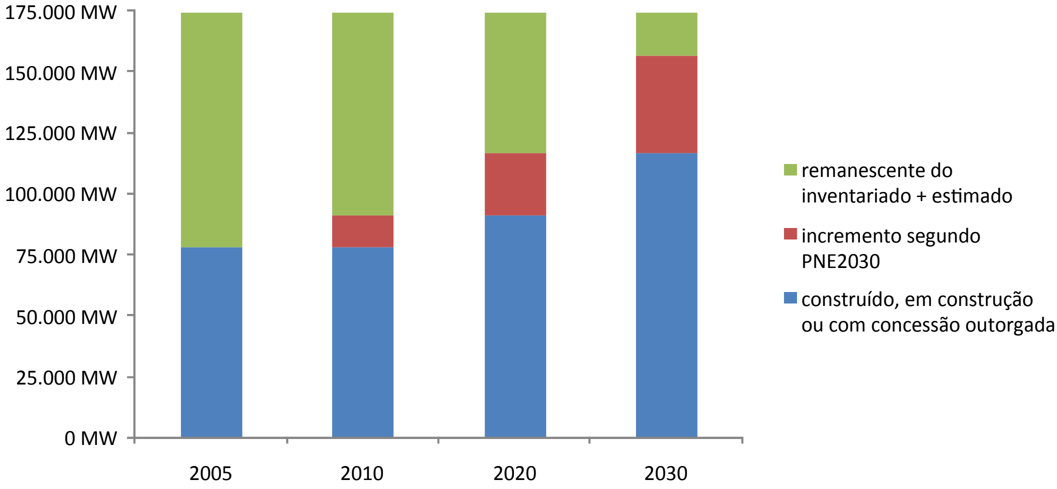
Source: EPE, 2007

The inventoried potential of 126 GW is reduced to 116 GW in cases where the schemes impact directly on national parks and native forest areas. If the schemes affecting indigenous reserves are taken out of the equation, potential is reduced to 87GW. A combination of these two constraints reduces the potential to 770 GW (EPE, 2007).

According to the PNE 2030, it is expected that electricity consumption will increase from 847 TWh to 1,244 TWh by 2030. By that year, the installed capacity of the large hydroelectric plants, including the binational plants, will reach 156.3GW (EPE, 2007). In order to achieve this level of installed capacity the addition of 68.6GW will be needed between 2005 and 2030. By way of comparison, 174GW was inventoried and estimated in 2005 and part of this potential is subject to a series of environmental constraints. For example, only 17GW out of the 105GW of inventoried and estimated potential in the Amazon basin is not subject to significant environmental constraints.

Of the total Brazilian hydroelectric potential that would involve installation of a capacity of around 260GW, 174GW of inventoried and estimated potential have been identified. In 2010 the installed capacity of the major hydroelectric plants, including the binational ones, could be of the order of 90.5 GW. This would involve increasing capacity by the addition of another plant the size of Itaipu. In 2020 and 2030 the installed capacity would be 116GW and 156GW respectively. The building of two plants with a power output identical to Itaipu would be needed before 2020 and three Itaipus between 2020 and 2030 (Graph 3).

Graph 3 – Potential in operation, inventoried and estimated and increases needed according to the PNE 2030.



Assuming that an installed capacity of 225GW will be needed to satisfy demand in 2030, around 61GW will be needed from other, non-hydraulic, generating sources, predominantly from thermal generation. The latter would be expected to produce a total output of 48GW, including that generated in 2005, according to figures produced by the MELP (*Model for Planning Long Term Generation Expansion*) [CEPEL] (EPE, 2007).

In order to make best use of the energy produced by the hydroelectric plants, the majority of which are distant from the load centers, substantial investments in transmission lines will be necessary.

At the end of 2007 Brazil possessed 87,184.4 km of transmission lines, with 995.4 km added in 2007 alone (ANEEL, 2008). According to the 10-year *Electrical Energy Expansion Plan 2006-2015* (PDDE 2006-2015) published in 2006, the increased load on the national grid over 10 years would be 186.6TWh. This will require investments in the transmission network of US $17.9 billion, with 68% of this amount needed for financing transmission lines carrying loads equal to or higher than 230 kV and a further 32% on substations and transformation. Considering the same costs base and bearing in mind that between 2005 and 2030 the expanded load carried by the system would be around 700TWh (taking into account increased energy efficiency) the total investments in transmission (basic network) would probably be in the region of US$68 billion. This amount would include expanding the interconnections as foreshadowed in the PNE (EPE, 2007).

4 Energy Demand - Energy Efficiency in Electricity Consumption

Around 95% of the total electricity consumed in Brazil is by the industrial (51%), commercial and services (22%) and residential (22%) sectors. The contribution that these sectors could make to reducing CO_2 emissions is relatively modest compared with other sectors, but the potential for reduction is nevertheless significant. The contribution of these sectors to emissions reductions would be 'indirect' given that any energy savings made would result from a need for less thermal power generation.

The present report shows the results of calculations of the average costs of avoided carbon (US$/ tCO_2), savings of electrical energy (in accumulated values for the period under analysis as well as annually) in the 2009-2030 timeframe and the total cost of efficiency measures introduced for certain equipments. The report also describes the methodology and data employed. The calculations were done in respect of equipment used in the residential, industrial and commercial sectors. A number of hypotheses are also submitted regarding the evolution of the penetration of more energy-efficient technologies in the consumer sectors up to year 2030.

4.1 Mitigation Options

Focused on energy efficiency, examines three sectors: residential, commercial and industrial.

4.1.1 Residential sector

In the residential sector six activities with GHG mitigation potential are assessed. These refer to four key residential end-uses as follows:

- ***Lighting:*** substitution of incandescent for compact fluorescent lamps (CFL) from 2010 onwards;

- ***Food refrigeration:*** (i) the adoption of mandatory standards of stricter energy efficiency for refrigerators from 2015 onwards and; (ii) a program targeted at replacing obsolete refrigerators in low income communities.

- ***Environmental refrigeration:*** involving the adoption of more rigorous energy efficiency standards for air-conditioning equipment involving: (i) adopting the USA standard from 2015 and; (ii) encouraging the substitution of existing equipment carrying the present PROCEL 'E' seal for equipment bearing the PROCEL 'A' identification.

- ***Hot water for bathing:*** to substitute 75% of all electric showers for solar heated devices, aimed at 1% of the households in the South East, South and Center-West regions every year, applying to 22% of all households in these areas by year 2030.

The above potential mitigation measures require an accurate appraisal to be done of the behavior of the equipment stock. The main factors affecting the stock would be (i) families needing to replace obsolete equipment and (ii) people buying equipment for the first time given the increase in the number of households and the penetration rate. Some of the specificities with regard to equipment stocks are described as follows (analyses based on Melo, 2009).

1) Substitutions [22]

22 In the case of solar powered heaters no substitution is taken into account and as far as lamps are concerned their replacement is in line with their useful operating life.

The replacement of obsolete equipment occurs more frequently when it is nearing the end of its useful life. Our study employs a logistic function determining the probability of a replacement based upon the age of any particular piece of equipment.

2) Penetration

Under this item a model is presented for projecting penetration and the results of its econometric estimation based on annualized data for the period 2000-2007[23]. This permits estimates to be made of the penetration/income elasticities and the penetration/price used to forecast the penetration of the equipment. The projection model is based upon the following basic assumptions:

- Penetration of equipment is defined as the ratio between the number of residences owning the equipment and the total number of residences.
- The impact of income increases is *positive* with regard to penetration and the influence of price rises is *negative*.

By doing a multiple regression of the historic series corresponding to these penetration variables the long-term elasticities can be determined.

No historic penetration series were found in the case of *air-conditioning equipment*. It was therefore decided to use the penetration indices observed in the base year according to research data provided by ELETROBRÁS, PROCEL and PUC-Rio, 2005. This supposition is based upon two principal factors: (i) that the considered income variations do not influence increased penetration of A/C equipment and; (ii) that over the period of the projections, significant price reductions of A/C which can modify penetration are unlikely. On the other hand, the substantial penetration of air conditioning units occurs among social classes with incomes of over 10 minimum salaries, where it is reckoned that income variations have no influence on ownership of equipment. Meanwhile, the incomes of the poorest are generally insufficient to permit purchase of new equipment of this type.

In the case of *lamps*, penetration was considered to be complete, with 100% of all households possessing at least one light source. The specific parameters used are described under item (a) below.

As for *solar powered heaters,* penetration amounted to 1% of the total number of households in the South East, South and Center-West regions per year.

The assumptions adopted for each of the scenarios are listed as follows:

(a) *Lighting*

- Baseline: continued use up to 2030 of incandescent lamps in 70% of the market, with the rest occupied by CFL lamps.
- Low carbon: substitution of 70% of incandescent lamps in 2010 and every three years (representing the useful lifetime of these lamps) and undertaking a new program depending on the stock variation.

(b) *Food refrigeration*

Refrigerators represent approximately 22% of the residential end use consumption of electricity (PROCEL, 2007) amounting to 5% of national electrical energy consumption. Two mitigation measures are analyzed:

(i) *Minimum Standards of Energy Efficiency*

23 According to the limitations presented by the data penetration by income class by the SIDRA (IBGE Automatic Recovery) system.

Based on the research undertaken by Melo (2009) using cross-referenced data between the aforementioned ELETROBRÁS/Puc-Rio (2005) research and domestic refrigerator data published by INMETRO (2008), the monthly average consumption of one-door and combined frost free (FF) refrigerators was calculated (by volume of liters).

(ii) *Replacement of obsolete refrigerators in low income communities*

This analysis is based on the Federal Government's target involving exchanging 10 million refrigerators (ABIN, 2009)[24]. The main reason for substituting obsolete for more energy-efficient equipment is basically to counteract the high consumption of energy of older equipment. The calculations were made on the basis of replacing one million refrigerators every year.

(c) *Air-conditioning equipment*

Air-conditioning units have significant penetration in the middle to higher income groups, accounting for approximately 4% of total consumption of electricity in the residential sector. Consumption by air-conditioning units in these households can amount to 20% of electricity demand in a given residence (Melo, 2009). Two mitigation measures are:

(i) *Minimum Energy Efficiency Standards: USA Standard*

By cross-referencing data between the models published by INMETRO and the ELETROBRÁS/PUC-Rio (2005) research, the average consumption of the models most commonly used in Brazil was estimated according to Btu output. Boosting the efficiency of these models involves employing a set of optimal engineering options focused on increasing efficiency and with the respective cost increments described by Melo (2009), based on CLASP (2007). The average costs of equivalent models in the market reflect the average prices of similar models in the retail market.

(ii) *Hypothetical Exercise - Minimum Standards of Energy Efficiency: withdrawing appliances with the "E" seal and replacing them with "A" seal equipment.*

This is a hypothetical exercise designed to assess the avoided carbon costs assuming that 20% of units sold possessing an output of 7500 BTU/hr and carrying the"E" seal are substituted by similar-powered A/C units with the"A" seal affixed. This assumes direct proportionality between the units measured by INMETRO (2007[25]) and the respective types of equipment existing in the market. It is important to note that the market share of sales of appliances bearing these seals is known only to the manufacturers.

(d) *Electric showers and solar heating*

Electric showers are responsible for approximately 16% of total electricity demand in the residential sector. With higher use recorded in the South East, South and Center-West regions owing to the annual average temperatures being lower than in the North and Northeast, around 73% of such equipment is of the 4000W and 4999W variety.

4.1.2 Industrial Sector

PROCEL published in 2008 a survey on the ownership and usage habits of the high tension industrial consumer sector, using 2005 as a baseline. The industrial sector accounts for 46.7% of Brazil's national electricity consumption (375,193 MWh) (BEN, 2006).

Two activities of the industrial sector with GHG mitigation potential are motive power (electric motors) and lighting.

24 Consulted on 28/02/2009 http://www.abin.gov.br/modules/articles/article.php?id=3885
25 The table refers to the labeling program (ENCE) based on 2007 criteria and in which 54 models were evaluated. 20% were given an E classification

(a) *Electric motors*

Motive power is responsible for 68.3% of electricity consumption in the industrial sector (PROCEL, 2008) corresponding to approximately 32% of Brazil's national consumption of electricity. This particular use for electricity is of extreme importance both to the industrial sector and more widely.

According to Garcia (2004) the following distribution of electric Motors operating in year 2000 involves around 12,481,262 Motors:

1- 84% accounted for by 1 to 10 cv motors;

2- 13% accounted for motors of over 10/40 cv;

3- 2% accounted for motors of over 40/100 cv; and

4- 1% accounted for motors of over 100/300 cv.

In order to facilitate calculation of the potential for reduction, a number of assumptions are made, including the following:

1) According to ELETROBRÁS (2008) the number of standard and heavy duty motors in Brazil is 90% and 10% respectively. It is assumed that for the baseline year (2009) this share remains unchanged. The present study considers the following increases in the market share of high-performance motors: 2009 (10%); 2015 (15%); 2020 (25%); 2025 (40%) and 2030 (50%).

2) The distribution by power category of motors remains the same during the entire timeframe of the study.

3) For our calculations a distribution of 1 cv, 5 cv, and 10 cv (the 10 cv to 40 cv range) and 100 cv (40 cv to 300 cv) was considered. For motors of 1 cv and 5 cv their distribution within the range from 1 to 10 cv was respectively 70% and 30%.

4) For the baseline year (2009) the number of motors operating in Brazil was estimated to be 21,481,262, assuming annual sales of one million motors between years 2000 and 2009. From 2009 onwards the average growth rate of the market for the past 17 years was used e.g. 12% for 1 to 10 cv motors and 4.25% for the 10 cv to 40 cv range (ELETROBRÁS, 2008). 1% was adopted for the 40-100 cv and 100-300 cv range.

5) We considered the motors load and efficiency data presented in the information available on electric motors manufactured by WEG, responsible for around 80% of the Brazilian motors market.

6) The average load factor used for our calculations is 0.70, very near to the average of 0.68 indicated in the study by Garcia et al (2004) and also used by PROCEL in its estimates of the energy saved by the use of the PROCEL energy efficiency seal (ELETROBRÁS, 2008).

7) By way of comparison with the baseline year we considered the minimum standards of energy efficiency for electric motors published in the Interministerial Directive Number 553 of 12/12/2005. This government directive establishes that from December 2009 onwards the classification of standard and high-performance motors will be altered. The 'standard' classification will cease to exist, to be replaced by the 'high performance' (heavy duty) standard, meaning that the minimum indices of energy efficiency will be applied. These minimum indices were used as a basis for comparison with the estimated yields for the period 2015-2030. The minimum efficiency indices remained unchanged throughout the period.

8) For 2030 we assumed that the high performance motors manufactured in Brazil would

be as efficient as those currently marketed in Europe. This is a conservative hypothesis because WEG motors comply with international standards in terms of energy efficiency given that the bulk of WEG production is exported to Europe and the United States.

9) The motors considered are 4-pole motors since according to Garcia et al (2004) these account for two thirds of the energy expended by industrial motors.

10) The useful life of such motors was considered to be 12 years, the same as indicated by both the manufacturer and PROCEL (ELETROBRÁS, 2008).

12) We calculated the price of motors at one of the WEG retail distributors in November 2008. We considered that the real price of motors would not significantly change before 2020 and that the replacement program will result in the prices of higher heavy duty motors being 10% lower owing to economies of scale.

13) We considered that the cost of developing and implementing the replacement program represents 10% of the price of more energy efficient equipment.

14) The discount rate used was 8% percent per year.

(b) *Lighting*

In the industrial sector fluorescent tubes are the most commonly used in internal areas. According to PROCEL (2008) 64% of these lights are used in "administrative" areas and 59% on the "factory floor".

In order to calculate the potential for reduction we used the following hypotheses:

1) We assumed that industry in general employs a common lighting system of four fluorescent tubes of 40W each, activated by two electromagnetic transformers of 11W each.

2) The replacement of the lamp-transformer would involve the following: the number of fluorescent tubes would be reduced from four to two, and their unit power from 40 W to 32 W by installing reflective panels in the two lights. This would lead to a reduction in the number of lamps needed while at the same time retaining, or even improving, lighting performance in the workplaces. The lamps are activated by electronic 3 W transformers.

3) According to the Brazilian Lighting Industry Association (ABILUX), 90% of all sales of lamps are replacements and the remaining 10% the result of general market growth (Gazeta Mercantil, 2004). We considered in this study that these proportions would remain constant throughout the period.

4) 70 million tubular fluorescent lamps were sold in 2007 (ABILUX, 2009). Bearing in mind that 10% of such sales were the result of general expansion, the stock effectively increased by 7 million. We also considered in this study a 10% annual growth of sales of fluorescent tubes throughout the period.

5) According to the Technical Director of ABILUX, the association has no record of the number of fluorescent tubes sold separately to the commercial and industrial sectors. The director recommended contacting the four largest lamp manufacturers which dominate the market in order to obtain this information but we assumed that the chance of the manufacturers divulging this data was remote. For calculation purposes, we considered that the industrial sector accounts for 20% of the number of lamps for internal use while the commercial sector accounts for 80%.

6) We also considered that 90% of the lamps used internally in the industrial sector are 40W fluorescent tubes and 10% are 32W tubes. The present study considers that by 2030 100% of

the existing lighting systems will be energy efficient.

7) We considered that with 2500 operating hours per year (the same as indicated by ELETROBRÁS [2008]) 40W fluorescent tubes have a life of 8000 hours and 32W tubes last 10,000 hours.

8) We also considered that the real price of lighting systes would not radically change by 2030 and that the replacement program would reduce the price of the more efficient lighting systems by 5% in view of economies of scale.

9) We considered that the costs of designing and implementing the replacement program represents 10% of the price of more efficient equipment.

10) The discount rate used was 8% per year.

11) Annual consumption of the individual systems is regarded as being 524 kWh and 193kWh respectively.

4.1.3 Commercial Sector

We evaluated the various activities in the commercial sector that possess a GHG mitigation potential with regard to lighting.

a) ***Lighting***

The same methodology and hypotheses employed for the industrial sector were used for the commercial sector. Note that no national surveys of the type conducted by PROCEL (2008) have been done for the commercial sector.

Three hypotheses are used in this study to calculate the potential for reduced emissions:

1) As mentioned above, we considered that the commercial sector is responsible for 80% of internally used lamps throughout Brazil.

2) We also considered that 90% of the lamps used in the commercial sector consist of 40W fluorescent tubes and 10% are 32 W tubes.

3) The present study considers that 100% of the existing lighting systems in the country will be “efficient” by year 2030.

4.2 Potential for reducing emissions and the Marginal Abatement Cost

For the residential sector, the projected electricity consumption/emissions in 2030 and accumulated over the period 2010-2030 for the end uses considered in our study are set out in Tables 28 and 29.

Compared with the Reference Scenario, the Low Carbon Scenario involves the reduction of GHG emissions and electricity consumption in the residential sector by 50% (Table 31). The reduced consumption of electricity and the resulting lower emissions results mainly from upgrading refrigerators (responsible for 53% of total emissions reductions).

In terms of end use, fewer and more efficient lighting systems and using solar heating to replace electric showers are the two measures with outstanding potential for reducing GHG emissions and boosting energy efficiency (79% for lamps, 75% for electric showers).

Table 28 – Estimate of CO_2 emissions for the period 2009-2030 in the Low Carbon Scenario: Residential Sector

	Emissions (tCO_2)		Total accumulated 2010-2030
Final use equipment	2009	2030	
Electric showers	23,320	108,757	992,668
Refrigerators	137,972	1,529,006	12,214,636
A/C units	27,247	493,678	4,255,247
Lamps	205,565	40,764	832,290
TOTAL	394,104	2,172,205	18,294,841

Table 29 – Estimate of electricity consumption for the period 2009-2030 in the Low Carbon Scenario: Residential Sector

	Consumption (MWh)		Total accumulated 2010-2030
Final use equipments	2009	2030	
Electric showers	248,170	1,384,863	13,342,015
Refrigerators	1,468,292	19,469,690	166,009,297
A/C units	289,958	6,286,275	58,136,803
Lamps	2,187,610	519,069	10,529,926
TOTAL	4,194,030	27,659,896	248,018,041

Table 30 – Potential for reducing CO_2 emissions and electricity consumption over the period 2009-2030: Industrial Sector

	Total accumulated potential 2010-2030		Potential (%)	
Final use equipments	Emissions (tCO_2)	Consumption(MWh)	Emissions (tCO_2)	Consum-ption (MWh)
Electric showers	2,978,005	40,026,046	75.0	16.4
Refrigerators	9,516,771	129,342,565	43.8	53.1
A/C units	2,592,172	35,415,234	37.9	14.5
Lamps	3,072,810	38,869,793	78.7	16.0
TOTAL	18,159,758	243,653,639	49.6	100.0

In the industrial sector the consumption of electricity and emissions for 2030 and accumulated for the period 2010-2030 for the end uses considered in this study are presented in Tables 31 and 32.

Compared with the Reference Scenario, the Low Carbon Scenario involves the reduction of emissions and electricity consumption by 3.6% over the total time frame (2010-2030) (Table 34). Of this total, elkectric motors were responsible for 71% of the reduction of emissions and consumption of electricity and new lighting systems for 29%.

In terms of end use, notwithstanding the substantial quantity of emissions and electricity economized by more efficient motors, the gain in emissions and efficiency was in fact 2.6% as a result of replacements, while for the new lighting systems the gains were of the order of 63.2% regardless of the lower volume of emissions and saved electricity.

Table 31 – Estimate of CO_2 emissions for the period 2009-2030 in the Low Carbon Scenario: Industrial Sector

Final use equipments	Emissions (tCO_2) 2009	Emissions (tCO_2) 2030	Accumulated total 2010-2030
1 CV motor	2,149,785	1,094,555	6,327,209
5 CV motor	4,545,260	2,387,668	13,802,210
10 CV motor	4,752,926	1,728,870	11,691,173
100 CV motor	10,968,292	3,830,266	26,407,391
Total motors 1-100 CV	22,416,263	9,041,358	58,227,983
Lighting	107,470	37,326	367,794
TOTAL	22,523,734	9,078,684	58,595,777

Table 32 – Estimate of electricity consumption for the period 2009-2030 in the Low Carbon Scenario: Industrial Sector

Final use equipments	Consumption (MWh) 2009	Consumption (MWh) 2030	Accumulated total 2010-2030
1 CV motor	22,877,866	13,937,572	85,756,937
5 CV motor	48,370,346	30,403,503	187,070,689
10 CV motor	50,580,317	22,014,666	158,745,219
100 CV motor	116,723,807	48,772,910	358,635,848
Total motors 1-100 CV	238,552,336	115,128,651	790,208,693
Lighting	1,143,693	475,292	5,021,002
TOTAL	239,696,029	115,603,942	795,229,695

Table 33 – Potential for reducing CO_2 emissions and electricity consumption over the period 2009-2030: Industrial Sector

	Total accumulated potential 2010-2030		Potential (%)	
Final use equipments	Emissions (tCO_2)	Consumption(MWh)	In final use	In total
1 CV motor	368,250	4,991,144	5.5	16.9
5 CV motor	353,903	4,796,684	2.5	16.2
10 CV motor	424,032	5,757,599	3.5	19.5
100 CV motor	402,143	5,461,460	1.5	18.5
Total motors 1-100 CV	1,548,328	21,006,887	2.6	71.0
Lighting	631,288	8,618,138	63.2	29.0
TOTAL	2,179,616	29,625,025	3.6	100.0

In the case of the commercial sector, the emissions and electricity consumption in 2030 and over the entire period (2010-2030), for the end uses considered in the present study are summarized in Tables 34 and 35 below.

Compared with the Reference Scenario, the Low Carbon Scenario involves a reduction of electricity consumption and emissions by 63% over the entire period (2010-2030) (Table 36). Figure 2 shows mitigation by state.

Table 34 – Estimate of CO_2 emissions for the period 2009-2030 in the Low Carbon Scenario: Commercial Sector

	Emissions (tCO_2)		Accumulated total 2010-2030
Final use equipments	2009	2030	
Lighting system	295,467	93,234	860,863

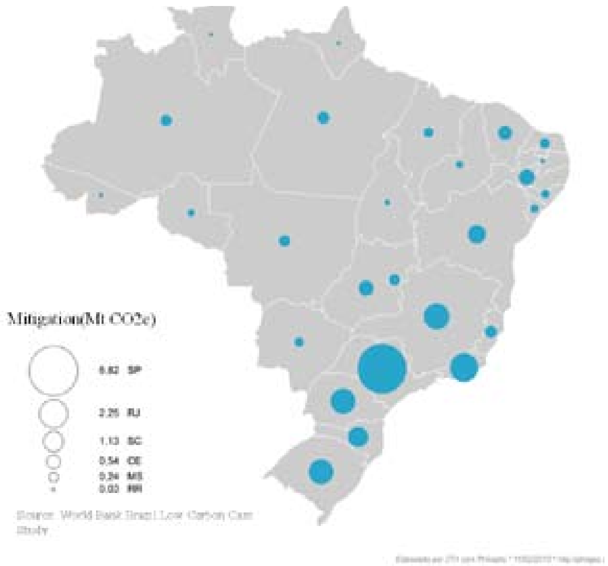
Table 35 – Estimate of electricity consumption for the period 2009-2030 in the Low Carbon Scenario: Commercial Sector

	Consumption (MWh)		Accumulated total 2010-2030
Final use equipments	2009	2030	
Lighting system	3,144,343	1,187,198	11,736,613

Table 36 – Potential for reducing CO_2 emissions and electricity consumption over the period 2009-2030: Commercial Sector

	Total accumulated potential 2010-2030		Potential (%)	
Final use equipments	Emissions (tCO_2)	Consumption (MWh)	In final use	In total
Lighting system	1,477,600	20,144,934	63.2	100

Figure 2: Emission Mitigation from Conservation of Electricity, 2010-2030



4.3 Existing Measures and Barriers to the Implementation of Low Carbon Options

Growing concern exists in Brazil for using energy more efficiently and over the last 30 years a number of different initiatives in this direction have been pursued by the public authorities. However these efforts have not led to coordinated, systematic and sustained long-term action. Programed investments and integrated physical targets related to planning for the electricity sector, with impacts on the national energy policy have beenfound wanting. All these are vital components of a national energy efficient policy[26], [27].

The existing initiatives could be regarded as mechanisms or instruments that have contributed to disseminating information about "good practice", involving the dissemination of more efficient technologies and encouragement for research and development in the area of energy efficiency.

For the purpose of the present report we chose to classify the different initiatives as: (a) support mechanisms; (b) financing mechanisms; (c) command and control mechanisms; and (d) market mechanisms.

The following is an account of the main actions aimed at supporting greater efficiency in the use of electrical energy in Brazil today, including the actions outlined in the National Climate Change Plan (PNMC).

4.3.1 Support Mechanisms

a) Guarantee Fund ('Fundo de Aval') for the ESCOS (PROESCO)

The PROESCO program was established by the National Bank for Economic and Social Development (BNDES) in 2006 with the aim of financing projects and performance contracts through Energy Services Companies (ESCOs). This guarantee fund also provides finance for final user projects and for projects undertaken by the electricity utility concessionaires.

A total of R$100 million was made available for this program. Applications to the fund can be made directly to BNDES or through registered financial institutions with specific mandates, regardless of the sum of financing required.

PROESCO finances projects that can contribute to saving energy in a range of final use areas: lighting, motors, compressed air equipment, pumps, air conditioning, ventilation, refrigeration and cooling, steam production and distribution, heating, automation and control, process optimization, energy management and distribution etc.

The commercial and industrial sectors are the main potential beneficiaries of 'performance contracts' (a means of raising money for investments in energy efficiency based on projected savings). Despite its significant potential this public sector mechanism is however hampered by a number of major barriers that undermine the action of the ESCOs preceding on the basis of performance contracts.

26 The PNE 2030 and previous plans regularly presented estimates of energy conservation in their projections. However, the major part of energy savings potential has been attributed basically to the market and very little attention has been given to planning for demand aspects. As a result, detailed information about investments, programs and physical targets for conserving energy do not exist.

27 After the 2001/2002 energy crisis Law Number 10.295/2001 was approved. This was called the *Energy Efficiency Law* and addresses exclusively the question of minimum standards of energy efficiency for equipment and buildings.

Barriers/Evaluation

Initially the creation of this fund excited a great deal of optimism among the ESCOs given that the fund responded to the pent-up need for more credit for small and medium firms seeking to reduce the risk of their operations through performance contracts with clients.

Information available for 2008 suggests that credit worth around R$55 million had reached the approval stage in BNDES, involving a total of 12 projects of which only one had not been negotiated by the ESCOs [28].

It is too early to affirm that the market for ESCOs is consolidated (highly improbable) or that this guarantee fund has genuinely helped to expand this type of activity to exploit existing potential.

b) Program for Combating Waste of Electrical Energy (PROCEL)

PROCEL, created in 1985, has to date been the longest lasting and most wide-ranging program in the area of efficient use of electrical energy in Brazil. Its performance, effectiveness and investment record have fluctuated over the past 25 years, but it still remains an important agent of institutional support for a number of useful programs such as the *Brazilian Labeling Program.* It also provides useful support to projects in the sanitation and public buildings areas as well as acting as a source of information for the general public on energy saving matters.

The program gradually lost ground in the energy efficiency area to the utility concessionaires. These had a standing obligation to make year on year investments in energy saving initiatives using a fixed percentage of their net annual revenues. As a result the resources applied by electricity distributing companies on energy efficiency projects amounted to over R$261 million during fiscal year 2006/2007, while PROCEL´s total contribution (in 2007) was only R$53 million.

Over the years a number of different programs were undertaken by PROCEL, some of which, such as the refrigerator labeling initiative, were relatively successful. The program could still have an important coordinating role in promoting energy efficiency in Brazil and working jointly with ANEEL on the programs run by the concessionaires.

PROCEL financing is currently largely dependent on the *Global Reversion Reserve Fund* (RGR), as can be seen in Table 37, but it also receives resources from ELETROBRÁS[29].

Table 37 – Annual investments obtained by PROCEL (1986-2007)

	1986/2003	2004	2005	2006	2007
ELETROBRÁS/PROCEL investments (R$ million)	252.01	27.18	37.17	29.24	13.62
Investments RGR (R$ million)	412.00	54.00	44.60	77.80	39.16
Investments of the Energy Efficiency Project for Brazil (R$ million)[(a)]	2.09	12.97	16.23	6.20	-
Total investments (R$ million)	666.08	94.15	98.02	113.24	52.78

Source: ELETROBRÁS/PROCEL Evaluation 2007. Notes: (a) Refers to the investment of US$ 11.9 million of the GEF (Global Environment Facility) and the ELETROBRÁS counterpart.

28 Taken from the Internet site of ABESCO: PROESCO AVANÇA E JÁ É REALIDADE NO BRASIL: http://www.abesco.com.br/datarobot/sistema/paginas/pagebody2.asp?id=35&msecundario=1239. Accessed on 15/01/09

29 Law Number 10.438 (Article 8) establishes that the annual quota of the *Reserva Geral de Reversão* (RGR) will be extinguished at the end of 2010. The RGR corresponds to a percentage of the shares of the electricity utility firms. This is collected on behalf of ELETROBRAS in order to endow it with funds for expanding the system and improving service quality.

Barriers/Evaluation

PROCEL has lost many of its national coordinating functions with regard to energy efficiency in the electrical sector, but it is still able to provide substantial support for a number of activities.

The fact that the program was closely linked to ELETROBRÁS always limited its performance and medium to long-term role in the energy efficiency policy. A number of barriers that might explain PROCEL performance over the years are listed below:

- PROCEL´s link to ELETROBRÁS has meant that many of its staff (particularly on the management side) are permanent serving employees of the company. A high turnover rate in this company´s management structure has clearly affected the continuity of PROCEL activities.
- Energy efficiency is not the principal activity of ELETROBRÁS and in certain situations this function has caused conflicts of interests for the company.
- Energy efficiency implies a more wide-ranging approach than that pursued by an electricity company such as ELETROBRÁS. Other markets and energy sources need to be developed as potential substitutes for electric power (for example solar energy and gas), with a view to securing greater efficiency in the energy sector and reducing the use of primary energy in the economy in general.

c) Brazilian Labeling Program (PBE) and Efficiency Ratings ('Seals of Approval')

The PBE program has been running since 1984. Its main aim is to provide reliable information to consumers on how to identify and compare the energy consumption of household appliances and other electrical goods. The program basically involves voluntary action on the part of manufacturers. PROCEL and CONPET are its institutional partners.

At present the PBE program has developed 22 labeling projects and has plans to develop a further 20 over the next few years.

The "efficiency rating labels", known as PROCEL 'seals of approval', are presented annually to the best electrical goods in each category. Over the years these labels have been awarded to electrical goods manufacturers more rigorously. They have proved to be an important marketing asset as well as being useful for customers shopping for more energy-efficient products.

Barriers/Evaluation

This program has the advantage of continuity. It also has a free hand to develop efficiency measuring methodologies for different types of energy-using equipment, including non-electrical equipment such as solar heating devices, gas ovens etc. With the support of PROCEL and CONPET the program is also authorized to register and label laboratory equipment throughout practically all of Brazil.

On the downside the program has little influence over the type of (constantly changing) technology used by manufacturers in their appliances or over their marketing strategies using PROCEL seals of approval. The effectiveness of the voluntary labeling program is thus subject to a number of constraints.

4.3.2 Financing Mechanisms

a) Global Reversion Reserve (RGR)

The Global Reversion Reserve is one of the charges imposed by electricity companies. (since 1957) and is responsible to a large extent for financing PROCEL activities. In 2007 around 74% of all the resources applied by PROCEL originated from the RGR (ELETROBRÁS/PROCEL, 2007).

While this source of finance is available for funding energy efficient activities in Brazil (R$1.3 billion in 2006) it is nevertheless not ring-fenced and has to compete with many other non-EE areas such as the RELUZ ('Relighting Program'), universalization of energy services throughout Brazil and the expansion of the electricity sector as a whole.

b) Sectorial Energy Fund (CTEnerg)

The CTEnerg was established by Law Number 9.991/2000 with the goal of funneling investments to R&D and energy efficiency programs. The Guidelines Manual of this fund [30] sets out the type of activities eligible for financing. These include R&D projects targeted at the development of more efficient technologies and processes likely to benefit consumers. The fund is also used to complement EE investments undertaken by the electricity utility companies (the 'ANEEL Program') and private sector concerns in general.

In the past the CTEnerg has financed the equipping of metrology laboratories. More recently the fund´s managers have approached universities with proposals to develop methodologies for monitoring and evaluation energy efficiency projects. It has also called upon the academic sector to undertake a new field survey to investigate the EE potential of the industrial, commercial and services sectors.

CTEnerg resources are a proportion of the annual net revenues of the electricity companies. In 2007, although CTEnerg received over R$200 million, only R$66 million was released[31] for investments. Note that this income source is the same that funds the energy efficiency R&D programs of the concessionaires - in other words its activities are funded by ordinary electricity consumers.

Barriers/Evaluation

The CTEnerg has suffered continuing resource cutbacks as a result of which its investment policies, particularly in the EE area, have been erratic and results have never been correctly monitored or evaluated. In 2008 there were signs of renewed interest by the fund´s managers in energy efficiency matters but there has still been no sign of resources being freed up (around R$5 million) for contracting studies, surveys etc.

The disbursement of CTEnerg funds has fallen far short of the money is spent on R&D and energy efficiency programs by the electricity companies.

4.3.3 Command and Control Mechanisms

a) Use of solar energy for heating water in buildings

A number of Brazilian cities have begun to introduce mandatory legislation covering the installation of solar powered water heating.

This represents a positive step forward for the wider dissemination of solar powered heating equipment as a substitute for electricity. However it is argued that the legislation has failed to play attention to the detailed technical specifications involved in installing and maintaining solar heating or to the possible negative impacts on consumers, such as increased water bills.

b) The ANEEL Energy Efficiency Program

The energy efficiency program run by the electricity concessionaire companies represents the

30 http://www.mct.gov.br/index.php/content/view/24015.html (accessed on 15 January 2009)
31 Ministry of Science and Technology (Resource Capture Secretariat). Available on http://www.mct.gov.br/upd_blob/0023/23095.pdf (accessed on 15 January 2009).

largest proportion of investment in the EE area in Brazil. Approximately R$261 million were invested by 61 concessionaires (2007) in programs supervised by ANEEL.

This program provides significant opportunities for undertaking activities throughout the country aimed at improving energy efficiency.

Over the past 10 years the ANEEL program has constituted the largest and most uninterrupted flow of investment in energy efficiency in Brazil.

Barriers/Evaluation

Over many years the programs undertaken by the electricity companies supervised by ANEEL have been subjected to constant modifications in their format, priorities and implementation rules. The absence of transparency and rigor with respect to performance evaluation of the programs casts serious doubt on the validity of the investments made.

The *ANEEL Manual* was reformulated 2008. This manual is intended to guide the planning and execution of the programs undertaken by the electricity companies with a view to improving the quality and overall performance of the various programs. The new approach prioritizes impact evaluation in terms of the number of kWh and kW saved (verified by standard monitoring and evaluation methodologies). Furthermore, the new manual simplifies a range of bureaucratic procedures in an effort to assist concessionaires when submitting programs for approval and execution.

c) The Energy Efficiency Law

The main focus of this law (Law Number 10.295) approved in 2001 is to provide the public authorities with a range of instruments for determining the minimum standards required for energy consumption in buildings and equipment.

i) *Minimum standards for energy consumption in buildings and equipment*

- Regulations in force:

  - Three-phase electric motors (government directive and target plan)
  - Compact fluorescent lamps (government directive)
  - Air conditioning (government directive)
  - Ovens and stoves (government directive)

- Directives not yet signed:
  - Gas water heaters
  - Commercial and public buildings

- Equipments under study:
  - Solar powered water heaters; electromagnetic reactors for fluorescent tubes; electromagnetic reactors for sodium lamps; sodium lamps; and incandescent lamps.

- Residential buildings: regulations being prepared.

4.3.4 Market Mechanisms

a) Information Programs

Brazil has not made much use of market mechanisms to encourage investment in energy efficiency. Virtually no differentiated taxes or charges related to product efficiency are applied. Moreover few other real incentives exist (such as significant price reductions) to attract consumers to purchase energy efficient products.

The most important initiatives have perhaps been the information programs developed mainly by PROCEL (for example PROCELINFO[32]) and the quality 'seal of approval' initiative (also by PROCEL) indicating the best products available on the market from the energy efficiency point of view.

Training programs have also been run by electricity concessionaires and PROCEL. These programs, generally targeted at specific audiences in the commercial and industrial sectors, have also boosted equipment replacement programs for the low-income population, including providing ordinary customers with information about good practices and affixing energy saving ratings stickers to domestic appliances.

Barriers/Evaluation

Information programs are certainly a step forward but are insufficient for producing significant impact in terms of conserving and using energy efficiently.

The efforts made by PROCEL and a number of concessionaires have nevertheless succeeded in drawing attention to good practices for both residential and commercial consumers.

4.3.5 The National Climate Change Plan (PNMC)

Some of the above proposals have been mentioned in the PNMC, although details about the impacts and contributions to emissions mitigation are not given in this plan. Disappointingly the PNMC sets out no priorities or financing requirements. Three points are nevertheless worth noting:

1) *The need for labeling and voluntary standards*[33], plus mandatory minimum standards of energy efficiency) to indicate energy consumption (and emissions): the PNMC is more explicit with regard to motor vehicles, commercial and public buildings but in its references to other energy-consuming equipment (electrical or not) it relies on the same legal instruments and makes no distinction between financing programs and institutional agents (for example in the case of vehicles, it is necessary to involve jointly ANFAFEA, CONPET, INMETRO in addition to the MME and CGIEE).

2) *Decrees on Efficient Public Procurements*: with this procedure the public sector could organize auctions of products and services according to specific standards, with energy efficiency being one of them.

3) *Strategic Plan for Energy Efficiency*: the PNMC mentions the possibility of using this plan to make a possible economy of 10% in 2030 (106 TWh)

4.4 **Proposed Measures**

Proposed policies and instruments to overcome the barriers in this sector are as follows:

4.4.1 Minimum energy efficiency standards

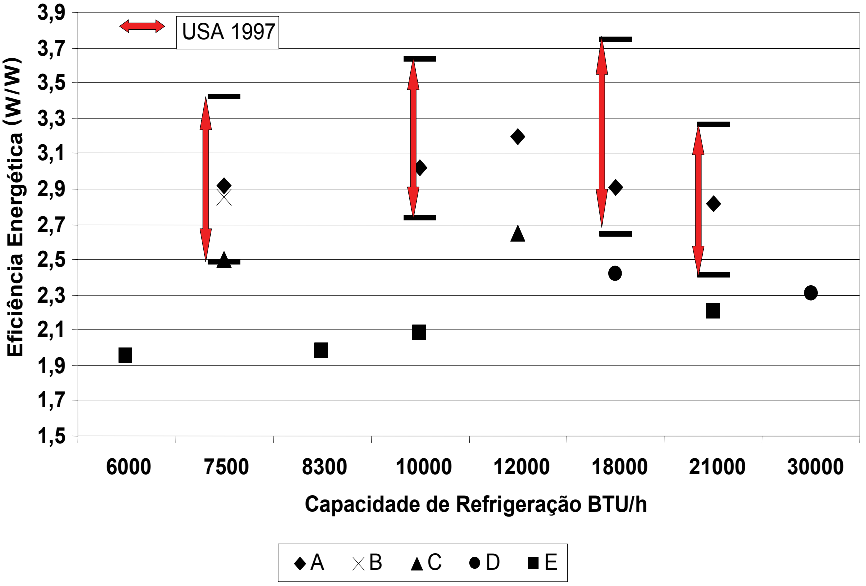
The indices for energy performance could be more ambitious and whenever necessary resources for research and development could be channeled into encouraging the adoption of more aggressive ways of reducing consumption. The existing R&D funds could finance the development of more efficient products than those available currently on the market and

32 http://www.eletrobras.com/pci/main.asp
33 Minimum mandatory standards of energy efficiency are not explicitly mentioned. These are also permitted and feasible in accordance with Law 10.295/2001.

encourage adoption of stricter EE standards.

Figures 2 and 3 below compare current efficiency indices adopted by Brazil with those in the United States (1997) for refrigerators and the European standards for air conditioning units. The best Brazilian-made refrigerators (label "A") are close to the bottom US rating for year 1997 (Figure 3). A similar situation can be seen in the case of Brazilian-manufactured air conditioning units when compared with the current standards imposed in the European Community (Figure 4). There is no obvious techical or manufacturing justification for the huge gap between the current Brazilian and US/European Community standards.

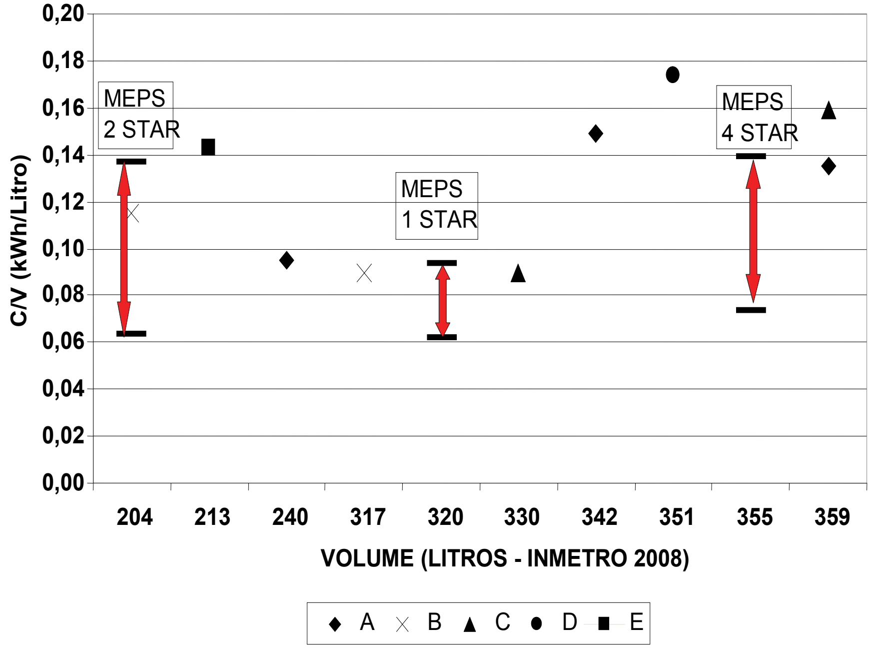
Figure 3 – Comparison between the standards of energy efficiency of air conditioning units adopted currently in Brazil and the standards in the USA (for 1997)



Source: Melo, 2009

Notes: A-E refer to the values of the efficiency standards of Brazilian-manufactured air conditioning units. The double arrows represent the variation interval of the permitted limits (maximum and minimum) for the same appliances in the USA.

Figure 4 – Comparison between the standards of energy efficiency (C/V) of efrigerators labeled in Brazil and European Minimum Energy Performance Standards (MEPS)



Source: Melo, 2009

Notes: A-E refer to the values of the efficiency standards of Brazilian-manufactured refrigerators. The double arrows represent the variation interval of the permitted limits (maximum and minimum) for the same equipment in the European Community.

4.4.2 Technical bidding processes by government agencies

Public sector agencies account for around 10% of total electricity consumption in Brazil. These agencies have the opportunity to specify performance standards which in turn could stimulate manufacturers to develop and supply appropriate products to meet this demand.

This kind of initiative is important especially when it concerns new technologies that have not yet been introduced on a significant scale into the market. The technical development risks involved in manaufacturing new and more energy efficient products can be a major disincentive for manufacturers unless it is made clear that a market exists for the equipment produced. Thus an initiative by public sector agencies involving the acquisition of large volumes of new equipment complying with well-defined specifications is one way of ensuring reasonable financial returns for manufacturers. The difficulties of putting this proposal into practice arise from the requirement for public agencies to comply with Federal Law Number 8.666 which obliges agencies to accept the "lowest price" bids in public calls for tender.

4.4.3 The public sector and performance contracts

Current legislation does not allow the public sector to enter into performance contracts with ESCOs, but the potential does exist and the benefits would be considerable.

It is necessary to reformulate or create legal mechanisms that authorize public sector agencies to pay for services undertaken by ESCOs for making energy savings. A further alternative would be to operationalize such projects in a Public Private Partnership (PPP) context.

4.4.4 White Certificates (CB)

These are documents attesting to the fact that a specified energy consumption reduction has been obtained. In other words they provide proof that energy savings have been made, for example "1 White Certificate = 1 MWh". The CBs are tradeable and oblige market agents to comply with energy-saving physical targets.

Under this system producers, suppliers and distributors of electricity (plus gas and petroleum distributors) would be under an obligation to implement EE measures in line with a predefined percentage of their annual energy supply. On the other hand, the ESCOs and the major energy consumers could generate CBs with their energy efficiency projects and would be able to trade these with producers etc which are under an obligation to reduce emissions (or make energy savings).

The White Certificates would be issued when a given quantity of 'saved energy' is certified by an independent body. The holder of the certificates could then use them to comply with his own targets or sell them to other parties who also have reduction commitments. The possibility of this kind of commercial transaction would in principle ensure that the total energy savings were obtained at minimum cost, while the existence of the CBs would guarantee that the total target of energy savings would also be achieved.

While the market would be the main financier behind this system it is also vital to ensure that the public authorities establish the obligations and set the rules for trading CBs, as well as to guarantee the quality of the entities charged with managing the certification process.

4.4.5 Actions that could be incorporated into the ANEEL Program

A number of actions are suggested below which could complement the compulsory programs undertaken by concessionaires and supervised by ANEEL. The purpose is to provide the means to enhance uptake of energy efficiency programs in Brazil and obtain the lowest unit costs, together with a better chance of transforming markets.

a) National or regional programs

The basic idea here is to suggest programs that could be adhered to by utility concessionaires in any part of the country. These programs would benefit from a "centralized management" responsible for standardizing procedures, technologies, support etc. Each concessionaire could earmark a given sum and receive a ready-made program in exchange.

***Advantages*:**

- These programs could prove attractive to small concessionaires which lack the appropriate staff to design and operate such programs;
- Economies of scale
- Enhanced guarantee that regional markets will be transformed
- Good-quality impact measuring.

Under this scheme priority would be given to education and training in addition to support for upgrading state or municipal energy management ('Priority Projects'). Low income programs could be other candidates for the scheme particularly if they were to form part of a wider social assistance approach ('Low Income Projects'). Another example could be a priority program focused on public lighting given that the national public lighting program (RELUZ) is currently experiencing problems. Note that these suggested projects are not confined to measuring results in terms of MWh and kW.

b) Energy Efficiency Auctions

The idea of auctions is not new (the US has had some experience). The idea would be to allocate some of the 'obligatory funds' [34] that the concessionaires use for energy efficiency programs for contracting projects that can ensure better costs for the quantity of kWh saved. This would be an opportunity for other agents to create and implement programs. The funds could be eligible for access by ESCOs, consortia of ESCOs and consumers - or a combination of all, including the electricity concessionaires.

The aims of this approach include:

- To seek to improve cost competitiveness
- To provide an alternative for using compulsory funds
- To enable other agents to participate directly in creating and implementing energy efficiency programs
- To combine the funds of different concessionaires in order to promote actions in specific areas of interest that could improve the system overall.

The possible criteria to be used in the auctions would be:

- To increase the reserve margin
- To postpone investments in transmission and generation
- To produce benefits for the interlinked system or region (not necessarily a concession area)
- To maximize benefits for consumers (e.g. tariff reduction)

It is important to explain that the programs to be funded through auctions would need to include a monitoring and evaluation model to be rigorously employed during the lifetime of the chosen project or projects.

4.4.6 Voluntary Agreements

Along with the introduction of performance standards for equipment, it is also vital to ensure that more efficient processes and technologies form part of the entire productive chain. The government should approve EE levels for all the productive sectors and prioritize energy intensive sectors firstly by targeting the most inefficient sectors which possess the highest potential for reducing energy use. The implementation of such targets could be done through Voluntary Agreements and only subsequently through penalties or fines in the case of targets not being reached.

4.4.7 Virtual Energy Concessionaire

This concessionaire could be a private company chosen by public tender possessing annual energy conservation targets over a a specific timeframe. The selected company could be regarded as a large ESCO working in the concession area. The virtual concessionaire would

34 The resources do not necessarily need to arise exclusively from contractual obligations of the utility companies.

benefit from the provision of technical assistance and financial incentives for the consumers in its area aimed at reducing energy bills through purchases of more energy efficient equipment, support for building projects, processes and energy management.

This concessionaire would sell energy efficiency services for a given geographic region and would effectively compete with the conventional concessionaires as well as with the electric energy tariffs charged in the area. The activities of the concessionaire would be regulated by ANEEL. The expectation would be to improve transparency in questions of public interest associated with energy efficiency programs. Some of the resources required could be provided by funds collected from consumers who currently finance programs run by distributors. The virtual concessionaire would also receive income generated by its activities, which could subsequently be reinvested in efficiency programs.

This would also be an interesting alternative for avoiding the conflict of interests normally experienced by the utility concessionaires reluctant to exploit the technical and economic potential of energy efficiency. It would also be a suitable way of facilitating monitoring, evaluation and verification of investments in energy efficiency programs.

This type of program has been running in the United States for a number of years, as for example the 'Efficiency Vermont' project [35] which has been in operation since 2003.

4.4.8 Differentiated taxes and financing

Different levels of tax (i.e. reductions) could be applied to energy-saving products. This could be applied at the Federal, state or municipal levels. Residential buildings for example using energy-efficient technologies such as solar-powered water heating systems could be eligible for reductions of local charges such as the IPTU (property tax). Domestic appliances such as ovens and refrigerators needed by low income families could also be sold on more attractive credit terms than at present.

4.4.9 Improvements in the law governing use of solar energy

Better specifications are needed to provide a framework for the use of solar energy for water heating, aimed at minimizing overall costs for consumers (including the costs of water and installation). In addition, more incentives could be provided for urban planning authorities to ensure adequate space between new buildings to allow for better air circulation.

35 http://www.efficiencyvermont.com.

Table 38 - Summary of Policies Proposed for Energy Efficiency

Policies proposed	Category of policy	Type of mechanism	Instrument	Level of government involved in deployment	Origin of financing
1- Minimum standards of energy efficiency	Rectification	Command-control	Law	Federal	CTEnerg, funds for R&D and studies
2- Public sector technical bidding procedures	Incremental	Market	Flexibilization of Law 8.666	Federal, state and municipal	Market
3- Performance contract for the public sector	Incremental	Market	Law	Federal, state and municipal	Market
4-Energy efficiency auctions	Incremental	Market	Regulation, government directives	Federal	Market, compulsory resources (ANEEL)
5- White Certificates	Incremental	Market	Law or regulation, government directives	Federal	Market, compulsory resources (ANEEL)
6- Law to govern use of solar energy in buildings	Rectification	Command-control	Law	Municipal	Market
7- Programs with compulsory resources (ANEEL)	Rectification	Command-control	Regulation, government directives	Federal	Market, compulsory resources (ANEEL)
8- Virtual concessionaire	Incremental	Command-control	Regulation, government directives	Federal	Compulsory resources (ANEEL))
9- Voluntary agreements	Incremental	Market	Formal contract, agreement	Federal, state and municipal	Market
10- Differentiated taxes and financing for efficient products and solar heating	Incremental	Market	Taxes	Federal, state and municipal	Fiscal waivers, public and private banks

5. Energy Demand - Reducing Emissions Resulting from Industrial Consumption of Fossil Fuels

5.1 Mitigation Options

This item deals with the Low Carbon Emissions Scenario up to year 2030 in the Brazilian industrial sector. It considers the implementation of the measures for mitigating greenhouse gas emissions (GHG), particularly CO_2 produced by the industrial use of fossil fuels.

The possibilities for mitigating emissions in the industrial sector (technical options) are grouped under five main headings as follows:

- Energy efficiency (subdivided into six groups)
- Recycling and saving materials
- Inter-energy substitution
- Use of renewable energy (solar energy and biomass)
- Reduction or elimination of nonrenewable biomass (produced from deforestation)

We estimated the mitigation potential of each of the above measures by employing different methodological approaches. However the chosen baseline consisted of the energy consumption data for each of the industrial segments according to the classification of the National Energy Balance (MME, 2008a). We also used certain “own” subdivided data in order to better provide further details of the potential for reducing both energy consumption and emissions.

Quantification of this potential was done by adopting the mitigation measures/technical options jointly (with the exception of the energy efficiency segment) with the aim of avoiding double counting or overlapping. In other words, the potential calculated was offset against mitigation measures that had been previously undertaken. The abatement potential obtained (‘composite or adjusted abatement’) follows a logical order, beginning with the simplest and generally less costly measures and then progressing to more complex and expensive measures.

Some specificities of the measures for mitigating CO_2 emissions are presented below.

5.1.1 Energy Efficiency

The concept of using energy efficiently has been of concern to the industrial sector for some years, mainly after the second oil price shock and, more recently, as a result of rising electricity prices.

Energy efficiency involves, as the phrase would suggest, the production of a given good, product or service while using the lowest amount of energy and at the same time maintaining the quality of the products or standard of services. Energy efficiency measures are focused on producing given products or providing services by reducing or eliminating energy losses and wastage. Efficiency measures can include the adoption of simple low-cost measures in the operational field (‘housekeeping’) or in other circumstances the deployment of more expensive and complex measures involving new technologies and processes that consume less energy.

With the aim of obtaining more accurate estimates for the suggested set of energy efficiency measures, we subdivided this item as follows: (i) measures for improving combustion; (ii) heat recovery in industrial processes (including integrating processes); (iii) heat recovery in steam systems; (iv) heat recovery in furnaces; and (v) implementation of new processes and other miscellaneous measures.

We employed two methodological approaches for establishing the potential for implementing energy efficiency measures. The first was to use the information contained in the Useful Energy Balance (BEU) (MME, 2005) for defining the values of potential savings that could be made by Brazilian industry. Our second approach involved comparing the specific consumption indices practised in the different segments with indices regarded as "best practice" produced by industrial concerns or obtained from international reference sources. In the first case, we accepted the values as the *minimum* potential values to be achieved, while in the second approach involving the correlation of specific consumer indices we defined *higher potential values,* although some of these were only appropriate for deployment over the medium to long-term.

In the case of the BEU, an analysis was made of the end use for energy (basically direct combustion and process heat) related to the *average* yields obtained in each specific industrial sector and of the optimized or expected *maximum* average yields. This produced aggregated estimates of the total energy efficiency potential for each productive segment. The values detected were fairly modest since generally only the efficiency of the end use equipment (e.g.furnaces and boilers) was calculated, with the possible gains in the process as a whole not taken into consideration.

In the "best practice" evaluation we consulted sectoral data supplied by EPE (including consumption and production indices of various firms[36]) and data from a selection of international and Brazilian studies where specific energy consumption indices and still existing typical potentials are discussed (La Rovere, 2006; PROCEL, 2007; CCAP, 2007; IEA, 2007b; IAEA, 2006; IEA, 2008; De Beer et al., 1997 and 1998; EGEE, 2007; Martin et al., 2000; Worrel et al., 2000 and 2008).

With the aim of securing greater accuracy and detail in the evaluations for the energy efficiency segment, we subdivided this into the following measures: (i) combustion improvements; (ii) heat recovery; (iii) optimization of steam systems; (iv) heat recovery in furnaces; (v) implementation of new processes and other general measures. Table 39 below shows the potential savings in energy identified and the origin of the maximum emissions reductions by type of specific measure in each industrial segment.

36 Information without the *imprimatur* of firms.

Table 39 – Energy efficiency measures: potential for saving energy in the industrial sub-sectors (in %)

Sectors	Savings range	Energy efficiency measures					
	%	Combustion optimization (%)	Heat recovery systems (%)	Steam recovery (%)	Heat recovery/ovens (%)	New processes (%)	Other efficiency measures (%)
Cement	10 - 23	2			21		
Iron and steel	6 - 35	3			7	24	1
Non-ferrous metals (except aluminum)	8	2			6		
Aluminum / alumina	5	1		2	2		
Ferro-alloys	7				7		
Mining/granules	8 - 21	3			18		
Paper / Cellulose	6 - 18	3		6		9,4	
Chemicals	6 - 22	3	3	3	6	7,2	
Ceramics	10 - 34	3			11	20	
Red Ceramics	40	3			14	23	
White Ceramics	15	2			6	7	
Textiles	7 - 16	2	3	5		4	2
Food	11	2	2	2	3	2	
Other	7 - 16	2		5	5	4	
Lime	16	5				11	
Glass	16	7			9		

Note: In the "savings" range the minimum values refer to the BEU analysis and the highest values refer to the analysis of the correlations of specific consumption/best practices.

Table 40 presents the values of the potentials converted into equivalent tons of petroleum based on year 2007. This served as a basis for projecting the quantities of energy (combustibles) and the scale of emissions to be abated.

Depending on the type of energy efficiency method a specific implementation period was adopted based on the "useful life" of the measure. An energy consumption growth rate of 3.7% (EPE, 2007) was used as the basis for constructing the scenarios up to 2030.

Table 40 – Potential for saving energy by using specific measures and by sectors in tons of petroleum equivalent -TPE (Baseline 2007)

Sectors	Consumption of thermal energy (1000s TPE)	Savings	Energy efficiency measures (in 1000s TPE)							% share of the sectors
		%	Opimization of combustion	Heat recovery systems	Steam recovery	Heat recovery/furnaces	New processes	Other efficiency measures	Total	
Cement	2,968	23	59			623			682	5
Iron and steel	16,795	35	503			1,175	4,047	167	5,895	43
Non-ferrous metals	2,628	7	52			155			207	1
Ferro-alloys	1,017	6				68			68	1
Mining/granules	2,108	21	63			385			449	3
Paper / Cellulose	7,037	18	211		422		661		1,294	9
Chemicals	5,440	22	163	163	163	326	391		1,207	8
Ceramics	3,506	34	105			396	701		1,202	8
Textiles	542	16	14	16	27		21	10	90	1
Food	18,964	10	379	379	857	91	303		2,010	14
Other	2,890	16	57		144	144	115		462	3
TOTAL	63,898		1,610	558	1,614	3,366	6,242	178	13,571	100
Saving %	-	-	2	1	2	5	9	0	21	

a) Improved combustion

Combustion processes generally contain energy inefficiencies due to limitations of the equipment or operational-side problems. Efficient high-performance burners certainly exist on the market but these are more expensive. Higher quality equipment produces better combustible/comburent mixtures and automatic modulations in accordance with heat demand. Better equipment also operates with lower levels of 'surplus' air, thereby reducing heat loss in the exhaust gases. On the operational side it is extremely common to find calibrated equipment operating with extremely high air/combustion ratios or generating high levels of soot (unburned carbon). Simply controlling the combustion gases, adjusting combustion levels and ensuring adequate maintenance of the burners can produce significant savings in industrial furnaces and boilers, often of between 2% and 5% (Combustion Handbook, 1978). The practice of operating with oxygen-enriched air also represents an alternative that could generate savings in certain high temperature processes, although this involves additional costs (ABM, 2008).

b) Heat recovery in industrial processes

Recovering heat in industrial processes involves optimizing systems which operate within an intermediate temperature range (100°C to 450°C), producing hot air which can be used for heating other fluids. Using heat exchanges or heat recovery devices in manufacturing processes in the chemical, petrochemical and petroleum refining industries can generate savings of between 5% and 15%).

Process integration employing the *Pinch* [37] technique enables simulations to be made of the energy balance and of the thermal currents of a particular process, resulting in overall energy optimization and minimization of operational and investment costs (Oil& Gas Journal, 1984).

c) Heat recovery in steam systems

This method of energy efficiency involves optimizing systems for generating, distributing and using steam. In general these are low-temperature processes (up to 180° C), which do not require substantial investment and which can generate rapid economic returns.

Steam systems are used in a number of Brazilian industrial sectors, including the paper and cellulose, food and beverages, textiles, chemicals, petrochemicals industries etc. Specific energy-saving measures that could be applied are of various types: condensate recovery, recovery of heat from boiler exhaust gases, optimization of the steam distribution network, calibration and control of steam pressure levels and harnessing *vapor flash,* using multi-effect systems in concentrators, controlling temperature and/or pressure in the various equipments, eliminating leaks, maintaining steam traps etc

d) Heat recovery in furnaces

Recovering heat from exhaust gases in furnaces is a relatively common practice in industry. While significant further savings in terms of heat recovery can potentially be made, the scale of the investments required is usually high and only promise medium to long-term returns.

Normally the most heat-intensive industries (cement, glass, steel, petrochemicals, granulization etc) employ heat recovery systems but these are not always adequately planned or operated under optimal conditions. The systems generally consist of heat recovery devices (recuperators) for preheating air for combustion or the heat load to be processed or preheating a process fluid. Substantial volumes of hot gases at high temperatures are involved. Large-scale systems might also possess heat recovery boilers, producing hot water or vapor both for processing and for converting into mechanical power.

e) Adoption of more modern and efficient processes

More modern energy efficient processes are being introduced into various sectors of Brazil's industry. This is the case of the steel sector for example, which has since the 1970s been replacing refining and steel fusion using the Siemens-Martin (*OHF - Open Hearth Furnace*) with modern furnaces *BOF (Basic Oxigen Furnace)* and electric processes *(EAF - Eletric Arc Furnace)* (De Beer et al., 1998; Martin et al., 2000). Another example is the cement industry where the manufacturing system based on the wet "slurry" process is gradually being displaced by the "dry" process where raw materials are ground, mixed, and fed to the kiln in a dry state, requiring less heat (IEA, 2007b).

Our evaluative approach involved comparing both the technology routes with one another and highlighting specific sectoral consumption indices. We considered for each sector (i) technologies that are already commercially available and (ii) technologies under development which hold out good penetration prospects in the market over the next 10 to 20 years. Some of these technologies are listed below:

37 The term "Pinch Technology" invented by Linnhoff and Vredeveld represents a new methodological approach to thermodynamic analysis guaranteeing a minimum level of energy in the design of heat exchange systems.

(i) Cement

-Installation of multiple-stage pre-heaters (4, 5 or 6 stages) and precalcinators (IEA, 2007b).

-The use of additives for reducing production of clinker (note that this item is addressed in the chapter on *Recycling/Economy of Materials*).

(ii) Iron and Steel

-The activation of obsolete, small capacity, low efficiency blast furnace plants.

-Installation of coke dry quenching and advanced wet quenching processes (US/EPA, 2007).

-Installation of Top Pressure Heat Recovery Turbines (TRT) for recovering blast furnace gases with an electric energy production capacity of between 15 and 40 kW/t of pig iron (IEA, 2008; US/EPA, 2007).

-Pulverized coal injection in blast furnace plants (aimed at reducing coke consumption).

-Use of natural gas as an auxiliary fuel in the process of blast furnace reduction of iron ores (also aimed at reducing coke consumption).

-Installation of electric plants with new technologies (IEA, 2008).

-Introduction of the 'continuous-casting' process at the steel refining stage (IISI, 2008).

-Gases and heat recovery in Basic Oxygen Furnaces (BOF).

-Substitution of continuous teeming as used at present by thin steel sheet ingoting or using mold shapes similar to end-products.

-Oxycombustion in reheating ovens of plates and billets.

-Introduction of new reduction and simultaneous fusion processes. This process combines the gasification of coal with direct reduction of iron oxide minerals. In this way the process does not use coke and dispenses with the need to prepare the ore (Martin et al, 2000). The process is now being used on a commercial scale by COREX, operating in South Africa, India, South Korea and China (Worrel et al, 2008). Other processes are also being developed such as the CCF, DIOS, AISI and HISmelt. Studies estimate a specific energy consumption of between 20% and 30% less than that required in most current blast furnace plants.

iii) Paper and Cellulose

- *Conde*belt mechanical drying

- Dry leaf formation

- Impulse drying of paper

- Direct electrolytic caustification of cellulose

- Integration of cellulose and paper manufacturing processes.

iv) **Chemicals**

- Enhanced integration of manufacturing processes

v) **Textiles**

- Polymerization of fabrics by direct heating

vi) **Ceramics industry**

- Employment of roller-hearth ovens

- Deactivation of low yield discontinuous kiln systems

vii) **Glass**

- Preheating of cullet

- Enhanced use of air enrichment and combustion in glass fusion

viii) **Lime**

Enhanced use of vertical ovens

f) Other operational measures

A series of other operational measures present possible energy savings. These are simpler measures which would result in lower potential savings, requiring small-scale investment and generally attractive from an economic point of view. The measures could be undertaken basically in the area of maintenance and control, for example: upgrading thermal insulation in equipment and heat pipes, correct maintenance of valves and ancillary equipment, controlling temperature, elimination of heat loss from kilns, ovens etc.

5.1.2 Recycling and economizing materials

Recycling and economizing materials could also be considered within this set of energy efficiency measures. Recycling can in some circumstances use less energy than that needed for manufacturing products from virgin materials and also avoids the energy and emissions problems associated with virgin raw materials extraction. The glass and aluminum sectors have demonstrated how economic and energy savings can be made (ABIVIDRO, 2008; ABAL, 2008), for example, in the processes employing glass cullet and salvaged waste metal respectively. While energy cost savings can be made in many other sectors the actual cost of recyclable material is also usually less than original or virgin raw material. The environmental and social benefits resulting from the recycling process are also worthy of consideration.

The sectors with clear prospects for obtaining energy and emissions reductions through recycling processes and saving materials are: cement manufacture (increased use of additives), iron and steel (re-using scrap metal), paper and cellulose (re-use of paper offcuts and waste, glass (cullet recycling), aluminum (recyclable cans etc) and ceramics (by reducing materials wastage).

In our study we transposed each of the technical possibilities for recycling and economizing materials into “energy gains” and “avoided emissions”, using 2007 as a baseline year. The methodological route adopted was to verify the current recycling index for each of the above products and to estimate the prospect of this increasing on the basis of its (i) recent evolution and (ii) correlation with indices pertaining to other countries. Given that each product has different properties, a specific analysis was conducted for the main industrial sectors with the greatest potential of reducing emissions. Examples are the use of additives in the case of the cement industry, recycling in the steel and aluminum sectors (the latter listed under “nonferrous metals”), recycling glass (under “other “), recycling offcuts in the paper industry and economizing materials in the ceramics sector .

a) Cement - Use of Additives

The reduction of the clinker-to-cement ratio in the production of Portland cement has been the key to reducing energy requirements in the cement industry, since manufacturing clinker is an extremely heat intensive process. Most of the energy used is in the form of fuel for the production of cement clinker and electricity for grinding the raw materials and finished cement. The clinker/cement ratio varies generally between 0.7 and 0.95 depending on the type of cement being produced (IEA: 2007b). The ratio of 0.95 for example represents 100% of the production of Portland cement with 5% gypsum added (i.e. 95% clinker and 5% gypsum).

The reduction of the clinker/cement ratio in many countries has been significant since 1990, with a worldwide average reduction of 1% per annum (IEA, 2007b), although China was responsible for much of this during the period between 1994 and 2004 (1.3% per annum). As is well-known, China has had an increasing supply of slag originating from steel blast furnaces and ash residue from coal-fired processes. The world average in 2005 of the clinker/cement ratio was in the region of 78% (0.78) (IEA, 2007b).

In Brazil the opposite story is true. The clinker/cement ratio has increased, according to an IEA (2007b) survey to around 81% and 82% (0.81 and 0.82) in 2005. This could be due to the high cost of additives compared with the low cost of residual fuels currently employed for manufacturing clinker such as petroleum coke. Nevertheless it is estimated that the clinker/cement ratio could reach, over the medium to long term, around 77% - 78% (0.77 to 0.78) - in other words closer to the current world average. As a result the reduction of cement clinker production would be 4%. Table 41 shows estimates for the reduction of consumption for each type of fuel resulting from increased use of additives, discounting the above-mentioned energy efficiency measure.

Table 41 – Energy efficiency and use of additives – cement sector (potential adjusted)

Forms of energy	Total consumption in 2007 (1000s TPE)	Savings with energy efficiency (1000s TPE)	Savings from use of additives (1000s TPE)	New consumption with energy efficiency + additives (1000s TPE)
Natural gas	17.00	3.91	0.52	12.57
Steam coal	36.00	8.28	1.11	26.61
Metallurgical coal	33.00	7.59	1.02	24.39
Other primary sources	268.00	61.64	8.25	198.11
Fuel oil	69.00	15.87	2.13	51.00
GLP	1.00	0.23	0.03	0.74
Mineral coke	55.00	12.65	1.69	40.66
Charcoal	222.00	51.06	6.84	164.10
Others petroleum	2,267.00	521.41	69.82	1.675.77
Total	2,968.00	682.64	91.41	2,193.95

b) Iron and Steel - Use of Scrap

In Brazil the current figure for steel recycling is 29% (MME, 2008c) which represented in 2007 around 9.8 million tons per year. Approximately 43% of the salvaged metal processed in Brazil originates from so-called "obsolescent scrap" from the collection of disused products such as old cars, metal containers, etc. 67% of the steel production of the Gerdau Group in 2007 came from scrap (Camarini, 2008, 2008).

The recycling index is the result of a combination of a number of different factors such as: the availability of scrap, its cost and the existing capacity for producing steel in every type of technology route. Electric processes facilitate more intensive use of scrap. In Brazil steel production using electric arc furnaces has grown more substantially than production in basic oxygen furnaces, although the latter has remained predominant in total production. Between 2002 and 2000 the electric arc furnaces increased their production by 4.7% per year (25.9% over the period) against only 1.6% a year (8.3% over the period) by oxygen generated furnaces. In 2007 76% of all steel in Brazil was produced using oxygen furnaces (25,703,000 t) and 24% using in electric arc furnaces (8,082,000 t) (MME, 2008b). If the current parameters are maintained, a larger share of steel production by electric arc furnaces is likely in the long-term, reaching something in the region of 30% to 32% around year 2030, which would provide more opportunities for using a higher proportion of scrap metal[38] (around 33-35%).

Our estimate for the reduction of fossil-based energy consumption was based on the specific optimized thermal consumption of 12GJ/t of steel in the oxygen generated steel making process (a figure which includes sintering and blast furnace reduction) (ABM, 2008), representing the quantity of energy that would be displaced by additional steel production using electric processes. This figure, multiplied by the quantity of additional scrap to be employed (originating from the gain of 4% - the difference between 33% and 29% of scrap) results in a fossil energy saving of 16,162 TJ in 2007, or around 386,000 TPE (2.3% of the sector´s consumption). The energy saved can be seen at Table 42 below.

Table 42 – Energy savings from efficiency and recycling– Iron and Steel Sector (adjusted potential)

Forms of energy	Total consumption in 2007 (1000s TPE)	Savings with energy efficiency (1000s TPE)	Savings due to recycling (1000s TPE)	New consumption with energy efficiency + recycling (1000s TPE)
Natural gas	1,171.00	411.02	26.93	733.05
Steam coal	6.00	2.11	0.14	3.76
Metallurgical coal	2,558.00	897.86	58.83	1,601.31
Fuel oil	129.00	45.28	2.97	80.75
GLP	69.15	24.27	1.59	43.29
Kerosene	1.00	0.35	0.02	0.63
Gas	1,083.00	380.13	24.91	677.96
Mineral coke	6,339.00	2,224.99	145.80	3,968.21
Charcoal	4,775.00	1,676.03	109.83	2,989.15
Others petroleum	584.32	205.10	13.44	365.78
Tar	79.68	27.97	1.83	49.88
Total	16,795.15	5,895.10	386.29	10,513.76

c) Aluminum/Alumina - use of scrap (results listed in the nonferrous metals segment)

The potential energy savings from recycling aluminum (basically electricity) could be made at the fusion/reduction stage. However in Brazil's case this energy can be considered to be neutral in terms of CO_2 emissions given that the estimated reduction of CO_2 in aluminum

38 According to the MME (2008c) the current European scrap steel recycling figure is 40% and in the USA 51%.

recycling in Brazil arises from reducing the amount of fossil fuels involved in the original production of alumina. This would effectively be displaced by recycled aluminum which would require only a small quantity of fossil fuels to be employed in the reduction process.

Estimating the reduction of fossil fuel consumption in the aluminum sector is based on the increasing amount of recycling that has taken place in Brazil -10% (from 36.7% to 46.7%). Furthermore, the following assumptions were adopted using data from ABAL (2008) and the *Metallurgical Sector Annual Statistical Bulletin* (MME, 2007a):

-1,919t of alumina is employed in the production of one ton of aluminum.

-Combustible oil consumed in the production of alumina: 0.239TPE/t of alumina

-Combustible oil used in the fusion of metallic aluminum: 0.043 TPE/t of aluminum.

Table 43 – Energy savings from efficiency and recycling : Aluminum/Alumina Sector

Aluminum production (000 t)	Equivalent of aluminum at rate of 10% recycling (000 t)	Quantity of alumina saved (000 t)	Consumption of CO avoided in production of alumina (TPE)	Consumption of CO avoided in production of aluminum (TPE)	Total consumption of CO avoided (TPE)
1,654.8	165.5	317.6	72.11	6.76	78.87

Note: This calculation incorporates the discounted energy efficiency measures, the estimated value of which was 5% on the original figures for combustible oil consumption of the aluminum/alumina sector.

d) Ceramics - Reduction of losses in the process and economizing materials

Wastage in the ceramics sector is caused by defects occurring at the molding, drying and firing stages of the products, especially in the red ceramics sector where wastage can reach 15% in many firms (INT, 2005a and 2005b). It is a reasonable assumption that the red ceramics sector loses an average of 8% of its production of which half (4%) impacts fuel consumption. This happens because the other half of the losses occur before the firing stage when the items with defects have already been eliminated, causing wastage only of electricity at the ceramic mass preparation, extrusion and drying stages. In the case of white ceramics the average level of losses is relatively low, generally in the region of 1% (INT, 2005a).

Table 44 – Savings of materials in the ceramics sector (adjusted calculation)

Forms of energy	Total consumption in 2007 (1000s TPE)	Savings with energy efficiency (1000s TPE)	Savings due to avoided wastage (1.000 TPE)	New consumption with energy efficiency + avoided wastage (1.000 TPE)
Natural gas	956.00	327.91	8.28	619.81
Steam coal	44.00	15.09	0.38	28.53
Fuel wood	1,885.00	646.56	46.3	1,192.15
Other primary sources	35.00	12.01	0.86	22.14
Diesel oil	1.05	0.36		0.69
Fuel oil	322.00	110.45	2.79	208.76
GLP	165.50	56.77	1.43	107.30
Other petroleum	98.00	33.61	2.41	61.98
Total	3,506.56	1,202.75	62.45	2,241.36

a) Glass - Increased use of cullets

Normally for each 10% of glass cullets added to the load for glass manufacture a saving of 3% of the fuels used in the fusion process is normally made (MME, 2007b; Martin et al, 2000). The figure for overall glass recycling in Brazil is 20%, and in the case of glass containers alone 47%, according to ABIVIDRO (2008). This saving is actually higher than the US saving for glass containers (40%) but much less than the savings found in Europe, in particular Germany, Belgium, France and Sweden where the figure is well above 90% (MME, 2007b).

Total annual glass production in Brazil is around 2.9 million tons (base year 2000) (ABIVIDRO, 2008) of which 44% consists of glass containers. It is reckoned that 80% of this amount could be recycled. As a result 1.02 million tons of glass could be recycled in Brazil, resulting in 35% recycled glass in the sector as a whole. In this event the amount of recycled glass would be 15% higher than the current percentage of recycled glass, resulting in a saving of 4.5% in energy used in the kilns.

For purposes of calculating existing savings in the glass sector we considered the consumption record of energy sources used by the sector and the specific consumption of average thermal energy of 10GJ/t. [39]

Table 45 – Savings made from conservation and recycling in the glass sector (adjusted calculation)

Forms of energy	Total consumption in 2007 (1000s TPE)	Savings as result of conservation (1000s TPE)	New consumption with energy efficiency (1000s TPE)	Savings due to recycling (%)	Savings due to recycling (1000s TPE p)	New consumption with energy efficiency + recycling (1000s TPE)
Natural gas	554.1	88.66	465.4	4.5	20.94	444.46
Fuel oil	138.5	22.16	116.4	4.5	5.24	111.16
Total	692.62	110.82	581.8		26.18	555.62

Note: 16% economy from conservation

f) Paper - Increased use of offcuts

The figure for recycled paper in Brazil is 45% (BRACELPA, 2008), while in various industrialized countries this exceeds 60% (Germany, Japan, United Kingdom), with Spain and Korea recycling as much as 80%. Curiously the countries with a substantial supply of cellulose (e.g. Canada and Finland) have extremely low recycling records (IEA, 2007b), possibly on account of the low raw material costs compared with the higher cost of collection and paper recycling.

The savings of thermal energy estimated for the paper and cellulose sector are linked to the amount of pulp economized or replaced by the volume of recycled paper. Since cellulose plants generally use black liquor (a renewable combustible subproduct) in their processes, the calculations for CO_2 emissions only relate to the relatively small amounts of fossil fuels employed in pulp manufacture (basically combustible oil and natural gas). The average equivalent value found for these fuels, according to the data supplied by EPE, is 7GJ/t of cellulose. Increasing the amount of recycled paper by 10%, equivalent to around 900,000 tons of cellulose, would result in a saving of 6300 TJ (150,466 TPE) using 2007 as a base year.

Abating the energy conservation previously estimated at 18.4% would result in 5.7 GJ/t of

39 Value obtained from a number of manufacturers in the Rio de Janeiro - São Paulo corridor.

cellulose originating from fossil fuels. Thus the value saved by additional recycling (10%) would be 5,141 TJ or 122,780 TPE of fossil fuels.

Table 46 –Savings from conservation and recycling –Paper Sector (adjusted calculation)

Forms of energy	Total consumption in 2007 (1000s TPE)	Savings with energy efficiency (1000s TPE)	Savings due to recycling (1000s TPE p)	New consumption with energy efficiency + recycling (1000s TPE)
Natural gas	565.00	103.96	61.39	399.65
Steam coal	85.00	15.64		69.36
Fuel wood	1,314.00	241.78		1,072.22
Sugarcane products	36.00	6.62		29.38
Other primary sources	4,513.00	830.39		3,682.61
Diesel oil	46.00	8.46		37.54
Fuel oil	453.86	83.51	61.39	308.96
GLP	24.70	4.54		20.16
Total	7,037.56	1,294.91	122.78	5,619.87

5.1.3 Inter-Energy Substitution (fossil for fossil)

Inter-energy substitution has been practised widely in Brazil over a number of decades. The cement sector for example has experimented with different fuels since the 1980s, when it began to use mineral coal to replace fuel oil. Subsequently the sector swapped these two sources for petroleum coke (EPE/MME, 2007).

Natural gas also began to be used in Brazil from the mid-1980s in the industrial sector. The use of natural gas was given a particular boost when the Bolivia-Brazil gas pipeline came on stream in 1999. Again, fuel oil was the main energy source replaced.

The inter-energy substitution considered in this study focuses on the potential for growth of the share of natural gas as a source of energy, bearing in mind the increased amount of gas to be supplied from the Santos and Espírito Santo basins, from GNL in Rio de Janeiro and Ceará and possibly from the new so-called "Pre-Sal" reserves off the Brazilian coast. In other words, emissions reduction will arise from swapping fuels with high carbon emission factors such as fuel oil, petroleum coke and mineral coal, for natural gas which has a considerably lower emission factor.

The technical modifications that need to be undertaken by industry in order to adapt to natural gas generally involve adapting or replacing items of equipment such as heaters or in other cases installing completely new systems (although this is highly uncommon). Whereas the investments normally needed for adapting to gas are not particularly burdensome the financial return on investment is uncertain given that natural gas can be more expensive than the original fuel used. In this case other prospective gains must be taken into account by industrial concerns such as eliminating stocks of oil or other energy sources, reduction of maintenance costs, reduction of preheating oil costs, improved quality of end products, cost savings arising from delayed payment for fuel consumed etc.

Additional investments to be taken into consideration by companies in the natural gas sector involving the need to upgrade the gas distribution and transport network.

In this measure the increased use of natural gas to replace fuel oil, mineral coal and petroleum coke (all sources with significant carbon emission factors) is considered.

In order to assess the size of the potential market for natural gas we proceeded to verify the number of distribution networks established in Brazil and to examine some of the expansion plans projected by the natural gas distributors (including the supply of GNL). We also made a preliminary assessment of specific industrial areas still not served by the natural gas networks as a result of investment constraints, low anticipated profitability or in some situations because of the limited amount of natural gas on offer.

At present natural gas serves the majority of Brazilian states with larger industrial sectors, involving a consumption of 7.7 million TPE (8.8 billion cubic metres/year or 24.1 million cubic metres/day) in 2007 (MME, 2008a).

In order to calculate the potential for substitution by natural gas more objectively, we proceeded to quantify the partial substitution of the energy sources (fuel oil, petroleum coke and mineral coal) still used in various sectors. The potential for substituting these energy sources is around 6.22 million TPE (base year 2007), equal to a volume of natural gas of 7,069 billion m^3 in 2007 (19.4 million m^3/day). Table 47 below gives an idea of the quantities of fossil fuels with high emission factors that could be displaced, together with the respective amounts of replacement natural gas involved.

Table 47 –Increasing the use of natural gas, energy conservation and recycling (baseline 2007) (adjusted calculation)

Industrial sectors	Quantities to be substituted (1000 TPE)					
	Fuel oil	Steam coal	Metallurgical coal	Mineral coke	Other petroleum sectors	Total
Food/beverages	348	37			67	453
Cement	51	0			0	51
Pig iron / steel	80	0			0	80
Non-ferrous metals	704	0			0	704
Paper and cellulose	278	69			0	347
Ceramics	146	28			62	236
Ferroalloys	48	0			0	48
Mining/granulation	558		510	66	134	1.269
Other sectors	148	53	68	2	368	641
Chemicals	458	47			1,790	2,296
Textiles	91					91
Total	2,914	236	578	69	2,422	6.220

Industrial sectors	Equivalent substitution in NG (1000 m3)					
	Fuel oil	Steam coal	Metallurgical coal	Mineral coke	Other petroleum sectors	Total
Food/ beverages	396,158	42,668	0	0	76,193	515,019
Cement	57,954	0	0	0	0	57,954
Pig iron / steel	91,761	0	0	0	0	91,761
Non-ferrous metals	800,988	0	0	0	0	800,988
Paper and cellulose	315,977	78,818	0	0	0,0	394,795
Ceramics	166,056	32,420	0	0	70,431	268,909
Ferroalloys	54,886	0	0,0	0	0	54,886
Mining/ granulation	634,068	0.0	579,518	76,017	152,928	1,442,531
Other sectors	168,358	60,852	77,272	2,897	419,204	728.585
Chemicals	521,170	53,931	0	0	2,034,295	2,609,397
Textiles	104.045	0	0	0	0	104.045
Total	3,311,425	268,690	656,790	78,914	2,753,053	7,068,875

5.1.4 Substitution of fossil sources by renewable energy

a) Use of renewable biomass

Biomasses consisting of fuel wood, sugarcane bagasse, charcoal and residues have been used in many years in different industrial sectors in Brazil.

Wood has been traditionally used in boilers and furnaces in a number of different sectors, particularly in the food and beverages, ceramics, paper and cellulose industries (MME, 2008a). If it originates in managed forests it does not emit CO_2 (adopted and proven by the the cellulose and paper sector).

While large quantities of sugarcane bagasse are currently consumed in the Brazilian energy matrix, amounting to 26.4 million TPE in 2007 (MME, 2008a), the sugar-alcohol sector could provide a significantly higher quantity of residues in the form of straw and sugarcane tips ('trash') left over following the sugar and alcohol production stage (Macedo, 2008; Leal, 2003).

Charcoal is another extremely important biomass, particularly in the steelmaking sector which consumed 4.8 million TPE (MME, 2008 a). At present 34.4% of pig iron production depends upon this energy source (Sindifer apud in AMS, 2008) although as already mentioned a significant part of this production still depends on burning nonrenewable charcoal.

In the paper and cellulose sector, the use of black liquor (a subproduct of the cellulose pulp manufacturing process) has increased significantly in recent years. Fuel wood and timber residues used in this sector originate from forests especially planted to provide the raw material for cellulose manufacture. Fuel wood and black liquor in the paper and cellulose sector account for 85% of the total thermal energy inputs into the sector, equivalent to 5.8 million TPE in 2007 (MME, 2008a).

Finally a number of other biomass of residues originating from agroindustry activities in Brazil can be considered. According to studies presented in the PNE 2030 (MME/EPE, 2007), in addition to sugarcane bagasse, enormous potential exists for harnessing energy sources such as the bark, leaves, straw and husks of various agricultural products[40].

We examined the prospects for the increased use of renewable charcoal and fuel wood as substitutes for fossil fuels in the steelmaking, paper and cellulose, food and beverages sectors. The proportion of nonrenewable biomass currently used [41] by these sectors will probably remain the same, but overall quantities appear likely to increase in line with sector growth up to 2030. In other words, substitution measures will not eliminate nonrenewable biomass but will involve substituting the various fossil energy sources that are still in use in these sectors. As for the use of nonrenewable charcoal in the steelmaking sector, attention needs to be drawn to the current legal restrictions which will outlaw virtually all use of this nonrenewable source in the steelmaking sector within the next few years[42]. As the legal rulings take effect on the steel sector, and in the event of possible shortages of renewable charcoal and fuel wood from plantations, mineral coke could turn out to be the most probable substitute for charcoal from native forests. Note that prohibiting the use of coke does not automatically result in increased planted forests. On the contrary, longer term substitution will largely depend on additional incentives, which are more in line with the Low Carbon Scenario.

At present 34% of Brazil's production of pig iron depends on burning charcoal (Sindifer, apud in AMS, 2008) (see Table 48). However, charcoal represents a series of technical constraints given its low mechanical resistance compared with mineral coal, which effectively rules it out from being employed in large blast furnace plants. It can however be used in middle-sized furnaces (e.g. 500,000 tons/year) and also in configurations of two or more smaller blast furnaces. In addition to being a renewable source, charcoal from planted forests possesses a series of other advantages: it dispenses for example with the need for coke ovens and sintering plants – both hitherto necessary processes in pig iron production using mineral coal. The difference in blast furnace operational costs is not particularly significant, although operations involving the use of renewable charcoal require large-scale investments and over the longer term the planting of woodland containing fast-growing species such as eucalyptus trees.

40 Some of these materials look promising for producing alcohol via enzymatic hydrolysis and could generate increased demand and competition in the energy supply industry.

41 The term "nonrenewable biomass" is used throughout this report to describe the use of wood or charcoal originating from unsustainable deforestation practices in contrast to the use of wood and charcoal originating from sustainable managed planted forests.

42 One example is the State of Minas Gerais, which represents approximately 70% charcoal-fired steel production in Brazil. A Bill of law is currently being examined by the State Legislative Assembly which will outlaw the use of nonrenewable charcoal over the next 8 to 10 years (a joint initiative taken by the government of the state, the legislative power and the manufacturing sector).

Table 48 – Production of pig iron using processes involving mineral coke and charcoal

Year	Coke generated steel manufacturing	Charcoal generated steel manufacturing	Total	Charcoal / Total (%)
1994	17,057,316	7,902,000	24,959,316	31.66
1995	17,849,340	7,115,000	24,964,340	28.50
1996	17,951,149	6,027,000	23,978,149	25.14
1997	18,832,000	6,180,820	25,012,820	24.71
1998	18,683,000	6,428,000	25,111,000	25.60
1999	17,738,793	6,809,787	24,548,580	27.74
2000	20,323,476	7,399,159	27,722,635	26.69
2001	19,577,677	7,813,278	27,390,955	28.53
2002	21,595,610	8,054,074	29,649,684	27.16
2003	22,564,026	9,450,617	32,014,643	29.52
2004	23,225,888	11,534,777	34,760,665	33.18
2005	22,460,688	11,423,114	33,883,802	33.71
2006	21,275,851	11,175,691	32,451,542	34.44

For the Low Carbon Scenario we estimated that the proportion of charcoal in the production of pig iron could reach 44% by year 2030[43]. Effective control will however need to be maintained over the origin of this energy source to ensure that all 'additional' charcoal is renewable from managed or planted forests. This assumption will obviously require integrated steelmaking plants as well as independent producers to increase the use of renewable charcoal in their production proceses. Note that the former are currently responsible for only around 10% of pig iron processing with charcoal while the independent producers dominate the sector with around 150 small blast furnaces using the remaining 90% (Sindifer, apud in AMS, 2008).

Given the steelmaking sector´s requirement for large supplies of renewable charcoal over the years and the likely growing demand for wood by the other sectors it is obvious that the acreage of planted forests needs expanding. In this respect a number of premises were adopted such as:

- All new biomass should be renewable, supplied from planted or managed forests;
- Growth cycle of trees: 7 years;
- Substitution of fossil fuels by renewables from 2017 onwards (given that new trees will have been planted from 2010 onwards);
- Forest productivity: 35 m3 of wood per hectare per year (SBS,2008; Homma et al, 2006);
- Growth of the industrial sector by 3.7% a year;
- Consumption of charcoal: 725 kg/t or 2.9 m3/t pig iron (Ferreira, 2000).

Table 49 below shows the amount of fossil fuels to be substituted by renewable charcoal or fuel wood and the acreage needed for planting energy-related forest reserves. Note that the steelmaking sector accounts for 83.3% of the fossil fuels to be substituted.

43 Estimate based on *PLANTAR*.

Table 49 – Quantities of fossil fuels to be substituted and the acreage needed for specialist renewable tree plantations

Sector	Quantities of fossil fuels to be substituted (TPE) (a)	Energy source to be substituted	Energy substitute	Total area of forests (000s hectares)	Costs of forests (000 US$) (b)
Steel industry	13,565,33	Coal and mineral coke	Charcoal	896,80*	2,262,644
Food & Beverages	998,24	Fuel oil	Wood	24,44	56,211
Paper/ Cellulose	796,35	Fuel oil	Wood	19,50	44,842
TOTAL	15,359,92			940,74	2,363,697

** As mentioned at the beginning of this section the total area of planted forests needed to substitute mineral coke could be significantly larger if the Reference Scenario were to consider implementing the recently reformulated legal instruments which will prohibit the use of nonrenewable charcoal. Once the relevant laws enter into force the tendency will be to substitute nonrenewable charcoal for mineral charcoal. However in the Low Carbon Scenario, the new areas of planted forests for producing renewable charcoal will be in a position to substitute mineral coke. Thus the area required for substituting this source of energy for steelmaking will be substantially increased with the addition of an area equivalent to item "v" below referring to the displacement of nonrenewable charcoal (2.4 million hectares).*

(a) Referring to the period 2017-2030

(b) Investment needed in 2010- 2030.

b) Use of solar energy

Changing to solar energy means installing new systems for heating water for low-temperature processes, particularly for sectors requiring firing, drying and other operations related to a wide range of products. The most promising sectors for adopting solar heating are the food sector and to a lesser extent the ceramics, textile, paper and chemicals sectors. One of the conditions required for implementing solar energy is of course the availability of appropriate areas for installing solar panels.

We have considered the employment of solar heating energy for the food sector and part of the chemical sector. Data on energy end-use were extracted from the BEU 2005 (MME, 2005) applying to processes involving low-temperature waterheating such as washing and sterilization. Table 50 below gives an idea of the composite (adjusted) potential for substituting fossil fuels with solar energy, using 2007 as the base year.

Table 50 – Reduction of fossil fuel-generated energy by adopting solar energy: Chemicals and Food & Beverages Sectors

Food and Beverages Sector			
Forms of energy	Total initial consumption (1000 TPE)	Savings due to use of alternative sources (1000 TPE)	New consumption with energy efficiency + recycling + substitution by NG + use of biomass and solar energy as alternative sources (1000 TPE)
Natural gas	553.00	49.75	897.85
Steam coal	42.00	0.00	0.00
Wood	1,904.00	0.00	1,702.18
Sugarcane products	15,925.00	0.00	14,559.96
Diesel oil	1.69	0.00	1.51
Fuel oil	433.28	0.00	0.00
GLP	30.51	0.00	27.28
Other petroleum	75.00	0.00	0.00
Total	18,964.48	49.75	16,904.50
Chemicals Sector			
Forms of energy	Total initial consumption (1000 TPE)	Savings due to use of alternative sources (1000 TPE)	New consumption with energy efficiency + recycling + substitution by NG + use of biomass and solar energy as alternative sources (1000 TPE)
Natural gas	2,196.78	300.40	3,704.96
Steam coal	61.00		0.00
Wood	51.00		39.68
Other primary sources	100.00		77.80
Fuel oil	655.00	3.82	47.14
Gasoline	0.00		0.00
GLP	58.96		45.87
Charcoal	17.00		13.23
Other petroleum	2,301.00		0.00
Total	5,440.74	304.22	3,928.68

5.1.5 Reduction or elimination of nonrenewable biomass (i.e. from deforestation)

This measure aims at substituting all nonrenewable biomasses represented by fuel wood and charcoal with biomass material originating exclusively from plantations. The initiative involves substantial investment and a medium-term timeframe in which to come into operation, given that 7 years are needed to grow new trees (generally eucalyptus) to an economically viable level. In addition to financing, a set of laws, regulations and effective command and control actions are called for in order to guarantee correct implementation of the measure[44].

The reduction or elimination of biomass addressed here considers those biomasses that cannot be renewed e.g. biomass originating from CO_2 emissions-generating deforestation and forest degradation. These omissions originate both from the burning process and from disturbing soil-based carbon reserves (these upstream emissions are not quantified in the present study).

The present measure aims to substitute nonrenewable biomasses in the form of native fuel wood and charcoal by 100% renewable (planted) biomass. The methodology used was the same as that used for the above section of biomass substitution.

In the case of nonrenewable fuel wood we prepared estimates based on data supplied by the Minas Gerais Silviculture Association (AMS, 2008) and used our own data on adoption of renewability indices. These indices attempt to elucidate how much of the biomass currently used is of renewable origin (more details in Item 3 below)

As for charcoal, basically used in steelmaking, the AMS (2008) has indicated that 50% of this comes from deforestation. Other estimates go even further: when the total production of pig iron in Brazil is taken into account, as much as 70% native charcoal is believed to originate from deforested areas[45].

As with the proposal for increasing the use of biomass, the measure for eliminating nonrenewable biomass would be implemented gradually from year 2017, in line with the 3.7% growth rate of the sector. Planting of energy-related forests would begin in 2010 with 'rapid growth' trees producing high amounts of biomass per area. The calculation is therefore based on the quantities of charcoal or wood of nonrenewable origin that could be displaced between 2017 and 2030 (in TPE or cubic metres). The areas of land needed for planting year-on-year are also obtained. Table 51 below indicates the acreage needed for such plantations.

Table 51 – Areas and investments needed for renewable sources of fuel wood and charcoal

Biomass	Area needed (000 hectares)	Percentage (%)	Investment (000 US$)
Wood	1,445	37.8	3,323,861
Charcoal	2,379 *	62.2	5,470,639
TOTAL	3,824	100.0	8,794,500

** The referenced area (2.4 million ha) could replace the use of mineral coke providing the laws currently under consideration are put into effect.*

44 The proportion of nonrenewable biomass to be substituted or not in a Low Carbon Scenario can vary significantly depending on a scenario in which the various regulations that are at present being formulated actually enter into force. In other words, in the case of nonrenewable charcoal being outlawed the source of energy to be substituted by renewable charcoal from the new plantations will be mineral coke.

45 PLANTAR and own estimates.

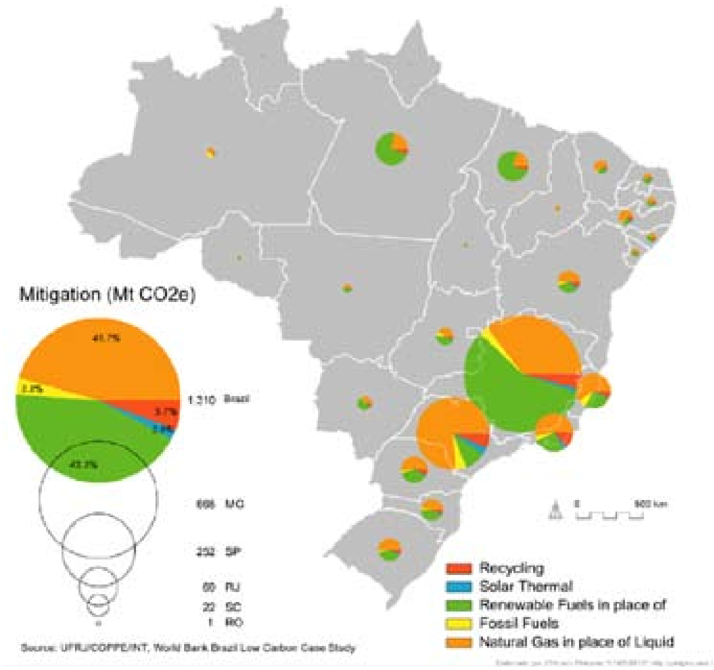
5.2 Potential for reducing emissions and Marginal Abatement Cost

Based on the assumptions presented in the above chapter it was possible to establish the year-on-year calculation of emissions for the Reference Scenario and estimate the CO_2 emissions to be abated for each type of mitigation measure within the Low Carbon Scenario. Table 52 presents the data for these scenarios and emissions at five-year intervals. In the Reference Scenario the emissions reached 291.7 million tCO_2 in 2030, almost 2.1 times higher than current emissions.

In the Low Carbon Scenario, adopting the technical options already described and calculating the adjusted potential (combining the measures in order to avoid overlapping), the emissions amount to only 176.3 million tCO_2 in 2030 or, in other words, 39.6% less than the 2030 emissions calculated for the Reference Scenario. Taking the entire period 2010-2030 (year by year) the 'avoided' emissions result in a saving of 1,379 billion tCO_2 or just over 10 times more than current emissions (for one year).

Figures 5 shows the estimate for emissions reductions for this sector after the various mitigation measures have been put in place.

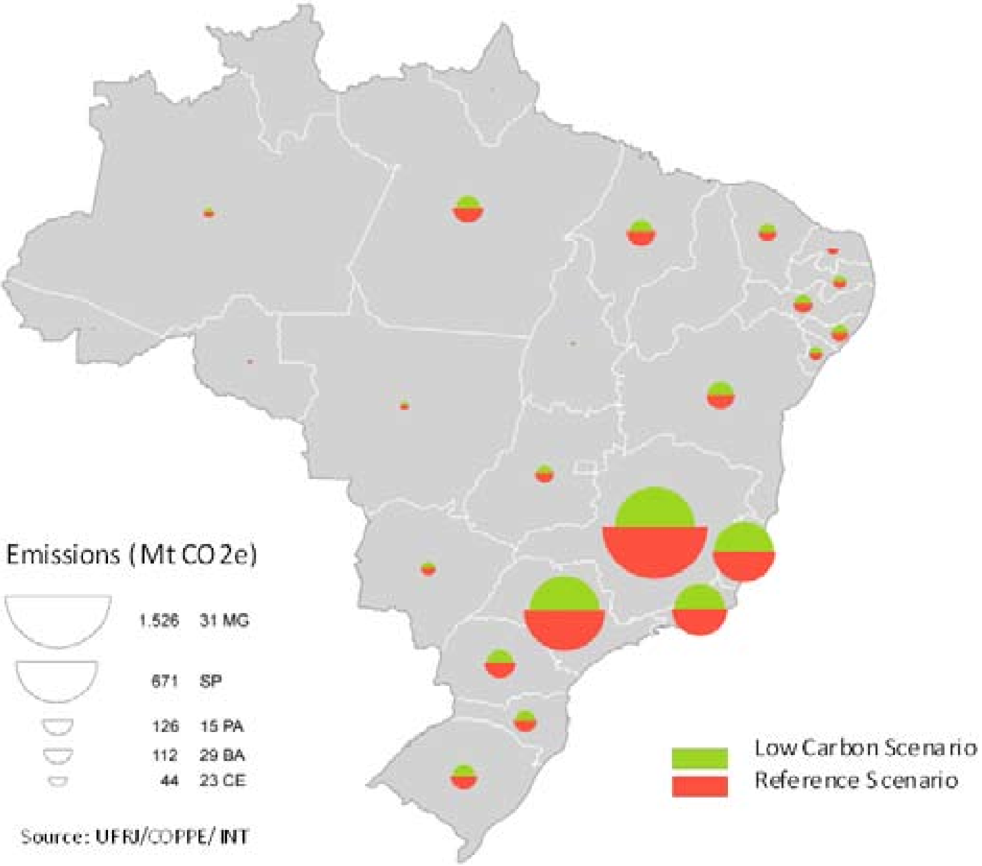
Figure 5: Mitigation by Activity, 2010-2030



The main contribution to the Low Carbon Scenario, equivalent to 567 million tons of CO_2 or 41.1% savings, will occur on account of the elimination of nonrenewable biomass (fuel wood and charcoal) in circumstances where it can be fully substituted by planted biomass. The remaining high impact contributions to emissions savings relate to heat recovery in furnaces (20.5%) and the deployment of new processes (9.8%).

However if the entire set of energy efficiency measures in the industrial sector is undertaken - the full range of heat/steam recovery operations, introduction of new processes and other procedures (e.g. improving combustion levels) etc - the amounts eligible for abatement due to these improvements will be of the order of 590 million tCO_2 resulting from the principal mitigation effort (43.4% of all emissions savings), followed by the elimination of nonrenewable biomass in industrial processes (41.1% of savings). Figure 6 compares the emissions from the industrial sector between the Reference Scenario and the Low Carbon Scenario between 2010 and 2030.

Figure 6- Comparison of CO_2 emissions of the industrial sector in 2010-2030 (Reference Scenario versus Low Carbon Scenario)



Finally, it is worth noting that in terms of specific mitigation measures the use of additional renewable charcoal in the steelmaking industry would represent 27.9% of all the emissions reductions in the industrial sector, amounting to 385 million tCO_2 (see Box 1). In addition to representing a quarter of the total emissions reductions estimated in this report, renewable charcoal also plays a key role in the second major emissions reductions segment - heat recovery - (20.6%) and the measure comes a close second to the segment of overall consolidated energy efficiency measures (Graph 4).

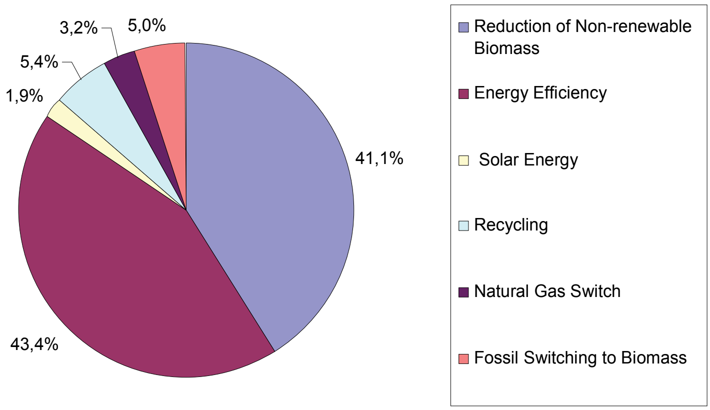
Table 52 – Emissions projected for 2030 in the Reference and Low Carbon Scenarios and emissions avoided by type of measure – adjusted potential (in 000s tCO_2)

	2010	2015	2020	2025	2030	Accumulated (2010-2030)	% share
Baseline	141,028	169,122	202,812	243,214	291,663	4,362,875	
Mitigation measures							
Combustion optimization	0	4,541	5,446	6,531	7,832	105,216	7.6
Heat recovery system	0	822	985	1,182	1,417	19,038	1.4
Steam recovery	0	1,612	1,933	2,318	2,779	37,341	2.7
Heat recovery Furnaces	0	6,849	16,427	19,699	23,624	283,035	20.5
New processes	0	5,845	7,009	8,405	10,079	135,410	9.8
Other measures (efficient use)	0	792	949	1,138	1,365	18,338	1.3
Recycling	0	3,229	3,872	4,644	5,569	74,815	5.4
Substitution by NG	0	1,888	2,264	2,715	3,256	43,745	3.2
Solar energy	0	1,112	1,333	1,598	1,917	25,752	1.9
Substitution by biomass	0	0	2,421	5,727	10,035	69,234	5.0
Reduction of nonrenewable biomass	0	0	36,678	41,787	47,476	566,993	41.1
Minimum emissions projected	141,028	142,433	123,494	147,469	176,314	2,983,959	

Note.1: The avoided quantities refer to net potential (adjusted).

Note.2: The proportion of emissions avoided due to substitution by biomass and by the elimination of nonrenewable biomass may vary, as explained under sub-item "a" in Section XXX

Graph 4 - Percentage contribution of the mitigation measures to total avoided emissions (including consolidated energy efficiency measures)



The abatement costs for the majority of mitigation measures present *negative* values, considering a discount rate of 8% a year, as can be seen in Table 53 below.

Table 53 – Overview of CO_2 emissions avoided and abatement costs by type of mitigation measure

	Total emissions avoided (million tons of CO_2)	Abatement cost ($US\$/tCO_2$) (rate at 8.0% per annum)	*Break-Even Carbon Price* ($US\$/tCO_2$) (rate at 15% per annum)
Combustion optimization	105,216	-44,1	n/a
Heat recovery systems	19,038	-91,7	n/a
Steam recovery	37,341	-97.0	n/a
Heat recovery /furnaces	283,035	-25.6	n/a
New processes	135,410	2.1	173.6
Other efficiency measures	18,338	-13.5	n/a
Recycling	74,815	-34.5	10.4
Substitution by natural gas	43,745	-20.2	68.9
Solar power	25,752	-54.7	n/a
Use of renewable biomass to replace fossil sources	69,234	2.8	41.8
Reduction / elimination of nonrenewable biomass	566,993	2.9	41.8

a) BOX 1 - The question of biomass in the steelmaking sector

The important iron and steel sector in Brazil is a major user of energy and emitter of greenhouse gases, accounting for 45% of the total CO_2 emissions in the industrial sector, equivalent to 57.2 million tons of CO_2 in 2007. If the current energy-using profile of the iron and steel sector is maintained, if no mitigation measures are pursued, if the production of pig iron increases to the projected 80 million tons a year in 2030 and if the current high levels of nonrenewable charcoal (extracted from virgin forests in an unsustainable way) continue to be employed in steelmaking processes as at present, emissions could reach 126 million tons of CO_2 per annum in 2030.

Apart from considerations of energy efficiency - normally attractive from an economic viewpoint and with a negative marginal cost of CO_2 abatement (with the exception of certain new technological processes) - employing renewable charcoal as a “solid biofuel” represents an excellent opportunity to abate carbon emissions in the steelmaking sector. This could contribute to partially substituting mineral coke and the banning of deforestation-related ‘natural’ charcoal. Hower a major problem can be foreseen in this respect: as control and enforcement and other restrictive legal instruments are applied to the use of nonrenewable charcoal, producers of pig iron could turn to using even larger quantities of mineral coal in view of the shortage of charcoal from an insufficient number of planted forests. Thus while the harmful effects of deforestation would be alleviated, the CO_2 emissions resulting from the use of fossil fuels would persist.

The two measures presented in the present study regarding the use in blast furnaces of biomass as (i) a substitute for mineral coal and (ii) to replace nonrenewable charcoal, can be considered together since the main investment decisions required needed in both cases amount to the same (e.g.more investment in ‘planted’ forests). The additional use of renewable charcoal in the steelmaking sector would result in an abatement of 385 million tons of CO_2 in the period between 2010 and 2030 (see Table 54), regardless of whether the emissions reductions were achieved by substituting mineral coal or nonrenewable charcoal.

In the steelmaking sector alone this is equal to 27.9% of the 60.5% of the total emissions to be abated in the entire industrial sector (see table 55). Note that this amount can be interpreted as a minimum or 'conservative' figure given that in our calculation the emissions avoided with energy efficiency measures and steel salvage recycling were previously abated in accordance with the methodological approach adopted here for " adjusted mitigation potential". These values do not include the stock of CO_2 in forest plantations (estimated in the LULUCF report).

On the other hand, if the two measures concerned with biomass are pursued jointly, without prior abatement of the above-mentioned measures, the so-called 'gross abatement potential' would be obtained, which is equivalent to approximately 474 million tons of CO_2 in the iron and steel sector alone over the period 2010-2030 (see Table 56). However the success of this measure depends on the implementation of a broad set of public policies targeted at increasing the planting areas for the production of renewable charcoal. This would obviously entail upscaling investment in plantations (for a fuller analysis see the *Special Report* on the use of renewable charcoal in the steelmaking sector).

Table 54 – CO_2 emissions to be abated during the period 2010-2030 employing mitigation measures based on the use of renewable biomass (adjusted potential)

Mitigation measures	Substitution of fossil sources by biomass		Elimination of nonrenewable biomass		TOTAL	
	Reduction of CO_2 emissions (000 tons)	%	Reduction of CO_2 emissions (000 tons)	%	Reduction of CO_2 emissions (000 tons)	%
Steel industry	62,457,650	90.2	322,447,875	56.9	384,905,525	60.5
Other sectors	6,776,369	9.8	244,544,861	43.1	251,321,230	39.5
TOTAL	69,234,019	100.0	566,992,736	100.0	636,226,755	100.0

Table 55 – CO_2 emissions to be abated during the period 2010-2030 by the use of renewable charcoal in the steel industry (adjusted potential)

	Reduction of CO_2 emissions (000 tons)	Reduction of CO_2 emissions (%)
Use of renewable charcoal in the steelmaking process	384,905	27.9
Other measures in all sectors (including the steel industry)	994,095	72.1
Total	1,379,000	100.0

Table 56 – CO_2 emissions to be abated during the period 2010-2030 by the use of mitigation measures based on the use of renewable biomass (gross potential)

Mitigation measure	Substitution of fossil sources by biomass		Elimination of nonrenewable biomass		TOTAL	
	Reduction of CO_2 emissions (000 tons)	%	Reduction of CO_2 emissions (000 tons)	%	Reduction of CO_2 emissions (000 tons)	%
Steel industry	99,772,604	21.0	374,252,161	78.9	474,024,765	100.0

5.3 Barriers against the implementation of Low Carbon Options

The main actions in Brazil´s industrial sector have focused on the area of energy efficiency, as well as on the use of natural gas as a replacement for more polluting energy sources. The key initiatives have been pursued under the aegis of programs run by CONPET, PROCEL and in conformity with the Energy Efficiency Law. Plans are also afoot for expanding supply of natural gas and a number of voluntary energy-saving initiatives have been taken by certain industrial sectors and individual firms. Other measures however, although apparently advantageous from an environmental standpoint, have run into economic and other problems. The above-mentioned EE programs still contain a number of gaps and deficiencies in their legal and regulatory frameworks as well as lacking financially attractive incentives.

5.3.1 Energy Efficiency

Energy *inefficiency* in the industrial sector arises from a number of different circumstances. It can originate from technically obsolete equipment or processes, incorrect or inefficient operation, inadequate maintenance of machinery etc. With appropriate information and technical assistance, it should however be possible for some industrial concerns to introduce simple, viable and low cost (or even cost free) energy efficiency measures. On the other hand a range of measures that might involve substituting complete manufacturing processes (plus 'in house' staff training or re-training) would inevitably involve high costs.

Wasted energy and low energy efficiency leads to low productivity and lack of competitivity and is frequently at the root of local atmospheric pollution and greenhouse gas emissions. The loss of competitivity has been a key factor in many cases for firms to move towards incorporating more efficient processes and equipment.

Much discussion has taken place over the last 20 years about the motives behind the non-deployment of energy efficiency measures in Brazil, including in the industrial sector (Geller et al., 2004; Jannuzzi, 2000). It is widely known that the technical upscaling measures involved can generally produce quick returns on investment and produce attractive internal rates of return for the firms involved. Such measures have however been de-prioritized by many industrial players who prefer to deploy resources in other parts of their manufacturing processes or in other developments rather than focusing investments on energy conservation.

The lack of priority given to investment in energy conservation is due mainly to the low cost of energy sources in Brazil. A further reason is that low cost energy sources constitute only a small part of overall costs for many firms, with the exception of high energy intensive firms in the steelmaking, paper, cellulose and glass sectors etc. The barriers against energy efficiency include: lack of information, paucity of attractive incentives, ineffective or non-existent liaison between agents and practitioners, low technical capacity, cultural resistance etc.

The shortage of technical information has proved to be a key bottleneck. Many firms are not familiar with the proposed energy efficiency measures and have failed to appreciate the economic and other benefits to be gained from improving productivity and/or quality in their businesses. In this respect, EE outreach and technical information programs or packages could be made available for firms on a sectoral or transversal basis - containing manuals, informative bulletins, case studies, examples of good practice, economic evaluations, guidance about expected results, etc. Energy efficiency-related technical assistance, already developed for certain sectors in Brazil on the basis of "energy audits" for participating firms is also an interesting alternative.

Real incentives for firms to practise EE upscaling would appear to be in short supply. Incentives could take the form of more flexible and attractive lines of financing[46], quicker

46 Note that when the possibility of financing exists the documentation and guarantees are just as

equipment depreciation write-offs, reduced taxes and other charges on more efficient products (e.g. on fuel-efficient vehicles), waivers and/or tax reductions to reward more energy conscious firms etc.

A preliminary critical analysis of the programs in the energy efficiency area in Brazil shows that little effort has been made to engage the industrial sector, with the exception of the activities undertaken by PROCEL in the area of electric motors and white goods. As for actions focused on better use of fuels by the industrial sector, wide-ranging initiatives (part of the CONPET program mandate) have not progressed. PETROBRAS, coordinator of this program, has been faced with a dilemma for many years. On the one hand its duty as a private company is to maximize sales and profits. On the other, the company´s high public profile should encourage it to play a more effective role in social and environmental questions, including energy saving. The same has occurred since 1999 with the natural gas being piped into Brazil from Bolivia. The core aim of PETROBRAS and the distribution companies has been to increase market share rather than to reduce demand or consumption. It follows that many conversions to natural gas have been concerned mainly with keeping investment costs low in order to increase the economic appeal of the schemes while paying scant regard to more modern and efficient technologies.

5.3.2 Recycling and economizing materials

Recycling in Brazil has developed in a realtively informal way although major firms in some sectors have discovered that manufacturing products from recyclable rather than virgin raw materials can save energy and therefore enhance profits. This is, for example, the case of the aluminum, glass, steelmaking, paper, cellulose and cement sectors.

The main barriers to across-the-board recycling by industry are (i) the difficulty of securing appropriate financing; (ii) the high cost of selective collection; (iii) the low level of interest shown by municipal authorities; and (iv) price fluctuations of many commodities and raw materials. For example, while the prices of bauxite and alumina remain low, the price paid for scrap aluminum is reduced, resulting in a shortage of scrap for recycling.

5.3.3 Inter-fuels substitution (fossil fuel for fossil fuel)

The substitution of fossil sources such as mineral coal, fuel oil and petroleum coke by natural gas involves three main barriers: the volume of gas currently available, the limited natural gas distribution network and the price of the gas (frequently not competitive with other energy sources).

The supply of natural gas is restricted by limited production and transport problems. In 2008, with the industry sector growing strongly, natural gas supply bottlenecks were common, but the situation has improved with the introduction of NGL units and increases in domestic production in the South East.

The natural gas distribution network requires major investment. The policy of expanding new market opportunities in anticipation of growing demand has been practised by various companies as well as building models where the so-called large "anchor" companies present opportunities for higher returns on capital invested.

The price issue is complex. Natural gas is a clean energy source which naturally tends to be more expensive than other more polluting residual fuels.

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complex for small firms as for large corporations.

5.3.4 Use of alternative energy sources and reduction of biomasses resulting from deforestation

Renewable sources of energy face several barriers. In the case of biomass (wood and charcoal) supply-side difficulties are caused by credit restrictions and low prices, especially for biomass originating in deforested areas. Other problems arise from the high cost of land, competition with other uses and the huge distances between industrial centres and plantations, making transport extremely expensive. A combination of all three usually means that the major industrial sectors remain unenthusiastic about using biomasses as a heat source.

Difficulties also exist from the social angle, given that many "informal" workers rely for their livelihoods on cutting trees and producing charcoal illegally. Legalization of charcoal burning activities in or near to the "planted forests" has to take into account the need to provide fit these people into the new jobs or compensate them in other ways.

In the case of solar energy barriers include the lack of technological expertise, the absence of credit for installing and maintaining new equipment and units as well as number of cultural impediments. Many firms are wedded to their traditional processes nd have great difficulty in adapting to change and innovation.

5.4 Existing measures and proposals

The Brazilian industrial sector has benefited for a number of decades from various financing mechanisms and incentives, generally targeted at increasing production capacity, enhancing modernization and import substitution, high-tech processes, strategic sectors etc. Since the 1970s industry has also enjoyed special support in the energy technology area.

These incentives and financing arrangements were established by BNDES, particularly through its FINAME program (BNDES, 2009b), [47]set up to assist industry to acquire capital goods. As part of its mandate to help modernize industry FINAME channeled funds to firms to enable them to purchase energy efficient equipment in an effort to encourage more use of natural gas, cogeneration and other alternative energy technologies. The PROESCO program, also under the aegis of BNDES, is still operational. The main aim of this is to provide financial support to the consultancy services run by the Energy Saving Companies (ESCOS).

In addition to the BNDES funds, industry also has access to specific funding lines (repayable or not) through FINEP (*Projects and Studies Financing Agency*) which supports projects involving technological development and innovation applicable to products, processes and equipment in general. FINEP funds, which are considerably less than those obtainable from BNDES, are provided under the *Science and Technology Sectoral Funds Program* managed by the Ministry of Science and Technology. The CTPETRO [48] possesses the largest volume of resources intended to benefit the petroleum and natural gas areas,

47 BNDES/FINAME provides credit for the purchase of new machines and equipment, manufactured in Brazil. The idea is to provide a boost to the capital goods sector and to generally modernize industry as a whole throughout the country. The various financial operations involve fixed interest rates of up to 12% per annum and include the financial institution' s return of up to 3.5%. Financing is also arranged at variable rates of interest, TJLP plus the BNDES return (0.5% per annum.) plus the financial institution' s return (up to 3.5% per annum.).

48 CTPETRO -funds from 25% of the segments of the value of the royalties exceeding 5% of oil and natural gas production.

while CTENERG [49] targets the energy sector as a whole. The various programs are funded from levies on companies exploiting state-owned natural resources and from fractions embedded in other taxes (FINEP, 2008). Industry has access to all these funds indirectly, through projects undertaken in partnership with universities and/or research centres, or directly via "subvention" programs.

Table 57 below presents a summary picture of the resources needed to implement the entire set of mitigation options evaluated. The investment estimates cover large industrial segments: machinery and equipment, selective waste collection, services, education, training and other activities.

Table 57 – Estimate of resources required

Mitigation option	Estimate of total resources/financing (distribution) (%)	Funding sources	Net investments (million US$)
Energy efficiency	- Equipment and machinery (9.0%) - Human resources training (1.0%) - R&D (2.0%)	Federal / BNDES SENAI, Universities FINEP / MCT	23,946,289
Recycling	- Equipment for collection and processing companies (25%) - Selective collection program (60%) - Education and public information program (15%)	Federal / BNDES	156,776
Inter-fuel exchanges	- NG distribution networks and gas pipelines (93%) - Financing for conversions in firms (5%) - R & D (2%)	PETROBRAS / BNDES / distributors BNDES / distributors / own resources FINEP / MCT	1,831,869
Use of biomass	- Equipment and machinery (19%) - Planting woodland for energy producing purposes (79%) - R&D (2%)	Federal / BNDES FINEP / MCT	1,366,977
Solar energy	- Equipment (98%) - R&D (2%)	Federal / BNDES FINEP / MCT	734,671
Reduction / Elimination of nonrenewable biomass	- Extending plantations (97%) - Increasing capacity for producing legally regulated charcoal (2%) - R&D (1%)	Federal / BNDES FINEP / MCT	5,294,247
SUMMARY			
Total equipment	US$ 26,147,91 x 10^6		78.4%
Total services / training	US$ 6,572,38 x 10^6		19.7%
Total R&D	US$ 610,54 x 10^6		1.8%
Total			33,330,829

49 CTENERG -funds arising from 0.75% to 1% collected on the net turnover of generation, transmission and electricity distribution concessionaire firms

In view of the amounts indicated in the present study that need to be invested in order to mitigate CO_2 emissions it is obvious that substantial effort will be needed in financial terms.

5.4.1 Energy Efficiency

In view of the barriers identified to implementing energy efficiency measures we suggest the following:

i) to increase the amount of information available regarding the use of energy in industry and the potential savings that could be made by introducing EE. This could be done through the 'energy audit' program which could result in the elaboration of a relevant database and the provision of an 'EE consultancy' for the firms involved.

ii) to create a information system or program for firms (e.g. to prepare bulletins with case studies, information about technologies, good practices etc). Programs of this type containing technical information have been running for some years in the United States and a number of European countries.

iii) to ensure effective liaison between the stakeholders involved (firms, banks, consultancy firms and others)

iv) to provide incentives in the form of IPI reductions on more energy efficient equipment (burners, boilers, furnaces, heat exchangers, steam traps etc)

v) to open financing lines through the BNDES and other registered banks with special interest rates and to set up other financial arrangements for firms interested in implementing energy efficient projects

vi) to develop training programs for potential consultants and employees

ivii) to develop a new cycle of technical assistance and outreach programs for firms

viii) to establish specific consumption targets for sectors or groups of similar firms, awarding prizes or bonuses to the best

ix) to foster the ESCO market (financial support already exists through BNDES PROESCO)

x) to develop 'demo' projects

xi) to increase the resources available for R&D for energy efficiency projects in industry by using CTPETRO and CTENERG (Ministry of Science & Technology) funds

xii) to enhance technology transfer through appropriately qualified partners

xiii) to reduce taxes on imported items that could result in energy efficiency

xiv) to review the Government´s energy efficiency programs, in particular CONPET with a view to it taking more effective and specific action to improve energy efficiency in industry.

xv) to create certification programs for energy efficient firms, possibly derived from ISO 14.000, on the basis of the 'seal of approval' programs run by PROCEL, CONPET, EnergyStar (USA) and others.

While all the points above focus on energy efficiency the ultimate objective is to reduce greenhouse gas emissions, especially CO_2. Other more specific steps designed to overcome the many barriers to mitigation proposals could be taken. A direct initiative might be for example to create a small tax aliquot on firms employing inefficient processes and fuels with high emission factors. The proceeds of this levy could be used for creating a fund for mitigation, research and innovation to minimize emissions.

The focal point for all the above would be the MME (Ministry of Mines and Energy), but the MDIC, the MCT and MMA would need to be engaged in addition to federal economic and development agencies such as BNDES and FINEP.

Table 58 – Summary of policies proposed for energy efficiency

Proposed policy	Category	Type of instrument	Funding sources	Source of financing
Information and dissemination system	Incremental	Programs	Federal	Federal
Liaison between stakeholders	Incremental	Regulations	Federal	Federal
Financing	Rectification/ Incremental	Regulations	Federal	Federal
Fiscal incentives (reduction of IPI, accelerated depreciation and write-offs, import tax reductions	Rectification/ Incremental	Law/regulations	Federal	Federal
Human resource training	Incremental	Programs	Federal	Federal
R&D resources	Rectification	Law	Federal	Federal /market
Technical extension projects	Rectification	Programs	Federal	Federal /market
Establishing minimum indices	Rectification	Law/regulations	Federal	Federal /market
Labeling program	Rectification	Law/regulations	Federal	Federal /market
Review/upscaling CONPET	Rectification	Law	Federal	Federal

5.4.2 Recycling and economizing materials

i) to support/finance "recycling" associations, cooperatives etc

ii) to establish/provide incentives for selective garbage collection programs in mid- and and large-sized cities (paper, glass, metals and plastics)

iii) to encourage the establishment of firms to act as a link between scrap collection and firms deliverying sorted waste by undertaking screening, sorting, cleansing, classification etc

iv) to ensure that successful recycling programs and projects are aired in the media and to draw attention to the 'green' certificates and seals of approval affixed to domestic and other appliances etc.

v) in the case of the ceramics industry to train staff in wastage reduction and quality improvement.

Table 59 – Summary of policies proposed for recycling

Proposed policy	Category	Type of instrument	Funding sources	Source of financing
Financing of cooperatives and 'screening' firms	Incremental	Programs	Federal	Federal
Increasing selective collection	Rectification	Law/regulations	Federal, states and municipalities	Federal
'Green' seal of approval for recycled items	Rectification/ Incremental	Regulations	Federal	Federal
Fiscal incentives (e.g.reduction of IPI)	Incremental	Law/regulations	Federal	Federal
Information campaigns	Incremental	Programs	Federal, states and municipalities	Federal

5.4.3 Substitution of fossil sources by natural gas

The proposed policies can be resumed as follows:

i) to accelerate the construction of gas pipelines and construct/upscale the distribution network in states with the largest industrial hubs

ii) to increase lines of financing for industry in order to assist firms to convert to natural gas

iii) to continue to invest in R&D with a view to developing markets for natural gas by developing new energy-saving products and equipment

iv) to support/finance NGC and NGL developments.

5.4.4 Increasing the use of renewable sources and reducing the use of nonrenewable biomasses

It is clear that although using biomass as an energy source is advantageous from an environmental point of view serious problems arise when the biomass is the product of deforestation. The measures considered for increasing the share of renewable biomass in the energy area are complex, calling for a series of multidisciplinary actions involving command and control measures (inspection/enforcement), a redefinition of the pertinent laws, rules and regulations, prospects for financial compensation and, most importantly, long-term funding for the planting and maintenance of energy-related renewable forests (with seven-year rotations and cycles of up to 21 years). The main difficulty concerns the latter, i.e. increasing the supply of planted biomass and encouraging the use of renewable fuel wood and charcoal as biofuels. Although the main present constraint is the shortage of plantations it is equally important to restrain the production and consumption of nonrenewable charcoal which causes environmental degradation and predatory competition. In addition to enforcement actions related to the illegal use of nonrenewable charcoal we suggest substituting all the Basic Oxygen Furnaces ("rabo quente" kilns) common in rural areas for more modern and efficient methods. Although the question of deforestation is closely related to the lack of planted forests, the use of such outdated methods also facilitates access to unsustainable production by people directly or indirectly responsible for deforestation. Moreover, old-fashioned carbonization processes emit large quantities of toxic gases which, apart from pollution, cause serious health problems for operatives. Hence the proposal is to provide incentives and finance for more modern carbonization technologies which can also be applied to large firms legally authorized to produce renewable charcoal in Brazil. This would in due course lead to the above-mentioned rudimentary charcoal kilns being taken out of service. The interests of small rural producers who perhaps have no other source of income need also to be taken into consideration in the new model. For example, compensatory mechanisms could be established or small producers could be invited to participate in the new energy-saving activities as e.g. direct suppliers to legally authorized industries in the charcoal sector or even as forestry inspectors (looking after virgin forest and forest reserves).

Many of the proposals presented here, together with the estimates of the financial resources needed to implement them, could be undertaken through Public Private Partnerships (PPPs) where the costs and liabilities could be shared.

The policy measures that need to be implemented are summarized as follows:

i) to provide financing for planted forests for producing wood for industrial heating purposes and the manufacture of renewable charcoal

ii) to ensure that the Clean Development Mechanism of the Kyoto Protocol is incorporated in public financing policies as an additional instrument for enhancing the attractions to firms of using renewable charcoal (making best use of the three methodologies employed in the steelmaking productive chain)

iii) to provide special financing conditions for firms to acquire industrial equipment to use these energy sources (pickers, ovens, boilers etc)

iv) to drastically reduce the IPI (tax) on solar energy products (water heating equipment and photovoltaic (PV) energy panels)

v) to earmark R&D resources to developing industrial equipment driven by solar energy (e.g. solar heat dryers).

Table 60 – Summary of the proposed policies for inter-fuel substitution and encouraging the use of renewable sources

Proposed policy	Category	Type of instrument	Funding sources	Source of financing
Financing of equipment /forests	Rectification	Programs	Federal	Federal
Boosting CDM as a mechanism to encourage action	Incremental	Programs	Federal and states	Federal and states
Resources for R&D	Rectification	Law/regulations	Federal	Federal
Fiscal incentives (reduction of IPI)	Rectification	Law/regulations	Federal	Federal
Combating biomass originating with deforestation	Rectification/ Incremental	Law/ regulations/ programs	Federal, states and municipalities	Federal, state, municipal and private sector

6. Energy Supply-Petroleum, Gas and Refined Products Sector: Refining and GTL

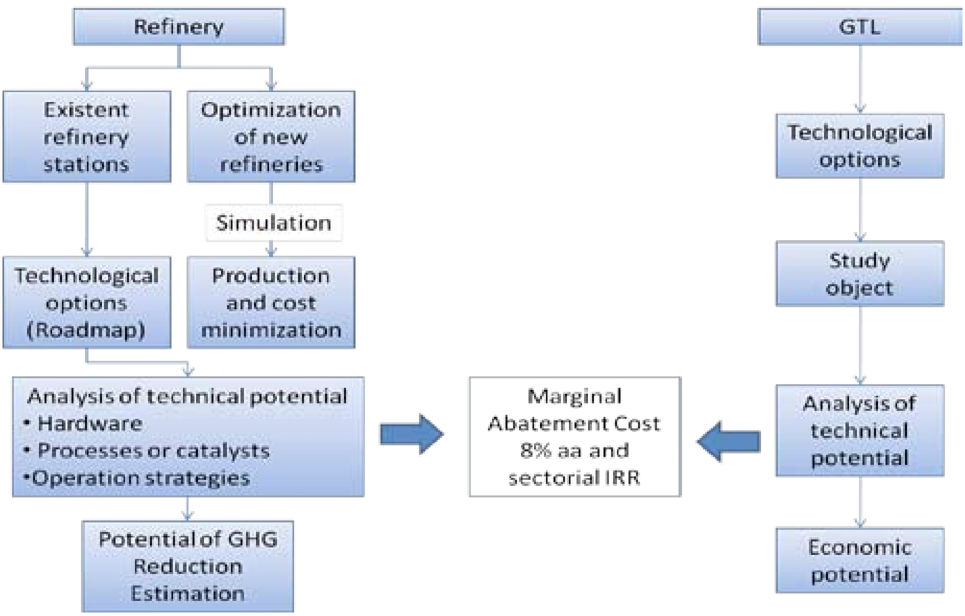
6.1 Mitigation Options

The aim of this item was to develop studies in preparation for a national reference scenario up to 2030 which would incorporate measures for reducing greenhouse gas emissions caused by (i) petroleum refining and (ii) natural gas production activities. Alternatives were studied for the petroleum refining area both for refineries existing at present and for the foreshadowed expansion of the refinery sector. In the case of natural gas, alternatives for the monetization of gas being flared or vented during petroleum production were considered and it was decided to give emphasis to the *gas-to-liquid* (GTL) solution.

Although addressed separately, the two subjects are closely linked insofar as the products of the *gas-to-liquid* (GTL) route forms part of the chain of petroleum derivatives and could have a major impact on optimal petroleum refining strategies. In the interests of clarity and objectivity this report addresses the Petroleum Refining Sector and the Natural Gas Sector as completely separate issues, focusing on the use of the GTL process for reducing offshore production platform gas flaring and venting.

The studies on petroleum refining and GTL will form part of the analysis of the long-term Brazilian energy scenarios with a view to contributing to a systematic evaluation of the carbon emissions mitigation options in Brazil. Figure 7 outlines the various stages of the methodology utilized in our studyl.

Figure 7 – Methodology Scheme



6.1.1 Existing refineries

According to Petrick and Pellegrino (1999) it will be possible over the medium to long term to establish a target for reducing energy use in refineries by between 15% and 20% (and consequently CO_2 emissions). The recovery and reuse of thermal residues is the main option in the short run, while mitigating incrustation and fouling and introducing new refining technologies are of crucial importance over the medium to long-term.

a) Energy integration and heat recovery

Energy integration and heat recovery in refineries is the main option for reducing their fuel "self consumption" in the short run. Little research and development has been done on these options to date, although chemical plants in Brazil and other parts of the world have already successfully adopted energy integration techniques (Szklo, Soares and Tolmasquim, 2004). In the refinery area the crucial differences of temperature between the cold and hot waste currents (the latter used to preheat the incoming feedstocks) indicate the possibility of energy integration, reducing the need for external heat or cold inputs. Furthermore a positive secondary effect of this integration is the simultaneous reduction of liquid effluents due mainly to the reduced use of direct contact with the cooling medium ('quenching') and the reduced need for boiler makeup water. Among the measures associated with thermal energy management of a refinery the following are particularly important:

- Use of low quality exhaust heat in refrigeration cycles by absorption (Olim et al, 2002);
- Use of thermal residues for preheating loads; [50]
- Energy and/or mass (water and hydrogen) integration basically employing the *Pinch Techniques* (Hallale, 2001;CEC, 2003);
- Improving burners through better burning control (API, 2000);
- Direct feeding of "intermediate products" to the processes, without cooling and storage, with a view to recovering part of the residual heat in these products. For example, the thermal energy of the products of the distillation column could be directly recovered in the *downstream* units when the sequence of processes is more continuous, thereby avoiding storage and cooling (EIPPCB, 2001);
- Using heat pumps (Worrell & Galitsky, 2005)
- Increasing turbulence in the heat exchange surfaces;
- Adoption of a steam management system (Worrell & Galitsky, 2005) [51]

The use of *Pinch Techniques*[52] generally provide energy savings in refineries of the order of 20% (Petrick and Pellegrino 1999); (EIPPCB 2001. According to Hallale (2001) and CTEC (2003), typical values would be between 10% and 25% (as a percentage of total fuel consumption only). Finally, Alsema (2001) estimated 2% of the reduction of fuel consumption in a refinery could arise from better heat recovery and that by introducing *Pinch Techniques* for energy integration this figure could be as much as 6%. Beer (1998) agrees with these figures, estimating a potential reduction with the *Pinch Techniques* of 5% in Dutch refineries at low-cost (under 10US$/GJ).

50 For example recovery systems can recover the heat produced in coking processes.

51 For example the quality of steam used in stripping, vacuum generation, atomization, etc, is normally lost in the cooling water or expelled into the atmosphere. Normally steam used for stripping ensures the flashpoint temperature and improves the fractioning of products, increasing the yield of the refining units.

52 For more details see Hallale (2001), Linnhoff et al. (1992) and Linnhoff (1994)

Two studies developed in the REPLAN refinery (Amorim,2005; Olim et al, 2002) and a study undertaken in the REDUC refinery (Schor, 2006) analyze the technical potential for using *Pinch Techniques* in Brazil in refineries for energy (energy integration) and water (mass integration).

These studies confirm that energy and mass integration networks are viable options over the short term for the two Brazilian refineries. The studies also show that not all the hot waste currents are available for heat exchange. Volatile products that need to be rapidly cooled with water contact ('quenched'), intermittent currents (Olim et al, 2002), currents containing suspended solids (as catalysers) can be cited as examples. Finally, some currents with very high thermal exergy (such as the FCC exhaust gases) are difficult to recover since they are generally present in inaccessible parts of the refinery (Olim et al, 2002).

According to the simulation by Moreira et al (2008) of the application of the *Pinch Technique* to a Brazilian refinery, a reduction of around 60% of consumption in the distillation tower should be possible. Considering the estimated share of atmospheric distillation in the final energy consumption of Brazilian refineries (an average of 20% in Brazilian refineries in 2015) this reduction of consumption in the unit would correspond to a final reduction of approximately 17%.

In some refineries (Amoco, Agip (Italy), BP, Chevron, Exxon (in the UK and the Netherlands) and Shell (in various European plants) where the *Pinch Technique* was applied, savings of between 20% and 30% were identified while the economically compensatory range was between 10% and 15% (Worrell & Galitsky, 2005).[53]

The first option for applying energy integration networks in refineries is the refinery atmospheric distillation column which possesses large load volumes requiring substantial quantities of energy. In the REPLAN column for example the temperature variation is between 124°C and 350°C for diesel (flow of 80.5kg/s), of 165°C and 350°C for QAV (flow of 16.6kg/s), 304°C to 350°C for light diesel (flow of 8.3kg/s) The first two of these products are hydrotreated after leaving the distillation column, while the last proceeds to the fluid catalytic cracking unit.

In addition, apart from introducing optimized heat exchange networks in Brazilian refineries, the use of waste heat of medium to low quality for generating cold in the absorption cycles can also be an interesting alternative. In this case the cold current generated could be used in the vacuum production system of the vacuum distillation column, thereby increasing the efficiency of the column.[54]

In summary, considering only energy integration and heat recovery in Brazilian refineries and using the data on two of our large refineries, a potential reduction of fuel consumption can estimated at 10% (on the total of fuel consumed) at an implementation cost based on Alsema (2001) of approximately 9 Euro/GJ per year for a project of 15 years useful life with a rate of 15% per annum. It is interesting to note that around 90% of these costs are concentrated at the beginning of the project. This value could be considered slightly conservative when compared with the values produced by the simulation done by Moreira et al (2008) i.e. between 15% and 21%.[55]

53 Rate of return of around 15% per annum for a useful life of around 15 years.

54 Petrick and Pellegrino (1999) describe the application of refrigeration units by absorption with the use of residual heat to recover additional GLP from catalytic reformers. This occurs for example in a refinery in Denver, Colorado with a payback of 1.5 years. The same authors have also reported the use of this type of refrigeration system associated with atmospheric distillation columns.

55 The results obtained in Energy Manager Training (2004) referring to a refinery with a processing capacity of 1 MMT of crude, show a saving of 10% of the fuel used. This amount was obtained by considering a self consumption rate of 6.5% (based on the similarity with the REGAP refinery). Given that this set of measures associated to energy optimization economizes 6.450 SRFT (Standard Refinery Fuel Ton), we calculate that energy optimization saved precisely 10% of the fuel used in the refinery (6.450/(1 x 1.000.000 x 6.5%)), thereby confirming the value employed in the

b) Incrustation control

The definition of approach and pinch point temperature in the designs of heat exchange networks is affected to a great extent by the control of incrustations. In heat exchange networks with incrustations the approach temperature can rise to 40°C (CTEC, 2003) when typical values in refineries are between 10°C and 20°C. Incrustations which reduce thermal efficiency and heat transference capacity are difficult to prevent since the composition of their formation is not entirely understood (API, 2000). Therefore it is important to control the incrustations in heat exchangers in refineries which, apart from reducing the thermal exchange area, also cause maintenance problems and the risk of accidents. [56]

The process of desalinization also assumes an important role in the reduction of energy consumption of a refinery by removing salts and contaminants from the load. Interestingly, it is an ambivalent situation because the improvements in heat transfer also have a positive effect on desalinization given that the efficiency of this process is linked to operations within an optimum temperature range. Heat exchangers with loss of thermal exchange area due to incrustations have no way of ensuring that this optimum band is reached, limiting the capacity for removing salts and metals from the desalinization unit (Jacobs, 2002). This leads to losses of oil which in turn contaminate the liquid effluent of the unit and produce high levels of contaminants in the load.

Estimates done in the early 1980s for a typical refinery of its period with a primary processing capacity of 100Mbpd suggested that the self-consumption of energy could be 30% less in the atmospheric distillation column if the problem of incrustations/fouling in the heat exchangers could be brought under control (Exxon, 1981). A more recent study however pointed to a lower potential reduction of energy self-consumption by controlling incrustations. Although still significant, the reduction was only 10% (ANL, 1998). According to Bailey (1999), the petroleum refining industry in the United States spends $US2 billion per year on fouling problems.

Increasing diversity of the load process, with frequent use of non-conventional oils, makes the process of developing anti-incrustation methods difficult. Studies on the thermal stability and solubility of asphaltenes and naphtenic acids play an important role in these circumstances. The same applies to the development of anti-incrustation chemical compounds and efforts to improve methods for removing scales, neither of which affects the quality of the refinery products. These challenges are explained by the fact that the incrustation phenomenon arises from different processes and mechanisms (Bott, 2001). It also it depends to an extent on the design of the heat exchange network.

In summary, incrustation in heat exchange networks is a bottleneck impeding the application of heat recovery systems.The gains achieved from reducing fuel consumption by controlling incrustation were estimated at 2% for refineries in the United States (Perick & Pellegrino, 1999). This percentage was similar to that obtained by Negrao, Madi and Massoqueti (2004) for Brazil. Meanwhile, Panchal and Huangfu (2000) claimed a higher percentage (indicating a need for new studies). These authors analyzed the effects of incrustation in a 100kbpd atmospheric distillation column and found an additional energy consumption of 13.0 MJ per barrel processed (or around 3.4% of specific energy consumption in Brazilian refineries).

Alsema (2001) estimates operating and maintenance costs of approximately 15 EUR/GJ and a useful life of the technology of 15 years, while the investment cost could be considered as zero.

At the same time Warrell and Galitsky (2005) identified a saving of 0.7% by undertaking duct

study. Data from Energy Manager Training (2004) also corroborate the economic estimate done by Alsema (2001).

56 For an analysis of the effects of incrustation in pipelines belonging to Brazilian refiners see Negrao, Madi and Massoqueti (2004).

cleaning, with a payback of 0.7 years. In other words, in order to achieve small reductions, the payback is low (uncertainty exists as to how low).

c) Advanced Process Control Systems (APC)

Advanced process control systems are based on computer models and the extensive use of sensors to increase production reliability. These systems also enable production quality to be controlled, reducing stoppages for maintenance (as well as costs). The potential savings from using APC are substantial (Hydrocarbon Processing, 2001). For example Timmons, Jackson and White (2000) combined on-line optimizers with existing control systems in order to improve the operation of an FCC in the CITGO refinery in Corpus Christi, Texas, producing savings of US $0.05/barrel.

According to Alsema (2001) fuel savings of between 2% and 4% can be obtained. For Warrell and Galitsky (2005) however these savings were anything between 2% and 18% with respect to US refineries based on controlling temperature, humidity, oxygen air and steam flow by using fuzzy logic. [57]

Studies of this type referring to Brazilian refineries do not exist. We suggest however the conservative value put forward by Alsema (2001) for Dutch refineries (2% reduction in fuel consumption). Cost estimates do not exist either. However, fixed costs are probably relatively high owing to the need to install a large number of sensors (resistant to aggressive environments) and to introduce intelligent control systems specific to each unit or plant. According to Katzer, Ramage and Sapre (2000) "the refinery of the future will look more like an automated chemical plant". This being the case, Alsema (2001) forecasts 25EUR/GJ per annum of levelled investment costs.

6.1.2 Optimization of new refineries

The second set of mitigation measures for refining petroleum involves the optimization of a possible new refinery in Brazil with the aim of minimizing its production costs (including an additional cost for carbon emissions) to satisfy a specific demand in the Brazilian market. Our model considered monetary values for the cost of CO_2 emissions in order to seek viable solutions for avoiding such emissions. The simulation was done with a Linear Programing model representating two types of new refinery in Brazil: one focused on producing diesel and the other on petrochemicals. These are precisely the two types refinery that are listed in the PNE 2030 scenario which describes the expansion of the Brazilian refining capacity with the building of 7 new refineries by 2030 (two of which are already under construction). 5 of these new refineries would focus on fuel products (especially diesel) and 2 on basic petrochemicals. Modifying the scheme with a view to reducing carbon emissions of the new refineries was exactly in line with PNE 2030 investment projections, which considered only the additional investments due to alterations in the new refineries scheme. [58]

The following procedure was adopted:

1) adjustment of the linear programing model for two basic refining configurations;

2) simulation of this model for these two configurations without using the financial incentives associated with the price of carbon emitted;

57 See also Aprea, Mastrullo and Renno (2004)
58 In the optimization modeling the insertion of financial incentives associated to a carbon price did not alter the output of the refinery regarding the quantity or quality of products, nor modify the basic operational costs. The operative margin of the refinery remained unchanged. The model emphasized the additional investments needed for modifying the refining scheme to assist reductions in carbon emissions.

3) simulation of this model for the two configurations with the insertion of financial incentives associated with the price of the carbon emitted. In this case the outputs of the refineries were kept unaltered in terms of products (quantity and quality) as well as of their operating costs. Control of carbon emissions by modifying the scheme for the new refineries was based on additional investments;

4) identification of the value of the financial incentives associated with the carbon price which alters the scheme of the new refineries in the optimized model to15% per annum and a useful operating life of 30 years.

5) obtaining the marginal cost at 8% per annum and 30 years for the refining

schemes.

The linear programing modeling considers an objective function subject to technical and economic constraints according to the equations and inequations seen in Figure 8 below:

Figure 8 -Equations of the Linear Programing Model

$$\left.\begin{array}{l} \text{Max } Z = \sum_{j=1}^{n} cj\,xj \text{ , ou Min } Z = \sum_{j=1}^{n} \\ \text{s.a.} \end{array}\right\} \text{Function objective}$$

$$\sum_{j=1}^{n} aij\,xj \leq bi \qquad (i = 1, 2, ..., m)$$

$$xj \geq 0 \qquad (j = 1, 2, ..., n)$$

In the case of a petroleum refinery, the model utilized can be of the *Profits Maximization* or *Cost Minimization* type in order to satisfy specific market demand. The two possibilities are equivalent if in the second case the possibility exists of exporting and importing products.

The principal variables are the flows of petroleum and intermediate/end products which circulate among the process units. The main equations of the model are:

- Mass balance equation of materials established in accordance with the outputs of the processing unit;
- Equations of qualities of intermediate and end products;
- Equations of demand for end products;
- Equations of unit capacity ;
- Equations of petroleum availability

The duality property is also an important feature of the linear programing models. In essence this establishes a relationship between the optimal results of the models of maximization of profits and minimization of cost, as can be seen in Figure 9:

Figure 9 –Relationship between the equations of the Primal and Dual models

PRIMAL	DUAL
Max Z = c.x	Min D = $b^T . \pi$
s.a.	s.a.
A.x ≤ b	$A^T . \pi \geq c^T$
x ≥ 0	$\pi \geq 0$

x = vector quantity of products sold

c = profit based unit vector obtained from sale of products

b = vector quantity of resources available for producing goods

A = matrix of resource quantities consumed in the production of each good

π = unit value vector of the resources (shadow price)

The objective of the model is to represent two possible configurations for establishing a new refinery to be constructed in Brazil with:

1) Focus on production of diesel

2) Integration with petrochemicals

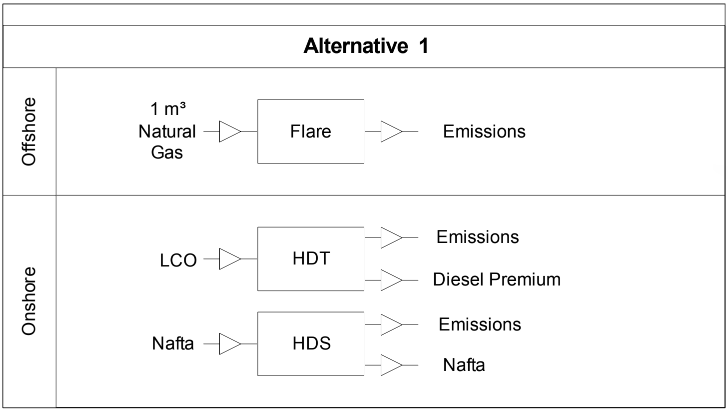
With the aim of testing the influence of financial incentives associated with a price for CO_2, the two refining configurations proposed were again optimized following the inclusion in the model of different values for the financial incentives. We also sought to determine the value of these incentives in order significantly to alter the emissions from the proposed configurations. The configurations proposed were optimized taking into account incentives with values of US$25/t CO_2, US$50/t CO_2, US$100/t CO_2 and US $150/ CO_2. The model employed a discount rate of 15% per annum and a useful life of 30 years, both values regarded as typical for investment in a petroleum refinery in Brazil.

6.1.3 GTL

The study sought to establish an energy and total CO_2e emissions balance between two alternatives with a view to comparing the two methods of obtaining diesel (specifically diesel S50). The production of diesel in Brazil is not sufficient to meet current demand. The study employed a simplified energy balance.

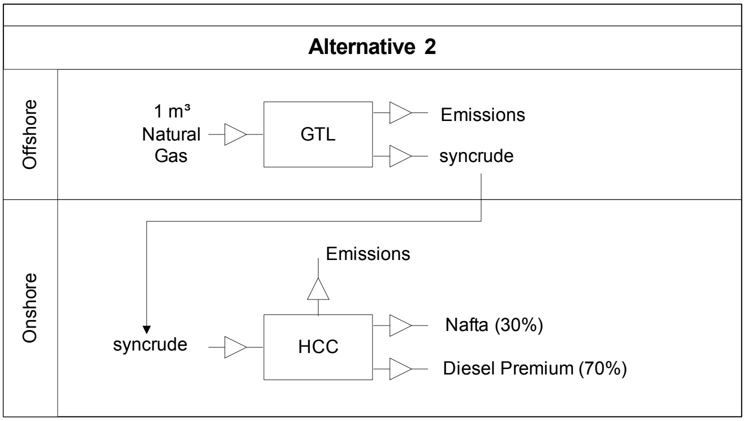
The first alternative, known as Alternative 1 (see Figure 10) throughout the study, represents the baseline and considers that the volume of gas flared at present will not be reduced. In this case diesel S50 will be obtained by investing in conventional hydrotreatment units in the refineries.

Figure 10 - Alternative 1 Scheme



The second alternative, Alternative 2 (Figure 11), considers the employment of a platformed offshore GTL plant for producing *syncrude*. In this case investment will be needed in the hydrocracking unit (HCC). This alternative would make it possible to obtain S50 diesel together with a significant reduction of flared gas in addition to high-quality naphta.

Figure 11-Alternative 2 Scheme



The complete process for indirect conversion of natural gas (the GTL process) to liquid form can be divided into three sections, with each representing different processes (Vosloo 2001; Basini 2005; Sousa-Aguiar, Appel and Mota 2005; Breed et al. 2005; Knottenbelt, 2002): production of syngas[59], transformation of syngas [60] and syngas upgrading. [61]

The three stages when considered individually are well-established, optimized technologies with proven commercial viability. However the combined use of the three technologies in the GTL process is not yet widely used (Vosloo, 2001) despite being commercially proven.

59 Synthesis gas or syngas is composed of CO and H2.
60 The study considers the Fischer-Tropsch synthesis at the transformation stage.
61 The viability of the upgrading operation was not demonstrated in the same conditions as the production stages of syngas and synthesis of FT (Worley International, 2000). Therefore the choice of finished products or the product used as a baseline for this stage (syncrude), can be strongly influenced by the conditions available for the offshore plants.

It should be emphasized that the GTL plant considered in the study for offshore operation does not possess the final upgrading stage, which would receive the output from the syngas transformation stage (*syncrude*) for obtaining the end products.

Despite the existence of commercially available technologies for onshore applications, the study considers a promising technology that could be applied in an offshore environment. This requires a GTL plant capable of operating in specific conditions. The offshore platformed GTL involves more compact non-conventional processes with flexible capacity.

Of the technologies identified in a technological roadmap of GTL technology for applying in offshore environments, the SMR microchannel process technology best met the operational conditions for the case under study. By way of example, efficiency data and data related to capacity and capital costs of the SMR micro-channels technology (from the firm CompactGTL) were used. The latter firm possesses a contract with PETROBRAS for developing and applying this technology in Brazil (CompactGTL, 2008).

a) Properties of syncrude

The transformation stage of syngas is now known as *syncrude* by many manufacturers and authors. However this name does not accurately describe the features of the product.

The Fischer-Tropsch (FT) synthesis, the process considered in our study for the syngas transformation stage in the GTL plant, can be divided into two categories according to operating temperature (de Klerk 2008): *high* temperature Fischer-Tropsch (HT-FT) and *low* temperature Fischer-Tropsch (LT-FT). The CompactGTL technology involves the LT-FT synthesis. [62]In this case the product to be obtained is an n-paraffin [63] or, in other words, a wax with a small amount of olephynes, oxigenates and aromatics. The product can contain C100 hydrocabons depending on the α [64]value of the LY-FY synthesis (de Klerk, 2008). However the FT synthesis product called syncrude is in fact a wax.

The description of the properties of syncrude is extremely important because these indicate how this product can be best employed. One option would be to mix syncrude with the oil produced on the platform and benefit from the existing transport structure. However this study proposes feeding syncrude, separately from the oil produced, to the upgrading stage given that its properties, together with the need to produce S50 diesel in Brazilian refineries, can justify its use.

b) Utilization of syncrude

The idea of using syncrude is not simply to send it to a refinery (basically to an atmospheric distillation unit) but to use it in the *downstream* stages of the refining process.

Bearing in mind the different properties of syncrude in relation to crude oil, there is no need for the syncrude load to undergo the same stages as the crude oil that is fed into the refinery in the Atmospheric Distillation Unit (UDA).

The same refining scheme for petroleum could be used for syncrude but it is less efficient (de Klerk, 2008). Refining syncrude is easier and consumes less energy and consequently has less potential to cause environmental damage.

62 CompactGTL considers the F-T synthesis occurring at a temperature typically between 200 and 350°C, for example 280°C and at a very high pressure, typically between 2MPa and 4 MPa (e.g. 2.5 MPa).

63 For example the products from the operation of the Sasol LT-FT reactor in Sasolburg are: gas, compensates and wax. The wax is predominantly paraffin with a level of approximately 94% wt of n-paraffins (Leckel and Liwanga-Ehumbu, 2006; Leckel 2007)

64 Further details on the distribution of the number of syncrude carbons see Stelmachowski and Nowicki, (2003) and de Klerk (2008)

In view of the limited market segment for each type of syncrude few technologies have been developed specifically for syncrude hydroprocessing. This could lead to the mistaken conclusion that hydroprocessing of syncrude and petroleum are similar given that the same basic principles and commercial catalysers are used for both (de Klerk, 2008).

Depending on the required derivative, the syncrude load needs to be treated by different processes. For example syncrude could be fed to a Catalytic Cracking Unit (FCCU) [65] in order to satisfy higher demand for gasoline or it could be fed directly into a Catalytic Hydrocracking Unit (HCC) if the desired product were diesel or lubricants. Catalytic hydrocracking is a flexible process for converting heavy, hydrogen-deficient oils into lighter and more valuable products.

Given the high demand for S-50 diesel in Brazil it would be wasteful to mix syncrude with crude oil.

This study considered a configuration at the upgrading stage which included the syncrude hydrocracking process[66]. The objective here was to compare the viability of syncrude hydrocracking in terms of energy consumption (and consequently CO2e emissions) with other possibilities for obtaining products with the same specifications and volumes obtained from the crude oil submitted to other refining processes. To make a valid comparison it was necessary to conduct a deeper analysis of the characteristics of the refining processes.

It is important to note that syncrude hydrocracking does not result in a single product. An output (volumetric basis) of 30% naphta and 70% diesel was considered (based on Holt Campbell Payton, 2005).

Comparing the final energy consumption and the emissions produced from obtaining the end product (S50 diesel) using the two alternatives involved taking into account the volume of naphta obtained in the HCC. The study therefore needed to focus on the following refining processes: hydrocracking (HCC), hydrotreatment (HDT) and hydrodesulphurization (HDS).

c) Catalytic Hydrocracking (HCC)

The processing of syncrude in HCC involves a number of peculiarities. The energy released during hydrotreatment is less on account of the high level of paraffin present, resulting in a virtually isothermic operation (de Klerk, 2008). [67]

Conventional HCC units for crude oil operate typically at temperatures of over 350°C and at pressures greater than 10 MPa, while syncrude hydrocracking units can operate at low temperatures and low pressures to reach the same conversion level (Leckel, 2007). The availability of hydrogen during the syncrude hydroprocessing procedure is significantly higher than during the hydroprocessing of residues derived from crude oil because fewer aromatics and heteroatoms are

65 The load for catalytic cracking normally comprises light and heavy gasoils from the atmospheric distillation unit (or from vacuum distillation), from the coking unit or from the deasphalting operations. However, the more paraphinic the load (or with a KUOP factor of above 11.5), the easier its cracking, because the catalyser would find it difficult to break the aromatic rings of the components in the FCC load (Szklo 2005).

66 For example, the study done by Marano and Ciferno (2001), which employed eight conceptual settings for a life cycle analysis) of the synthesis of FT, confirms the high costs considered in this study regarding the sending of the syncrude load directly to a downstream unit. The studies cited consider eight options that differ according to the length or complexity of the upgrading processes utilized for converting the products of the FT synthesis into final derivatives. Other refining process were not taken into account: only HCC and the conversion of syncrude into naphtha and distillates.

67 The process of syncrude hydrocracking (LT-FT) is almost isothermic on account of the resulting balance between cracking (endothermic) and olefin saturation (an exothermic process). In the hydroprocessing of crude residues the reaction is exothermic on account of a high level of aromatics and heteroatoms (de Klerk, 2008).

present to consume the hydrogen.[68] Moreover, there is no need for pre-treating the load in order to increase the efficiency of the hydrocracking process (Leckel 2007; Leckel and Liwanga-Ehumbu 2006; Meyers, 2003).

The operation of the HCC at low pressure (3.5 MPa) increases the ratio of iso-paraffin for n-paraffin to the carbon number range of between C15 and C22 but does not affect the level of isomerization significantly for ranges of over C22. Higher pressure (7.0 MPa) reduces isomerization and the part in the C23+ range and increases the selectivity of the diesel through the inhibition of secondary cracking (Leckel and Liwanga-Ehumbu 2006).[69]

In the estimate of energy consumption the fixed bed UOP Unicracking HCC was used [70]. The UOP uni-cracking process is undertaken at moderate temperatures and pressures in the fixed bed where the input is cracked in an atmosphere rich in H2. The precise conditions of the processes vary in accordance with the properties of the inputs utilized and of the type of products to be obtained. Reactions generally occur at pressures of between 3.5 and 21.5 MPa and at temperatures of between 280°C and 475°C (Meyers, 2003).

Energy consumption was estimated on the basis that all the hydrogen consumed in the unit is produced basically by the process of steam reforming. The energy consumption data were based on Energetics (2007), Gary, Handwerk, Kaiser (2007) and Meyers (2003).

d) Hydrotreatment (HDT)

The need to reduce the sulphur level imposed by new Brazilian legislation will require a number of alterations to be made to the refining scheme. The majority of Brazilian diesel is straight run [71] and is fed to the refiner´s diesel pool together with the Light FCCU Cycle Oil (LCO), a product of the catalytic cracking unit (FCC). Once the new legislation covering the obligatory use of S50 diesel enters into force a compulsory requirement will exist to upgrade the LCO so that this can continue to enter the diesel pool. The LCO is the marginal production of the diesel produced currently which will cease to be classified as 'diesel' when it is obliged to conform to the new specifications governing its sale. The hydrotreatment process (HDT) was chosen as the option for treating LCO. The costs of a unit for treating LCO arise from a number of different factors such as the price of the product and the values attributed to the LCO feedstock which varies according to its end-product disposition (Thakkar et al, 2005).

e) Hydrodesulphurization (HDS)

An equivalent amount of naphta obtained in Alternative 1 needs to be treated in a hydrodesulphurization unit (HDS) during the refining process in order to produce the same specifications of naphta obtained in Alternative 2 in the processing of syncrude in the HCC unit. This was the solution we found to enable a volume and quality comparison to be made in our study between Alternatives 1 and 2 with regard to the respective products obtained (for marketing).

68 Syncrude possesses more oxygen as heteroatom in its composition than the typical loads of a conventional HCC. Since HDO is easier than HDN, using HDN catalyses should lead to a good results with HDO (de Klerk 2008; Leckel 2007). For iso-structural components the facility of hydrogenation of heteroatoms typically follows the order (de Klerk, 2008):-Hydrodesulphurization (HDS) > hydrodeoxigenation (HDO) > hydrodesnitrogenation (HDN).

69 Leckel (2007) also supports the idea of HCC the diesel at a lower pressures (3.5 MPa). He also strengthens the claim that consumption of H2 is lower because syncrude contains no aromatic.

70 UOPLCC is a licensor of the 'Unicracking' process (Trademark and/or service Mark of UOP).

71 Obtained directly in the distillation columns.

6.2 Potential for reducing emissions and Marginal Abatement Cost

For the new refineries planned under the PNE 2030 (5 new refineries not counting the ones under construction), the mitigation options are associated with both the possibility of revising or modifying the refining scheme (choice of production units) and with efficiency gains in specific units. For existing refineries (12) and those under construction (2) only the mitigation options linked to efficiency gains in refining units will be evaluated in terms of abatement cost and incorporated in the Low Carbon Scenario.

For the existing refineries and those under construction two stages of deployment of mitigation measures were considered in our study. The first phase focused on the implementation of mitigation measures in year 2015 in the following refineries: COMPERJ, RENEST, REPLAN, REDUC and REGAP. The second phase, planned to come into operation in year 2020, examined implementation of the measures for the remaining refineries: RPBC, RECAP, REVAP, REFAP, RLAM, REMAN, LUBNOR, REPAR and IPIRANGA.

The PNE projections were taken into account in the case of new refineries. It should be noted that the COMPERJ and RENEST refineries were considered together with the existing refineries because there are already under construction and possess well-defined refining schemes.

The results of the potential gross reduction and of the marginal abatement cost were obtained by considering a discount rate of 15% for each of the three mitigation measures and for the modifications in the refining scheme. These are summarized in Table 61.

Table 61 - Summary of the potential for reducing emissions and costs in the refining area

Mitigation or sequestering options	Potential gross reduction between 2010-30 ($MtCO_2e$)	Costs of average abatement in the period (US$/$tCO_2$) Discount rate (8%)	Break-Even Carbon Price (US$/$tCO_2$)
Modifying design of new refineries	51.8	19.1	106.1
Improving energy use of existing refinery units			
Heat integration	52.3	6.6	74.8
Fouling mitigation	7.0	72.9	208.5
Advanced control	7.0	95.1	431.5

In order to construct the Low Carbon Scenario for the existing refineries and those under construction we considered two stages in the deployment of the mitigation measures. The first phase involves the implementation of the measures in year 2015 in the following refineries: COMPERJ, RENEST, REPLAN, REDUC and REGAP and the second phase, planned for year 2020, covers the implementation of mitigation measures for the remaining refineries (RPBC, RECAP, REVAP, REFAP, RLAM, REMAN, LUBNOR, REPAR and IPIRANGA.). Tables 62, 63 and 64 summarize the results of the application of the three mitigation measures in the existing refinery sector.

Table 62 – Description of the adjusted energy mix proposed in the Low Carbon Scenario for existing refineries -Measure: Heat Integration

Existing refining Heat Integration	Accumulated total over period	2010-2014	2015-2019	2020-2024	2025-2030
Number of refineries	15	0	5 refineries: COMPERJ RENEST REPLAN REDUC REGAP	10 refineries: RPBC RECAP REVAP REFAP RLAM REMAN LUBNOR REPAR Ipiranga Manguinhos	0
Total adjusted cost in the Reference Scenario (US$ million) (*)	0	0	0	0	0
Total adjusted cost in the Low Carbon Scenario (US$ million)	1,499,764,744	0	996,653,227	467,513,752	35,597,764
Difference of total cost (US$ million) (Low Carbon-reference)	1,499,764,744	0	996,653,227	467,513,752	35,597,764
Mitigation volume (MtCO2)	52.3	0	10.1	19.2	23.0

(*) In the Reference Scenario no investment in this measure.

Table 63 – Description of the adjusted energy mix proposed in the Low Carbon Scenario for existing refineries – Measure: Fouling Mitigation

Existing Refining Fouling Mitigation	Accumulated total over period	2010-2014	2015-2019	2020-2024	2025-2030
Number of refineries	15	0	5 refineries: COMPERJ RENEST REPLAN REDUC REGAP	10 refineries: RPBC RECAP REVAP REFAP RLAM REMAN LUBNOR REPAR Ipiranga Manguinhos	0
Total adjusted cost in the Reference Scenario (US$ million) (*)	0	0	0	0	0
Total adjusted cost in the Low Carbon Scenario (US$ million)	371,204,669	0	151,164,131	140,934,394	79,106,143
Difference of total cost (US$ million) (Low Carbon-reference)	371,204,669	0	151,164,131	140,934,394	79,106,143
Mitigation volume (MtCO2)	7.0	0	1.4	2.6	3.0

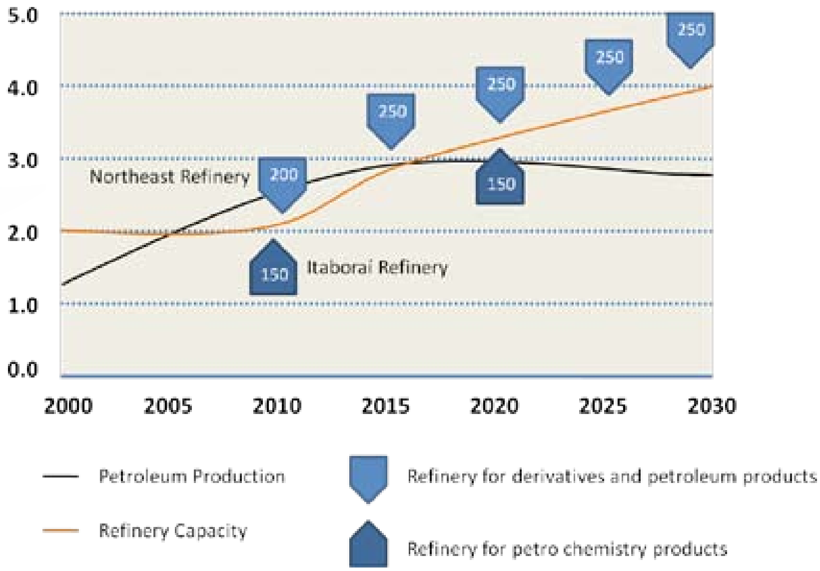
(*) In the Reference Scenario no investment in this measure.

Table 64 – Description of the adjusted energy mix proposed in the Low Carbon Scenario for existing refineries – Measure: Advanced control

Existing Refining Advanced Control	Accumulated total over period	2010-2014	2015-2019	2020-2024	2025-2030
Number of refineries	15	0	5 refineries: COMPERJ RENEST REPLAN REDUC REGAP	10 refineries: RPBC RECAP REVAP REFAP RLAM REMAN LUBNOR REPAR Ipiranga Manguinhos	0
Total adjusted cost in the Reference Scenario (US$ million) (*)	0	0	0	0	0
Total adjusted cost in the Low Carbon Scenario (US$ million)	555,468,423	0	369,130,824	173,153,241	13,184,357
Difference of total cost (US$ million) (Low Carbon-reference)	555,468,423	0	369,130,824	173,153,241	13,184,357
Mitigation volume (MtCO2)	7.0	0	1.4	2.6	3.0

In the case of new refineries the PNE projections presented in Figure 12 were taken into account. It is worth noting that the COMPERJ and RENEST (which appear as the 'Itaboraí' and 'Northeast' refineries respectively) were considered together with the existing refineries because they are already under construction and have their refining schemes defined. Table 65 below shows the results for the new expanded refining sector.

Figure 12 – Expansion of refining capacity in Brazil



Source: EPE, 2007

Table 65 – Description of the adjusted energy proposed in the Low Carbon Scenario for new refineries

New refineries	Accumulated total over period	2010-2014	2015-2019	2020-2024	2025-2030
Number of refineries	5 refineries	0	1 diesel refinery	1 petrochemical refinery 1 diesel refinery	2 diesel refineries
Capacity (000 bpd)	1,150	0	250	400	500
Investment adjusted in the Reference Scenario (US$ million)	23,755,349,062	0	11,032,881,358	8,639,427,894	4,083,039,811
Investment adjusted in the Low Carbon Scenario (US$ million)	24,586,745,293	0	11,539,709,806	8,776,429,014	4,270,606,473
Difference of investment (US$ million)(Low Carbon - Reference)	831,396,231	0	506,828,448	137,001,120	187,566,662
Volume of mitigation ($MtCO_2$)	51.8		6.1	16.9	28.8

Figures 13 and 14 show the CO2 emissions for the existing refineries before the mitigation measures and the reductions estimated for existing and new refineries after the mitigation measures have been implemented.

Figure 13 – CO2 emissions by refineries in Brazil

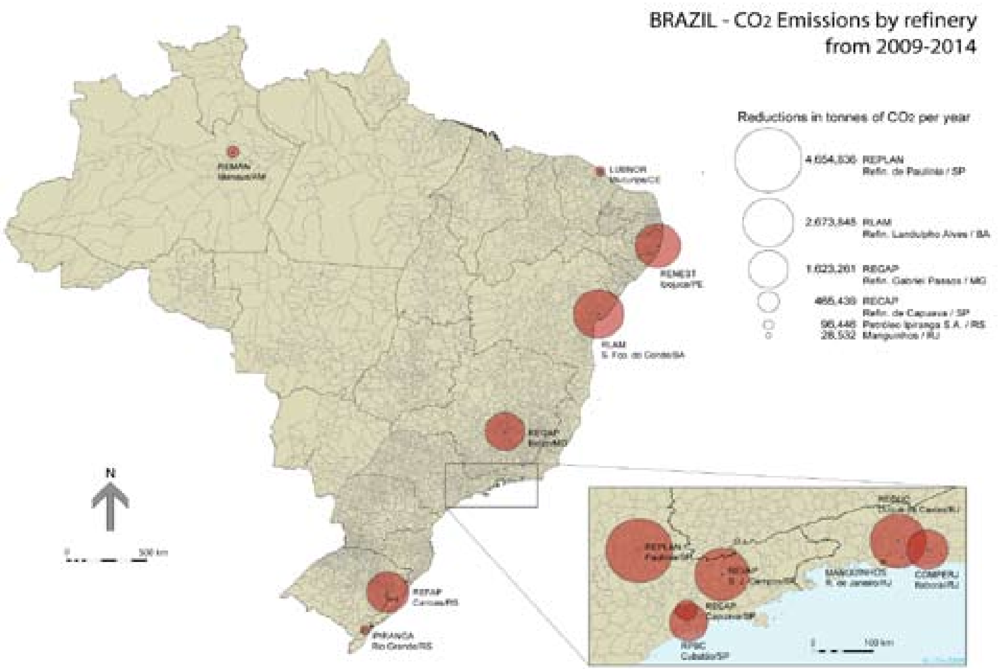
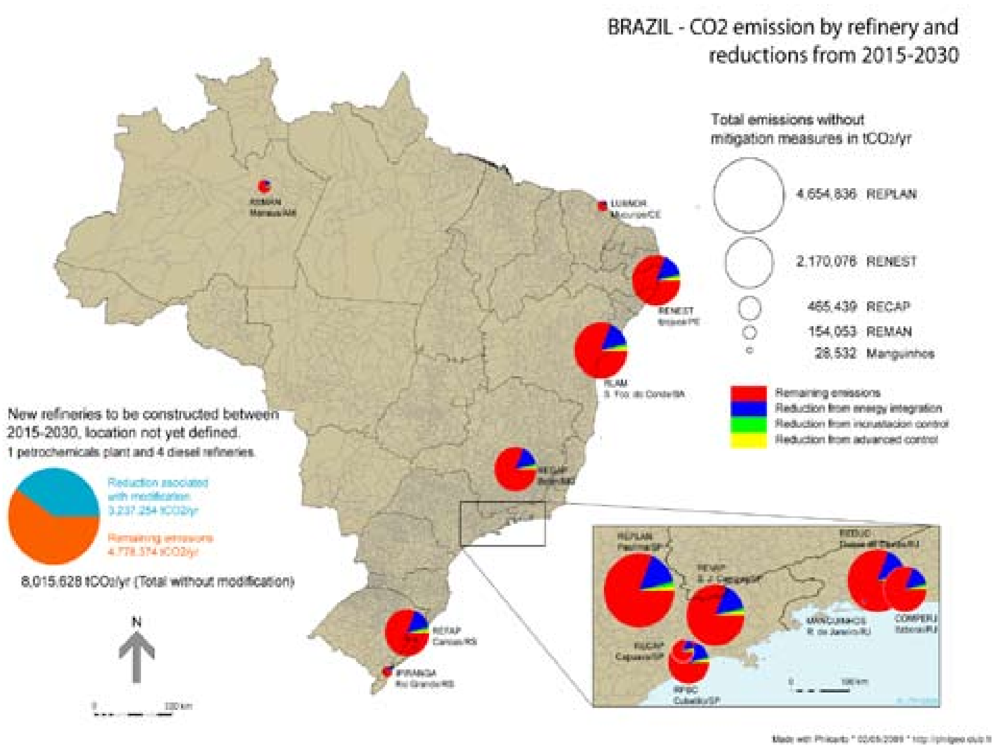


Figure 14 – Estimated reductions of CO2 for existing and new refineries



We selected compact GTL technology for the Low Carbon Scenario - specifically the Steam Methane Reforming (SMR) microchannel technology - in preference to other technologies, given the need to examine the existing technological options and processes involved in producing *syngas* in offshore operating conditions. Consequently we decided on liquids production which allows the existing oil production structure to be used.

The data employed in the study need to be constantly revised. In future studies, in addition to revising data, the prospects for reducing the costs of GTL technology must also be taken into account. This reduction would involve factors such as new technical developments, economies of scale and training for operators and systems designers.

We used the assumptions contained in the PNE 2030 for constructing the Low Carbon Scenario. The results obtained are different from the example applied to the PETROBRAS robust price assumptions given that the petroleum price projections considered are different in the two cases. However the sensitivity analyses in the latter example, particularly those concerning cost sensitivity of investments in GTL plant and flaring efficiency, are valid lessons.

It is important to note that a 1000 bpd plant, equivalent to consumption of approximately 283,000 m^3 of natural gas per day or 103,295,000 m^3 per year, represents a project or module. According to the scenario for domestic natural gas production outlined in the PNE 2030, the reinjection portion, self-consumption and/or burning/losses will amount to approximately 105 million m^3 per day of natural gas. Thus the volume of flared gas for 2030 was estimated at 9,581,250,000 m^3 of natural gas.[72]

Using the GTL project annual consumption values of natural gas and associated gas flaring, we estimated the technical capacity of a total of 93 plants for 2030. Not all the flared gas could be used due to a series of technical reasons such as the dispersed nature of the offshore units. Table 66 below summarizes the estimated potential for installing the GTL projects and the reduction of flared gas for the respective years (five year intervals). Note also the prospect for a gradual insertion of GTL modules throughout the period of the scenario aimed at enhancing the technological learning curve..

Table 66 – GTL Option for reducing Gas Flare

	2010	2015	2020	2025	2030
Operational capacity (number of projects of 1000 bpd of syncrude)	0	10	20	35	55
Emissions avoided (MtCO2e/year)	0	3.4	6.7	11.8	18.6

The results obtained for marginal abatement costs employed a discount rate of 8% (which would represent a "social" discount rate as suggested in Szklo, Carneiro and Machado [2008]) and a discount rate of 25% (representing the 'view' of the refining company) show that a different spread of investments is required for the two cases. At an 8% discount rate, which was also the rate adopted by the PNE 2030, the abatement cost is *negative,* while the GTL project in this case is *positive*. The results obtained for marginal abatement costs and for total emissions reduction for the timeframecale analyzed are summarized at Table 67.

72 In the estimates of burned gas was it considered that the percentages of own consumption and reinjection were maintained approximately constant and the variation would be the result of the reduction or increase of the segment relating to the flaring or losses of natural gas. A percentage of 40% was used and an own consumption of 35% (ANP, 2008a). 25% of the aggregated data relate to flaring natural gas, equivalent to 26,250,000 m^3 a day or 9,581,250,000 m^3 a year. The figure utilized chimes with the EPE estimate of 8.4 million TPE or 9,651,000,000 m^3 in year 2030.

Table 67 – Cost of CO2 abatement

	Cost of abatement and Break-Even Carbon Price (US$/t$CO_{2e}$)	Reduction of emissions (MtCO_{2e})
Discount rate 8%	-1.5	128.1
Discount rate 25%	33.9	128.1

Table 68 shows the description of the proposed adjusted makes in the Low Carbon Scenario for GTL.

Table 68 –Description of adjusted mix proposed in the Low Carbon Scenario for GTL

GTL	Accumulated total over period	2010-2014	2015-2019	2020-2024	2025-2030
Operational capacity (number of projects of 1000 bpd of syncrude	55	0	10	10	35
Adjusted cost in Reference Scenario (US$ million)	209,207,868	0	128,077,435	47,859,102	33,271,331
Adjusted cost in Low Carbon Scenario (US$ million)	606,729,069	0	374,901,876	136,592,787	95,234,407
Cost difference (Low Carbon-Reference Scenarios)	397,521,201	0	246,824,441	88,733,685	61,963,076
Mitigation volume (MtCO2)	128.1	0	16.9	33.7	77.5

6.3 **Barriers for Implementation of Low Carbon Options**

6.3.1 Refining Sector

Deployment of the mitigation options in the refinery sector faces a number of barriers:

- The level of maturity of some of the technologies considered in our study (for example CCS, GTL, ODP) negatively affects the risk perception of private agents, in this case PETROBRAS, which could lead to higher transaction costs.
- Even for the commercially available technologies considered in the study (energy integration, advanced control, incrustation control etc) a considerable difference exists between the discount rate used by the private segment of the petroleum industry and the discount rate used by the State for comparing infrastructure investments. This gives an idea of the high opportunity cost of the oil companies.

It is important to stress that the oil companies would normally inventory their carbon emissions and they certainly possess the technical and financial capacity to act in this respect. However they generally prefer to invest in their core business which is exploration (new reserves) and oil production.

6.3.2 GTL

The key factor inhibiting investment in reducing gas flaring with the use of GTL plant is the high cost of this technology as well as its lack of maturity. Private agents (in this case the oil platform operator) therefore choose to work with a high discount rate, usually in the region of 25% per annum. The main barriers identified related to using GTL technology are:

- Offshore GTL is not yet a 'commercial' technology. Therefore it is regarded as a riskier mitigation option and faces higher transaction costs.
- Various factors can nevertheless contribute to reducing the capital costs of GTL, such as good training for the operators and installations designers. One of the reasons for the high cost of the first plants is precisely the need for training appropriate staff to oversee and operate the new technology.
- Investment in R&D is vital

6.4 Existing measures and proposals

6.4.1 Oil refining sector

Despite the barriers that have been identified, part of the differential of the marginal abatement cost could be covered by programs to provide incentives for refineries to increase energy efficiency.

At present a number of programs of this type exist under the aegis of CONPET. For example the *National Program for Rationalizing the Use of Petroleum Derivatives and Natural Gas* (CONPET) is a program run by the Ministry of Mines and Energy, coordinated by the Federal Government, with participation by the private sector. PETROBRAS is responsible for supplying its technical, administrative and financial resources. The CONPET Energy Development Executive Board is effectively the Executive Secretariat of the program responsible for project design, operationalizing strategies, promoting institutional links and disseminating information about the actions undertaken by the program. This Executive Board works closely with the Director of the Gas and Energy Division who in accordance with the relevant Presidential Decree is also the Executive Secretary of CONPET (CONPET, 2008). Given that the annual budget of the program is relatively low (under R$5 million per year (REA, 2008) other sources of finance have to be tapped.

CONPET activities could be improved if assistance from BNDES programs were forthcoming. The BNDES (National Bank for Economic and Social Development) is linked to the Ministry for Development, Industry and External Trade. Its principal function is to support activities that contribute to the country's development. The BNDES normally finances large industrial and infrastructure developments. The main thrust of its operations is to provide support for investments in agriculture, trade and services. It also makes financing available for micro, small and medium-sized firms, education, health, family agriculture, basic and environmental sanitation and public transport systems. BNDES has two subsidiaries - the Special Agency for Industrial Financing (FINAME) and *BNDES Participações* (BNDESPAR). The first of these is responsible for financing the marketing of machines and equipments while the latter is intended to make it possible to trade securities on the Brazilian stock market. This group of three agencies forms the basis for the so-called "BNDES system" (BNDES 2009a).

Finally, a further group of mitigation alternatives analyzed for the oil refining sector involves the modification of the 'optimum refining scheme' now faced by the foreseen carbon costs.

As we have seen, the refining sector only modified its refining scheme to take account of high carbon values of around 100 US $/t CO2.

This result was different when the possibility of capturing and sequestering carbon (CSC) at a cost of 50 US$/t CO_2 was taken into consideration. In this case, the refining scheme was effectively modified to benefit the production of H2 for HCC (to the detriment of the most energy intensive unit of FCC), for energy use in the refinery and to capture the CO_2 produced in the H2 production unit.

This indicates that CSC could become a key measure for reducing CO_2 emissions from refineries in the future, altering the unit refining operations and especially the refinery scheme. This alternative would also produce technological advances and cost reductions.

In addition to CSC, two promising alternatives could also be developed in Brazil: the bio-desulphurization and oxidative desulphurization (ODP) of diesel. The former involves a set of promising processes designed to reduce the hydrogen sulphide level of petroleum derivatives in soft conditions (with less energy consumption). The latter involves a process of desulphurization without hydrogen for removing sulphur-containing compounds by oxidation of crude oil, again a very promising development given that diesel is the key derivative used in the Brazilian energy matrix. Reducing the legally established diesel sulphur level should lead to a reduction of CO_2 emissions of the Brazilian refineries sector (Szklo and Schaeffer, 2007).

The ODP process, although still at the development stage, holds out good prospects for diesel (Lü et al. 2006) but not for gasoline given the competitive reactions of epoxidation of olefins (Ali et al, 2006). Some studies also recommend the use of the ODP technique in combination with soft HDS. The latter serves to reduce the level of sulphur in diesel from over 1000 ppm to a matter of 100s of ppm while ODP can be used for deep desulphurization of diesel (Ali et al, 2006).

Note that the use of desulphurization techniques without the addition of hydrogen would permit the use of hydrogen produced in the refinery as a fuel. This will reduce even further the carbon emissions of industrial units and could be undertaken simultaneously with CSC in the refining process.

Both in the case of CSC and the other promising alternatives, the R&D stage is indispensable. Again, the CT-Petro Sectoral Fund could well be the key instrument for promoting these alternatives. The CT-Petro is a fund created in 1999 with the aim of encouraging innovation in the productive chain of the petroleum and natural gas sector. It also aims to train and qualify human resources and develop projects in partnership with universities, higher education institutions, research institutions, and private businesses. The overall goal is to increase production as well as productivity, reduce costs and prices and improve the quality of petroleum sector products. The fund is financed with 25% of the value of the royalties exceeding 5% of the production of petroleum and natural gas (FINEP, 2008).

Use of the science and technology funds earmarked for the *National Fund for cientific and Technological Development* (FNDCT) depends in the first place on them being included in the budget proposals submitted by the government. The latter are based on overall tax revenue forecasts and their approval by the National Congress (Pacheco 2007). Even when the total amount collected matches the value authorized in the Budget Law this does not guarantee that the funds will be automatically forthcoming. During budget execution the funds frequently fall victim to cutbacks imposed by the Executive Power.

Financing the science and technology sector suffers from being decoupled from the revenues collected by CT-Petro. This enables the Federal Government during calculation of its revenue forecasts to discount the 'unlinked' funds. The decoupling of funds and their placement in the Contingency Reserve engenders a gap between the revenue growth curves of CT-Petro and the budget commitment limitations. Pacheco (2007) explains that even if the government´s revenue tripled between 2001 and 2004 (involving a total of R$1.6 billion) the committed values would be virtually constant – around R$595 million in 2004 (around only 37.5% of the total collected in that year)[73]. Table 69 summarizes the policies for the national refining sector [74].

Table 69 – Summary of policies for the Brazilian oil refineries sector

Policies adopted	Classification	Observations
P&DD/CT Petro	Rectification	Annual disbursement of R$ 600 million on science and technology (S &T) through sectoral funds in Brazil. Modification of refining scheme for 50 $/t$CO_2$, when the CSC option is considered
BNDES/FINAME	Rectification	From April 2007 to April 2008, expenditure by FINAME exceeded R$18 billion. In 2008, disbursements by BNDES on the industrial sector totaled around R$ 40 billion. The most recent PETROBRAS investment plan (2009-2013) foresees capturing around $12 billion from BNDES.
Extension of Upscaled CONPET program	Rectification	Expenditure of under R$5 million per year. This sum is lower than, for example, the leveled cost of abatement in refinery energy optimization (between US$ 35 and US$70 million)

In order to assess the implications and possible problems that could exist with the adoption of mitigation measures, we carried out a preliminary analysis of probable winners and losers, expecting to be able to identify the degrees of resistance against or support for the proposed mitigation measures and if necessary to examine the need for compensatory action.

In the event of prospective upscaling of CONPET, the winners identified are: society as a whole, the government and possibly PETROBRAS. In the latter case reduction of the end use of energy in PETROBRAS refineries could be a 'win-win' type strategy leading to a reduction of operational refining costs (energy consumption is responsible for around 50% of these costs - Szklo and Uller (2008). Depending on the resources to be allocated to these measures, PETROBRAS would eventually be a 'loser' given that the annual CONPET budget, at under R$5 million, is relatively low (REA, 2008). Thus the activities currently financed by CONPET could be compromised. A possible compensatory approach would be to use PETROBRAS fiscal waivers for the company to invest in energy efficiency. In this event, the government would lose part of its revenue from the oil sector but in exchange the scheme would provide a powerful incentive for PETROBRAS to invest in energy efficiency through the CONPET program.

If the CT-Petro fund were to be used for investing in R&D, the winners would be the consumers, research centers, universities and PETROBRAS itself. The government would

73 The present study is not the place to discuss the microeconomic virtues of maintaining the primary surplus in Brazil on the basis of economizing the resources collected such as those that could be directed to CT-Petro. Our aim here is only to indicate the fact that more revenue is collected than that effectively used in CT-Petro. These monies could be used for R&D targeted at the reduction of energy consumption in Brazilian refineries.

74 The policies were classified as follows: INCREMENTAL – new policies; RECTIFICATION – existing policies adjusted; SUBSTITUTION – existing policies 100% substituted; DEROGATION – impaired/unhelpful policies suppressed.

effectively be a loser in view of the loss of revenue (affecting the primary surplus). In this case there would be no possibility of compensation except in terms of the better application of public funds. Nevertheless it is important to note that while the initial loss of fiscal revenue reduces the government's budget it could stimulate economic activity and generate a secondary delayed (by comparison with the first) effect involving the prospect of enhanced tax-take.

6.4.2 GTL

The most appropriate agent for underpinning GTL projects is the BNDES. The BNDES (National Bank for Economic and Social Development) is linked to the Ministry for Development, Industry and External Trade and its main function is to support activities that contribute to the country's development. The BNDES normally finances large industrial and infrastructure developments, with the main thrust of its operations being support for investments in agriculture, trade and services. It also provides financing for micro, small and medium-sized firms, education, health, family agriculture, basic and environmental sanitation and mass transit systems. BNDES has two subsidiary agencies - the Special Agency for Industrial Financing (FINAME) and *BNDES Participações* (BNDESPAR). The first of these is responsible for financing the marketing of machines and equipments while the latter is intended to make it possible to trade securities on the Brazilian stock market. This group of three agencies forms the basis for the so-called "BNDES system" (BNDES 2009a).

A further way of dealing with the problem would be to reduce the technological uncertainties by promoting technical training in offshore GTL. This would involve R&D which could involve PETROBRAS and sectoral petroleum funds earmarked for technical development.

While funds for R&D certainly exist in Brazil which could be invested in reducing gas flaring with the installation of GTL plants, the problem is how to ensure that these resources are directed to doing this.

Important players in this sense would be research institutes and universities. These institutions could become involved in elaborating a GTL offshore plant pilot project with a view to increasing the country´s fund of knowledge and expertise regarding this technology, as well as examining ways of reducing costs.

For example an offshore 1000 bpd GTL plant would involve an investment of approximately US$75,000,000. This figure amounts to 25% of the annual average spend (R$600 million with science and technology through the sectoral funds in Brazil). This estimate was based upon the forecast of US $75,000 per bpd capacity of the manufacturer CompactGTL. This plant could be used as a demonstration unit in projects designed by equipment manufacturers and research institutes. One advantage of the micro-channels technology is that it does not require scale up. Therefore its scale could be increased in 'modules' which effectively means that training on a pilot demonstration unit of 1000 barrels/day would in due course come to resemble training on a commercial unit. Investment in a demonstration unit could possibly engender investments in commercial plants.

A further measure could be based on the gradual reduction of the permitted limits of flaring by insisting on compulsory targets for harnessing the natural gas. Non-compulsory measures have already been adopted in Brazil (in Malaysia these types of measures justified the Bintulu GTL plant). The measure could be on the lines of the "Zero Flare Plan" (PQZ) [75]under which ANP

75 The *Programa Queima Zero* (PQZ) was employed by the Campos Basin Unit with a view to reducing gas flaring, in the context of increased production in the Basin and the prospect of a growing market for natural gas (PETROBRAS 2007).

was responsible for monitoring the use of natural gas in production activities in Brazil´s offshore fields (ANP, 2001).

The best solutions for reducing gas flaring were assembled in an Action Plan introduced in 2001 whereby PETROBRAS and ANP tightened control over gas burning in the Campos Basin, resulting in a series of actions to actions complement the PQZ. Progressive targets for reducing gas burning could also be implemented, with penalties levied in the event of targets not being reached. Such penalties could be equal to the break-even price of carbon emitted by gas flaring (around 35 US $/t CO2 at the rate of 25% per annum according to the PNE, 2030 petroleum price scenario).

Petroleum royalties are applied to burnt or ventilated natural gas. In Brazil royalties are calculated by multiplying the royalty rate by the market value of the production of the input - in this case natural gas (Thomas et al, 1996). In effect, the royalty is calculated by the producer field and obtained by multiplying the aliquot by the value of the production. The total value of the field´s production is the sum total of the value of petroleum and gas production. The value of the petroleum is equal to the volume of petroleum produced multiplied by the price of the petroleum, while the value of the gas is obtained by the volume produced of gas multiplied by the price of gas. The compulsory payment of royalties for the burnt gas has to be taken into consideration regardless of any zero economic return. More information on the oil business fiscal regimes and government participation in Brazil can be found in Pacheco (2007). Except in highly specific situations (e.g. emergencies) the authorization for non-payment of royalties for the burnt gas is necessary. Law number 9478 of 6 August 1997, known as the *Petroleum Law*, contains details of Brazil's national energy policy, describes the activities related to the oil monopoly and establishes both the National Energy Policy Council and the National Petroleum Agency[76] . In Clause III of Article 47, this law refers to the burning of natural gas in the following terms: "flaring gas rather than marketing it represents a loss of the product by the concessionaire and the (flared gas) will be included in the total volume of the production to be computed for calculating the royalties owed" (ANP 2008a).

One possibility would be to remove the royalties on the unburnt natural gas used for gas-to-liquid purposes. Royalties would be charged on the flared natural gas but not on the proportion of gas to be converted into GTL. Many examples of royalty relief exist elsewhere but perhaps the clearest example of this is in the US (Hallwood, 2007). Note that this measure does not involve a simple tax waiver but heralds a change in the current law which will attract other costs and measures that are outside the scope of the present study. With royalties of 10% on the gross value of production, a price of R$0.7 0/m3 of natural gas and a volume of 96,226,800 m^3/yr, this would mean a return of R$6,735,876 a year for the company to invest in GTL[77].

It is important to point out that we are not recommending allocating investments in response to public policies but simply a set of policy options for reducing flaring. Table 70 below summarizes GTL-related policies[78].

76 See ANP (2008b).

77 A percentage and price were applied here only by way of example. Prices and percentages of royalties applied to each field can be obtained at ANP (2008c). The volume was based on the capacity of a plant capable of producing 1000 bpd of syncrude.

78 The policies were classified as follows: INCREMENTAL – new policies; RECTIFICATION – existing policies adjusted; SUBSTITUTION – existing policies 100% substituted; DEROGATION – impaired/unhelpful policies suppressed.

Table 70 – Summary of policies for GTL

Policies adopted	Classification	Observation
BNDES/ FINAME	Rectification	For the abatement of 337.000 tCO2, equivalent to a plant with 1 kbpd capacity for producing syncrude, a differential exists of US$ 50 million per year, to be financed
P&D/ CT Petro	Rectification	Demonstration offshore GTL plant producing 1000 bpd requires an investment of US$ 75 million. This is equivalent to 25% of the average annual expenditure of R$ 600 million on S&T through the sectoral funds in Brazil) and less than 10% of its total received annually by CT-Petro
Royalty relief on gas for GTL	Incremental	For royalties of 10% of the gross value of production, a NG price of R$ 0,70/m^3 for gas and 96,226,800m^3/year, would produce approximately US$ 3.5 million per year for the company to invest in GTL
Progressive targets	Rectification	Progressive targets for reducing flaring to be achieved with the application of penalties equivalent to the value of the carbon emitted

With the aim of assessing the implications and possible problems that could arise from the adoption of mitigation measures, we undertook a preliminary analysis of the probable winners and losers.

If CT-Petro were used to finance implementation of GTL technology, the clear winners would be the consumers, research centers and PETROBRAS. The government would effectively be a 'loser' on account of loss of tax revenue, with implications for the primary surplus. As with the refining sector, there would be no possibility of compensation except in terms of better application of public funds. Nevertheless the increased economic activity flowing from GTL plants that would be installed by 2030 would partly compensate for the government´s shortfall[79].

If financing involved using BNDES/FINAME resources the consumers and PETROBRAS would be the 'winners', possibly disadvantaging other industrial sectors seeking FINAME funds. A possible compensatory measure would be to expand FINAME by opening special credit lines and extending fiscal benefits for the sectors which would lose access to the program.

A further measure could be based upon the gradual reduction of the permitted limits for flaring the gas, using compulsory targets for harnessing the associated natural gas. In this case a possible winner would be the consumer. PETROBRAS would be a loser insofar as it would be subject to a penalty if it were to burn gas over and above the established targets. The size of the penalty could be exactly equivalent to the value of a tons of CO_2 that would be emitted.

Finally, the concept of *royalty relief* on natural gas could be introduced. In this case the winner would be PETROBRAS while the Federal, state and municipal governments would lose tax revenue. A secondary effect in this case would be the prospect of growth of economic activity at all three levels. Compensation could take the form of a return of part of the losses incurred by 'royalty relief'. This sum could be effectively "reimbursed" in the form of the ICMS (tax) on diesel to be produced using GTL and marketed (the same for naphta). If such a penalty were applied, the 'loser' would obviously be PETROBRAS, with the government and consumers emerging as 'winners'.

79 Note that an evaluation of the benefits of the primary surplus for the Brazilian economy falls outside the scope of the present study. We also avoided analyzing how the shortfall in the primary surplus would be compensated as the result of cutbacks in the resources available to the CT-Petro by the use of other sources of revenue.

7 Energy Supply-Electricity Sector: Cogeneration from Biomass

7.1 Mitigation Options

This chapter addresses the question of surplus electricity generation from sugarcane biomass. The industrial producers of sugarcane possess the best potential for producing electricity from residual sugarcane biomass: installed capacity according to ANEEL (2009) is almost 4 times higher than the installed capacity in the cellulose and paper industries (using black liquor) [80]and 15 times higher than the generation capacity with wood waste[81]. On the other hand, while the prospects for significant growth in electricity generation from residual sugarcane biomass in the sugar processing plants are substantial given the investments that are already underway and those that are planned for the short-term, the prospects for energy generation from other residual biomasses are more limited[82]. In view of this, the analysis in this chapter is confined to examining the potential for electricity generation based on sugarcane biomass waste.

The contribution of this option to reducing greenhouse gases arises from the fact that biomass (bagasse and straw) can be used for generating electricity. Importantly, it is also a renewable source of energy, used to produce both sugar and ethanol[83]. Given that sugarcane production is basically determined by the international and national sugar and ethanol markets, it can be reckoned that there are no additional emissions associated with the use of biomass in the sugar plants. In other words it is accepted that ethanol and/or sugar are responsible for all the emissions from the manufacturing process.

In Brazil all the sugar processing plants are self-sufficient from the electric energy point of view during the sugarcane harvest. The situation analyzed deals with the production of surplus electricity which replaces other electricity generating options. Thus the avoided emissions in the electricity sector are linked to changes in the electricity generation matrix over the period 2010-2030. Graph 5 below shows the evolution of electricity generation from waste sugarcane biomass (in this case only bagasse) in terms of Wh per ton of milled cane for the period 1990-2007. Electricity generation above 12 kWh/tc (represented by the horizontal line in the graph) corresponds to the level of self-sufficiency in terms of electric supply (an average for sugar mills without large-scale electrical equipment). It can be seen that on average the production of surplus electricity in Brazil only became viable from the mid-1990s.

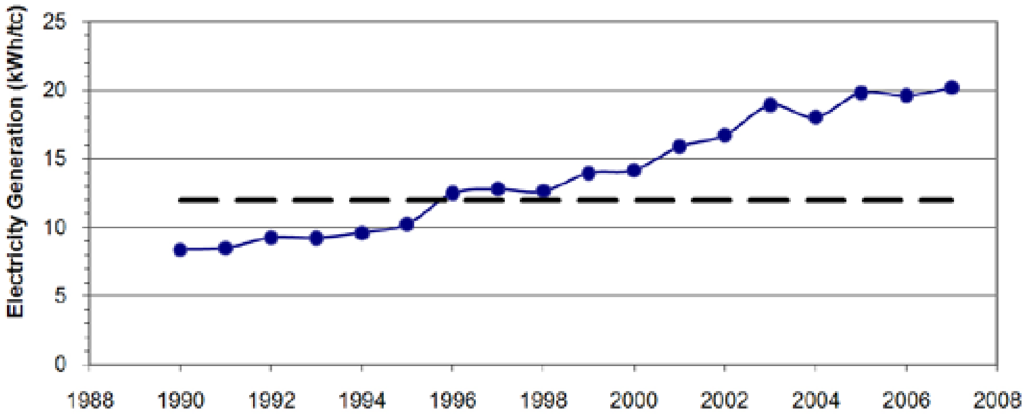
80 According to the National Electricity Agency installed capacity based on bagasse in April 2009 was 3.732 GW, with 1.024 GW based on black liquor.

81 240 MW based on wood waste. The other biomasses (biogas, rice husks and charcoal) contribute with under 100 MW. In total the installed capacity based on biomass amounts to 5.094 MW.

82 Again according to ANEEL, over 330 MW are under construction and around 2,500 MW already authorized out of a total of 3,000 MW that could remain viable in the short term from using biomass (i.e. 91% of the total).

83 With the arrival in due course in the commercial market of the so-called second generation biofuels technologies there will be competition between electricity production (surplus) and biofuels.

Graph 5-Generation of electric energy with sugarcane bagasse (1990 to 2007)



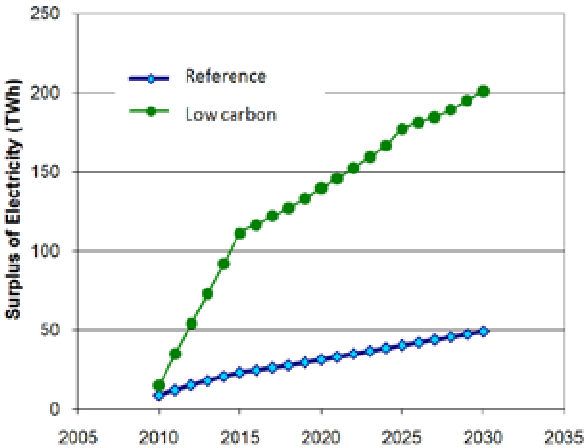
Estimates of the electricity that can be generated in the sugar processing plants depend on the following: (i) the availability of biomass from the production of sugar and ethanol as well as the recovery of straw in the sugar plantations for use as fuel[84]; (ii) the steam pressure and temperature settings of the cogeneration systems which operate either only during the harvest or during the entire year; (iii) energy demands of the industrial process (ie the power necessary and steam demand); (iv) the configuration of the production process (ie purely conventional or with an additional hydrolysis unit [85]); and (v) the penetration rates of new technologies such as that which entails electricity generated in cycles in which the gasified biomass is burnt in gas turbines (BIGGT cycles of the Biomass Integrated Gasifier to Gas Turbines).

As mentioned above, once it is assumed that the greenhouse gas emissions are negative in the case of electricity production from sugarcane biomass waste, the avoided emissions depend on the electricity generation matrix considered during the period under analysis. In this event we adopted the profile of electric generation planned in the National Energy Plan (PNE), with a timeframe up to year 2030. The emission factors considered are the same as those presented in PNE 2030 (EPE, 2008).

With regard to the Reference Scenario, the 400%+ growth in surplus electricity production is due to (i) increased production of sugarcane resulting from the growing demand for ethanol; (ii) increased straw recovery; (iii) greater efficiency of electricity generation due to the alternatives considered (configurations and more efficient units). The development of surplus electricity generation in Brazil for the period 2010-2030, in both the Reference and Low Carbon Scenarios can be seen at Graph 6.

84 These parameters were defined jointly with the *Sub-project F team* which worked on large-scale ethanol production.
85 In this case the efficiencies of the hydrolysis process are important parameters .

Graph 6 –Development of surplus electricity generation from biomass residues in cogeneration systems



We considered three technical options for the Reference and Low Carbon Scenarios with respect to the generation of surplus electricity production from sugarcane biomass. Two alternatives involve cogeneration systems with steam turbines: in the first case only counterpressure steam turbines are considered (operating only during the harvest period), and in the other extraction and condensation turbines (capable of operating throughout the year). The difference between the Reference Scenario and Low Carbon Scenario is that in the latter we considered systems with higher generated steam pressures and temperatures. The parameters for our study were 90 bar, 520°C (the parameters of the best systems currently manufactured in Brazil). Technically no difference exists between the cogeneration systems with extraction and condensation turbines in the units that will be modernized and those that will be installed in the new distilleries (without added hydrolysis or BIGCC systems).

Possible installation of the BIGCC systems would aim at maximizing the quantity of surplus electricity generators. Although the technology is not yet available commercially we considered that the first system would be installed in 2018.

7.1.1 Technical description of the options

a) Systems with counter pressure steam turbines

In the Low Carbon Scenario the cogeneration technology using counterpressure turbines was only considered for the new distilleries that will have hydrolysis production incorporated into conventional distilleries, in which case the production of ethanol should be maximized. The measurements were done so that as near 100% of the bagasse could be fed to the hydrolysis unit. Cogeneration systems with extraction and condensation turbines would not be possible in this event since the biomass to be used in the power system is only sufficient to satisfy the demand for process steam[86].

Generation of surplus electricity could be increased by sacrificing the production of ethanol

86 In the cogeneration systems using counter-pressure turbines the smaller the demand for process steam means that less electricity is generated. In this case more biomass could be used for production of ethanol by hydrolysis.

by hydrolysis or with improvements made to the cogeneration system parameters (i.e. pressure and temperature of the generated steam). The reduction of surplus electricity generation would not lead to higher production of ethanol by hydrolysis. A reduction in the production of surplus electricity, if this were the objective, would only occur if the parameters of the cogeneration system were to decrease (i.e. pressure and temperature of steam generated). We considered that all the systems installed during the period 2010-2030 would have steam generation at 90 bar, 520°C.

Burning straw in steam generators (i.e. controlled burning) instead of prior burning straw in the field provides environmental benefits on account of the reduction of emissions of nitrogen and methane oxide particles. This advantage can be indirectly attributed to the high generation of surplus electricity but in fact it arises from the mechanized harvesting process which will be compulsory in most of Brazil by the end of the next decade.

With these systems there is no need for steam condensation and the possible negative effects associated with capturing water for use in cooling systems would not arise.

b) Systems with extraction and condensation turbines

In the Low Carbon Scenario, we considered the technology employing cogeneration with extraction and condensation turbines in the case of the modernization of the power systems of existing sugar mills and their use in the new distilleries which will not have hydrolysis production incorporated. The aim remains the same: to maximize the production of electricity using all the available bagasse in the industrial units and over 50% of the straw available in the field (to be collected mechanically and transported to the distillery or sugar mill).

In the event of this technology being used, electricity generation would depend on process steam demand, which would be higher when industrial consumption were lower. Since the flow of steam extracted from the turbines is minimized with a reduction of process steam demand, more steam can be condensed. Thus the generation of electricity is maximized, although possible constraints have to be considered in terms of capturing water for cooling purposes.

In our study we considered that all the systems to be installed during the period 2010-2030 would be capable of generating steam at 90 bar, 520°C and that the demand for process steam would be 300kg/tons of processed sugarcane. These hypotheses were applied to the systems to be installed in the course of modernization of the existing sugar plants as well as in the new distilleries. As for reduction of demand for process steam the hypothesis is fully justifiable over the medium term but highly improbable over the short term.

The same comments about the controlled burning of straw presented in the previous section are also valid here.

c) BIGCC systems

In the Low Carbon Scenario the employment of power production systems based on biomass gasification with the use of combustible gas in gas turbines was considered for the years after 2018. As a hypothesis we considered that this option would be sufficiently competitive in 2025 and that after this date only BIGCC would be constructed - providing the basic objective was to maximize surplus electricity production[87].

The complete integration of the BIGCC systems in an industrial unit requires a significant reduction of demand for process steam. We considered (conservatively) that the demand for

87 After 2025 only BIG-CC systems would be constructed in the new distilleries which did not possess hydrolysis equipment. This initial hypothesis was not entirely consistent given that the cost of the electricity produced in BIG-CC systems would still be 67% to 40% higher than the generation costs in the CEST systems between 2026 and 2030.

process steam would be reduced to 300kg of steam per ton of sugarcane processed, or in other words the same parameter considered for the CEST systems .

The systems were assessed assuming the biomass was subjected to atmospheric gasification involving a technology that needs to be made commercially available before large-scale pressurized gasification is introduced and which could impose restrictions on the system from the point of view of electricity generation efficiency.

Our comments about the above-mentioned indirect benefits of controlled burning of straw could be repeated here. As for water consumption, the capture of water necessary for steam cooling would be less than that needed in the CEST systems, given that combined cycle applications are being considered.

7.1.2 Information about the implementation of the options

a) Systems with counterpressure turbines

Cogeneration systems with counterpressure turbines are usually employed in sugarcane processing industrial units. In the Low Carbon Emissions Scenario considered in our study the difference between this technology and that used in conventional systems lies in the fact that its implementation was considered exclusively for the plants that will possess units for producing ethanol by hydrolysis. With the objective of maximizing ethanol production, the systems were designed to enable them to operate solely with the steam flow required for meeting the thermal demand of the industrial process. We based our low carbon estimates on the assumption that steam generators operating at 90 bar, 520°C would become standard practice within a few years in all the systems still to be constructed.

The cost of a unit of 25 MW of total installed capacity was estimated at 1,907 R$/kW in December 2008. We based this evaluation upon the parameters of economic appraisals of cogeneration systems using biomass with counterpressure steam turbines with values corrected by the IGP-M. In the evaluation we were able to obtain specific costs based on installed capacity so that the effects of scale could be considered. On the other hand, the effects of specific technical training were not considered given that this has not yet been included (or verified) in the costs of steam power systems in Brazil. It was considered that each distillery would possess two modules of equal capacity (i.e. steam generator, steam turbine and alternator) designed to enhance the reliability of the systems. It was estimated that the cost of interconnection to the electricity network would amount to 35% of the investment in the power system. The calculation was made on the basis of a distance of 10-12 km between the industrial units and the main electric power network. In order to calculate the costs of surplus electricity we discounted the investment made in the cogeneration system used for guaranteeing the industrial unit´s self-sufficiency.

The annual costs of O&M were estimated as being equivalent to 3% of the value of investments in the power system. The cost of the bagasse was estimated at R$22.60/ton of dry biomass (opportunity cost) and the cost of straw was estimated at R$40.70/ton of dry biomass (recovery cost). Constant values were assumed for the entire 2010-2030 timescale. In the case of power systems in the distilleries possessing units for ethanol production by hydrolysis, we took into account the costs of all the straw consumed as a fuel (i.e. the entire cost of the straw was allocated to electricity) but no cost was attributed to the sugarcane bagasse consumed since we assumed that the amounts of bagasse needed to be burnt in future for power generation would be significantly lower than in the existing conventional systems[88].

88 The idea here is that the generation of more surplus electricity causes no increase in the consumption of bagasse compared with the current systems.

b) Systems with extraction and condensation turbines

Cogeneration systems using extraction and condensation turbines are commercially available but their use is very limited in the industrial units that process sugarcane in Brazil in view of the few opportunities available for marketing surplus electricity. In the Low Carbon Scenario, this technology was considered in conjunction with the hypothesis for maximizing the generation and marketing of electricity. The technology would be employed in all the older units to be modernized over the period 2010-2030 and also in the new distilleries that would have incorporated hydrolysis (BIG-CC systems would be installed in some of them).

The cost of constructing a unit with 40 MW of total installed capacity was estimated at 2.526 R$kW in December 2008. This evaluation was done on the basis of specific costs adjusted to a series of real development costs, with values corrected by the IGP-M for December 2008. The effects of associated technical training were not taken into consideration. In the case of the new distilleries the effects of scale were considered since we reckoned that the milling capacity of the plants would tend to increase over the period. In the case of the existing modernized sugar mills the effect of scale was not taken into account since the evaluation was done for a plant with an average milling capacity of 1.6 million tons of sugarcane per harvest. In this situation the investment costs are the same as for all the modernized plants.

It was considered that each distillery would possess two modules of equal capacity (i.e. steam generator, turbine and alternator). It was estimated that the cost of interconnection with the electricity network would amount to 25% of the value of the investment in the case of new distilleries. A distance of 16-18 km was assumed lbetween the industrial unit and the electricity network. In order to calculate the costs of surplus electricity we discounted the investment made in the cogeneration system which guarantees the industrial unit´s self-sufficiency.

The annual costs of O&M were estimated as being equivalent to 2% of the value of investments in the power system. The cost of the bagasse was estimated at R$22.60/ton of dry biomass (opportunity cost) and the cost of straw at R$40.70/ton of dry biomass (recovery cost). Constant values were assumed for the entire 2010-2030 period. We took into account the costs of all the straw consumed as fuel but no cost was attributed to bagasse which would amount to 12% of the total availability (estimated additional consumption over and above the conventional system ensuring electricity self-sufficiency).

c) Systems with biomass gasification (BIGCC)

Systems based on biomass gasification - using combustible gas for feeding a combined cycle gas turbine (CCGT) plant - are not yet commercially available. In the Low Carbon Scenario it was considered that biomass integrated gasification combined cycle (BIGCC) technology would begin to be used as from 2018 and by 2030 it would be installed in a total of 29 industrial units (distilleries) in Brazil.

In our survey we estimated that the BIGCC systems modules would possess a variable capacity of between 80 and 120 MW depending on the milling capacity of the distilleries. Each distillery would have two modules of equal capacity in order to reduce costs and increase reliability. The first unit (a module of 80 MW) to be constructed in 2018 would cost the equivalent of 4500 US $/kW installed. Taking account of the training requirement (*progress ratio* = 0.85) over the years the specific costs were reduced to 1237 US $/W in 2030. The costs of connecting to the transmission grid were estimated as being 25% of the value of the investment in the plant´s power system, assuming a 35 km distance between the industrial units and the main network. In the evaluation of the cost of electricity generated, investment in the conventional system (ensuring electrical self-sufficiency) was discounted.

The O&M costs were estimated at 15.5 US$/MWh for the first module, with a reduction on account of the staff technical training costs. The cost would be 6.8 US $/MWh for the units constructed in 2030. As for biomass, the costs were estimated on the basis of consumption, with the same hypotheses employed as described in the case of the cogeneration systems with extraction and condensation steam turbines.

Table 71 – Hypotheses of the technical-economic analysis (2010 – 2030) (in US$ million)

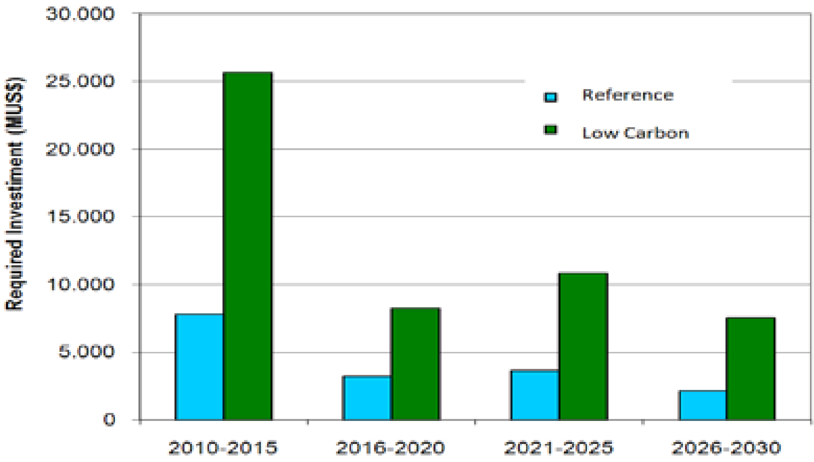
Cumulative	Reference Scenario			Low Carbon Scenario		
Proposal considered	Investment	O&M	Biomass	Investment	O&M	Biomass
Counterpressure	5,193			3,174	95	217
Extraction and condensation	6,465					
- modernized				19,712	394	793
- new distilleries				17,781	368	755
BIG-CC	5,099			11,597	254	169
Total	16,756	716	800	52,264	1,111	1,935

The total investment cost for constructing units for large-scale electricity generation in all the new distilleries, as well as for modernizing the majority of existing plants, amounts to US $52.3 billion over the period 2010-2030 in the Low Carbon Scenario and US $16.8 billion in the Reference Scenario. The difference between the two scenarios amounts to US $35,507,000. Investments in the Low Carbon Scenario include the cost of the interconnection for selling surplus electricity, estimated at around US $10 billion.

The capacity to be installed in the Low Carbon Scenario in the period 2010-2030 would be around 39.5 GW (24 GW in new industrial units), which would result in an average cost of 1,324 US$/kW installed (in the timeframe 2010-2030), including interconnection, or 1,074 US$/kW without the interconnection costs. The average costs are affected by the construction of the BIGCC systems in 29 distilleries, with unit costs varying from 4,500 US$/kW for the first unit up to 1,237 US$kW for the units constructed in 2030. Therefore in 2030 the unit cost of the BIGCC systems would be equivalent to the cost of a conventional steam system with extraction and condensation turbines, but the costs of the electricity generated would also be higher.

The investments schedule is illustrated in Graph 7, in which the required investment costs are presented under four subperiods between 2010 and 2030. The concentration of investments up to 2015 reflects the assumption that the power systems of existing plants will undergo modenization. While the modernization period has been extended over and above the period described in the PNE 2030, the impact is nevertheless substantial.

Graph 7 –Investments required for large-scale electricity generation, by cogeneration, based on sugarcane biomass waste



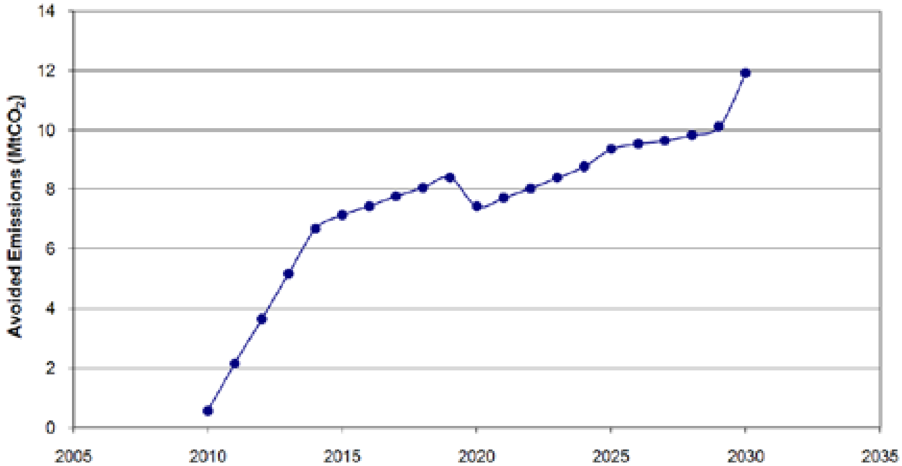
7.2 Potential for reducing emissions and the Marginal Abatement Cost

The avoided emissions of carbon dioxide were calculated on the assumption that the generation of surplus electricity in cogeneration systems based on burning sugarcane biomass waste would offset emissions from other power generation units feeding into the interlinked electricity system in the period 2010-2030. As mentioned above, the assumption is that the generation of electricity in cogeneration does not cause carbon dioxide emissions since the biomass used is renewable and the other GHG emissions are attributed to ethanol (the main product of the activity).

The emissions were calculated on the basis of the generation of surplus electricity in the two scenarios and on the carbon dioxide emission factors involved in operating the national power system estimated for 2010-2030. This estimate was done on the basis of the system being expanded over the period (PNE, 2030) and on typical emission factors related to the various sources and technologies employed in electric energy generation. The emission factors vary from 94 kg CO_2/MWh in 2010-2013 to 69 kg CO_2/MWh in 2020-2029. These factors are very low, based on the hypothesis that the future increased capacity of electric generation will be mainly due to expansion of the hydro generation sector. Note that the emissions of carbon dioxide associated with the operation of the Brazilian electrical system in 2008, when the thermoelectric plants were operating on a fairly regular basis, varied from 384 kg CO_2/MWh (in November 2008) to 625 kgCO_2/MWh (in February) (MCT) 2009).

The total emissions avoided in the period 2010-2030, taking into account the difference between the Low Carbon Scenario and the Reference Scenario, were estimated at 157.9 Mt CO_2, with 7.5 Mt CO_2/year is the annual average for avoided emissions over the period. The ascending pattern of avoided emissions can be seen at Graph 8.

Graph 8 - Emissions avoided between 2010 and 2030. Differences between the Low Carbon Scenario and the Reference Scenario regarding the alternatives for expanding the electrical system (Base: PNE, 2030)



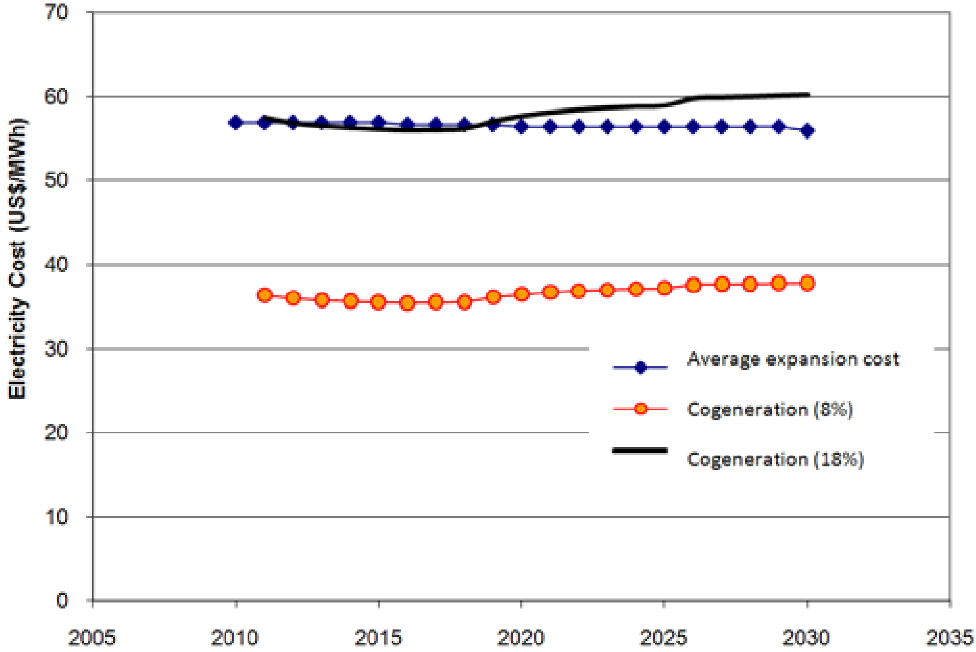
For the Low Carbon Scenario the average abatement cost (in relation to the Reference Scenario) over the period 2010-2030 was estimated at -262.8 US$/t CO_2 at a discount rate of 8% a year. This is the same as the cost of electricity generation over the period (cogeneration with sugarcane biomass vis-à-vis the generation alternatives foreshadowed in PNE 2030) and is allocated totally to the avoided emissions. This effectively amounts to the *marginal abatement cost* associated with cogeneration using sugarcane biomass waste.

As can be seen in Graph 9 below, the cost of cogeneration based on sugarcane biomass waste in the Low Carbon Scenario, at a discount rate of 8% a year, is less than the average cost of expansion foreshadowed in the PNE 2030. This results in negative mitigation costs over the whole period (36.60 US$/MWh as against 56.57 US$/MWh).

With a discount rate of 18% a year, required by the traditional firms in the sugar-alcohol sector for investments in cogeneration[89], the average cost of mitigation is 27.9 US$/t CO_2. With a discount rate of 18% the costs of expansion through cogeneration are higher than the referential costs of expansion of the Brazilian electrical system from 2018 onwards, as illustrated in Graph 9 below (on average 58 US$/MWh against 56.57 US$/MWh).

89 For investments in the *core business* of the sector– i.e. production of sugar and ethanol –the normal discount rate is 15% per year. The expected discount rate is however greater where generation of surplus electricity (which is not the core activity of the sector and which involves a greater perception of risk for potential investors) is concerned.

Graph 9 - Estimate of average cost of electricity generation (PNE, 2030) from cogeneration systems using sugarcane biomass waste (discount rates of 8% and 18% per year).



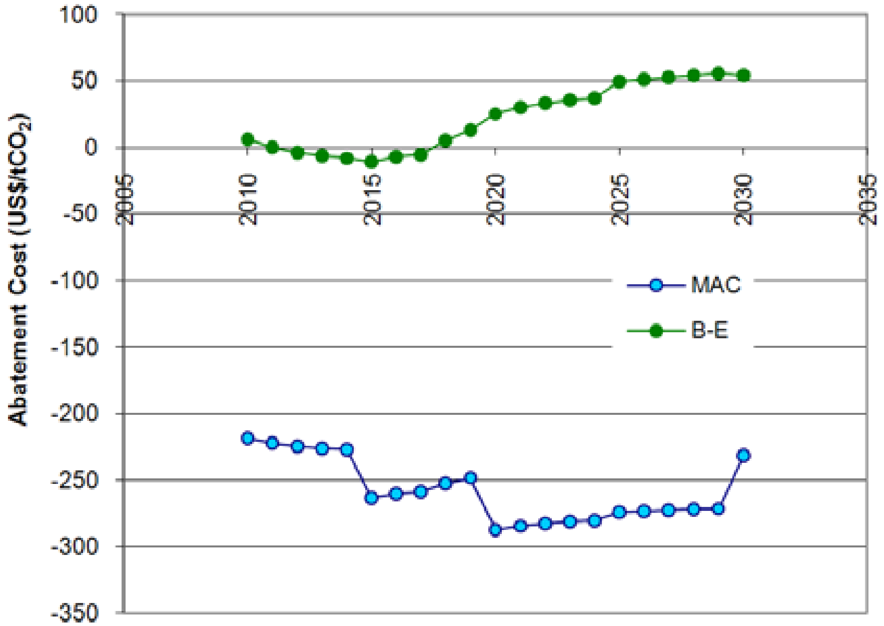
The alternative evaluation of the abatement cost is *the break even carbon price*, which is done for the discount rate expected by the typical investor in electricity generation using cogeneration systems based on sugarcane biomass waste (18%). The value of a ton of carbon dioxide is calculated which enables investors to achieve the hoped-for return on investment in addition to selling surplus electricity at the marginal expansion cost. As for the sale of surplus electricity at marginal expansion cost (average of 56.57 US$/MWh in 2010-2030), the break even carbon price was evaluated as the average cost of mitigation of 34.0 US$/t CO_2. In Table 72 the results of the avoided emissions and the abatement costs of cogeneration based on sugarcane biomass waste are summarized. Graph 10 presents the marginal costs and the *break even carbon price* estimated for the period 2010-2030.

Table 72- Emissions avoided (difference between the Low Carbon Scenario and the Reference Scenario)

Mitigation or sequestering options	Potential for gross reduction in period 2010-30 (tCO_2e)	Average abatement cost over the period ($US\$/tCO_2$) – at discount rate of (8%)[1]	Break-even carbon price ($US\$/tCO_2$)[2]
Emissions avoided	157,901,348	-248.2	34.0

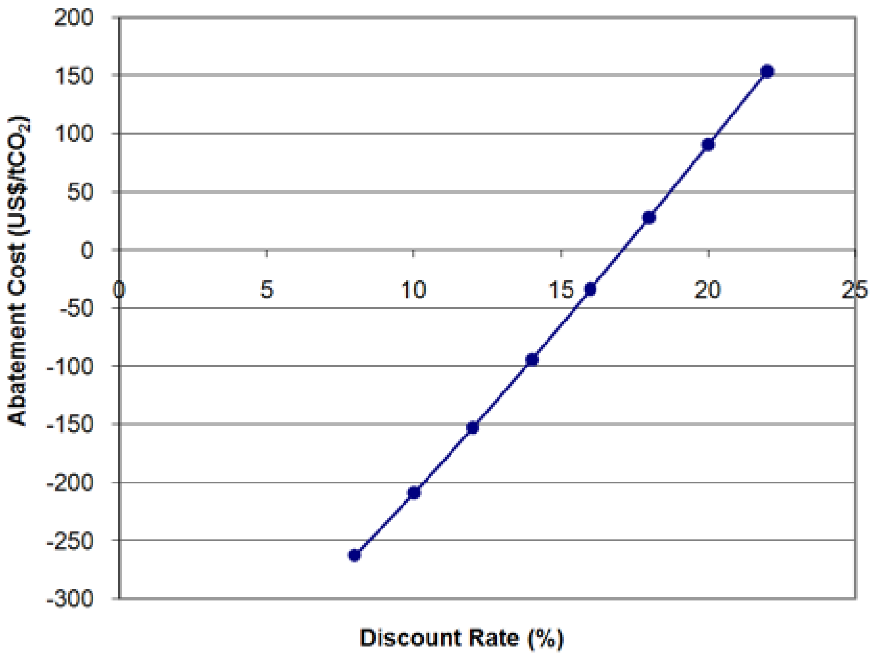
Notes: [1] Value of ton of CO_2 which equals the electricity costs generated from cogeneration with biomass and conventional generation taking into account the expansion foreseen in PNE 2030.
[2] Value of ton of CO_2 which produces return of 18% per year for the investor who generates surplus electricity and sells it at the marginal expansion cost.

Graph 10-Development of the Marginal Abatement Cost (MAC) and Break Even Cost (B-E) in the period 2010-2030 for cogeneration using sugarcane biomass waste.



The abatement cost (US$/$tCO_2$) taking into account the required discount rate is presented in Graph 11. Note that for discount rates of over around 17% the mitigation cost is positive.

Graph 11- Abatement costs of CO_2 emissions as a function of the return on capital expected by investors



7.3 *Barriers to the implementation of low carbon options*

We refer below to a number of barriers which at present make it impossible to generate surplus electricity in cogeneration systems based on biomass waste in accordance with the assumptions of the Low Carbon Scenario. The barriers are listed according to type.

Technological barriers. Among the various technologies considered, the only one that is not commercially available at present is BIGCC. In our study we considered that the first of these units would come on stream in 2018. However this would appear to be fairly improbable given that in order to use this technology substantial investments need to made in R&D (which has not been the case in recent years). Note that while no R&D is being done currently in Brazil the necessary development of the system has been, and will probably continue to be, carried out in other countries. Even if the required technology becomes commercially available by 2018, it is highly improbable that 80 MW modules can be installed within such a short period. On the other hand, even if some BIGCC system came to be built during the period and conventional systems with steam extraction and compensation turbines were constructed in their place, the electricity generation potential will be reduced by at least 10% in 2030 (compared with the estimate in the Low Carbon Scenario). In this event, the average costs of electricity generation will be reduced. However this barrier does not have a significant impact on the results presented here.

A more substantial and restrictive technological barrier concerns the present difficulties encountered in burning sugarcane straw in large quantities. The straw has a different chemical composition from bagasse and the risks of operational problems known as *fouling* and *slagging* are considerable. In the absence of progress over the short term, electricity generation potential could be undermined since in all the systems considered the energy contribution of straw is important. In the specific case of the distilleries that would have, or will have, units producing ethanol by hydrolysis the impossibility of burning straw on a large scale would practically make the technological route based on bagasse unviable. The need for research and development in this area is obvious and initiatives will need to be made almost exclusively by Brazil given that interest in using sugarcane straw as a energy source is not significant in other countries.

Barriers associated with the size of systems. Effects of scale were considered in the evaluation of the investments (and consequently of the costs of electricity generated). If the power systems were to have less capacity than that estimated in the present study, the generating costs will be greater. This would imply a reduction of generation potential as well as the higher costs involved in mitigating carbon dioxide emissions.

We estimate that around 40% of potential electricity generation in 2030 would be produced by existing plants eligible for modernization. Evaluation of the generating costs involved examining a typical plant with a grinding capacity of 1.6 million tons of sugarcane per harvest. In these industrial units, the capacity to be installed amounts to 40MW in systems with extraction and conventional steam turbines. However, in much smaller plants the same technology could probably not be employed since the cost of the electricity generated would be high.

Note that the potential restriction arising from the need to capture water for condensing steam in systems with extraction and conventional steam turbines must also be considered. In certain regions it will not be possible to install this type of technology. As a result the electricity generation potential will be reduced, together with carbon dioxide emissions.

Regulatory barriers. A major barrier to giving concrete expression to the potential estimated in the present paper concerns physical restrictions (e.g. long distances, overloading existing transmission lines, etc) and the high cost of interconnection to the grid. Installation of sugarcane processing plants/distilleries in a given place is not governed by proximity to electricity networks or ease of interconnection, unlike in the case of thermal electric plants driven by fossil fuels (e.g. combustible oils and diesel oil).

An important consideration in this respect is that according to the electricity sector regulations the 'generating' firm is responsible for making the required connections to the main distribution or transmission network. The firms potentially interested in biomass cogeneration systems have identified the following drawbacks with these regulations:

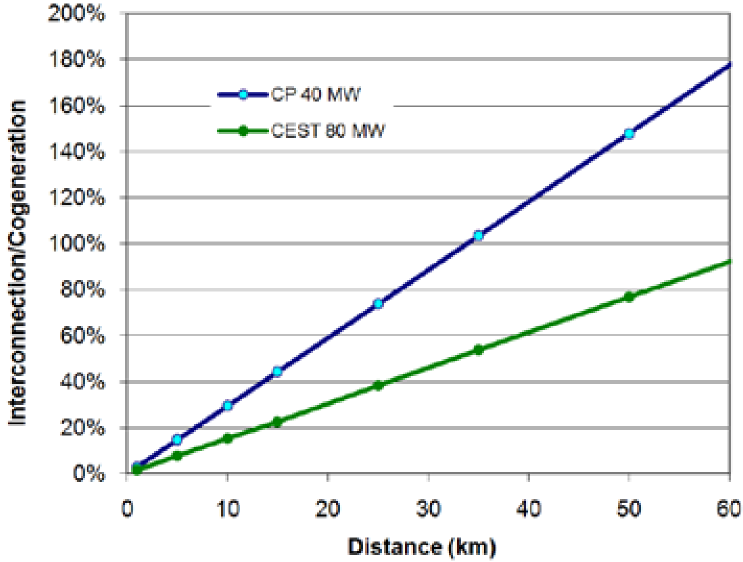
a) The interconnection point is decided by the distributor company, which often alleges technical reasons for placing the interconnection some distance away from the generation source and/or claims that reinforcement work is needed before connection can be effected. Conflicting information means that the generating firm is often ignorant of the measures required to comply with the distributor´s technical and cost demands. This is a classic restriction forced on the distribution system which the present regulatory system has failed to address adequately. Under the present regulatory regime firms engaged in cogeneration are neither properly identified nor provided with fair compensation for the energy produced or in respect of their future capacity. As a partial response to these problems, ANEEL approved by Normative Resolution in December 2008 a new version of PRODIST (*Procedures for Distributing Electrical Energy in the National Electric System*) but to our knowledge the problems mentioned in this report have not yet been resolved.

b) Given that the cost of the interconnection can be substantial compared to the investment in the power system (see Graph 12) this can significantly affect the viability of the investment;

c) The generator firms claim that they are unfamiliar with investments of this kind and that they are obliged to pay more than the electricity companies for similar works;

Graph 12 contains an estimate of the investment cost of interconnection for a cogeneration system using biomass with steam turbines (system with counterpressure, extraction and condensation turbines with generating capacity of 40MW and 80MW respectively). It can be observed from the graph that over a similar distance the smaller the capacity of the system the higher the cost of the connection. Note that in some cases the interconnection costs can be prohibitively expensive for distances of over e.g. 15-35 km.

Graph 12-Percentage of the investment cost for interconnection compared with the investment in a cogeneration system (distance between the generation system and the connection point in km)



Note: Connection of a system with a counterpressure turbine for generating 40 MW and of a system with an extraction and condensation turbine with a generating capacity of 80 MW.

In Brazil the expansion of the sub-transmission network is a non-specific problem for the cogeneration units using biomass - a situation that has existed since the reform of thee electricity sector in the 1990s. Although many years ago the tariffs for using the transmission-distribution system were reduced in the case of *Small Hydroelectric Plants* (PCH) this was not the case with cogeneration systems. More recently, for cogeneration firms producing under 30MW discounts of 50% were conceded for the use of transmission/distribution systems (30 MW is the upper limit of eligibility for systems to be termed PCHs). However this capacity is too low for the installations considered in this report.

For plants that involve generating electricity for distribution in areas where the existing transmission network has low spatial density, as for example in the Center-West of Brazil, the solution found is the construction of "Collector Plants" aimed at reducing the costs of interconnection. Specific studies have already been done on the potential for these plants in the states of Mato Grosso do Sul and Goiás. This would however minimize the above-mentioned problem rather than resolve it definitively.

Given that the production of surplus electricity will not be economically viable in all the plants involving biomass cogeneration, it is vital that whatever regulatory solution is found should be selective i.e. directed towards plants which show greatest potential.

Cultural barriers. The prevailing culture in the Brazilian energy sector in general and in the electricity sector in particular is driven by the priority treatment awarded to hydro generation: in other words harnessing Brazil's still largely untapped hydroelectric potential should be the first priority and that existing hydroelectric capacity is fully used. Despite this overriding concern to boost the attractions of hydo power, auctions have recently been introduced favouring the construction of fossil fuel-fired thermoelectric plants, although it is widely conceded that these would in fact be called on to operate infrequently or not at all (due to high cost and their expected deleterious environmental impact).

Although the potential complementarity between cogeneration based on sugarcane biomass waste and hydro generation could represent a substantial gain, particularly in the Center-South region of the country, the benefits of this kind of two-pronged regime have never been acknowledged in terms of e.g. lower tariffs for the surplus electricity. Furthermore, the continued operation of cogeneration systems is still considered to be unjustified in view of the hypothesis of a sporadic requirement to dump water, while the probable need for burning fossil fuels is fairly readily accepted.

The sugar-alcohol sector is also constrained by cultural barriers. Practitioners in the sector claim that *electricity* generation does not present the same returns on investment as for example *ethanol* and *sugar* production. Because electricity generation is not the core business of this sector, and because the majority of stakeholders are not familiar with the electrical sector, it follows that their perception of risk is much greater. However management in the sugar-alcohol sector is being gradually upgraded and some practitioners in the sector already possess a more enlightened view of the opportunities in the surplus electricity generation business. Given that the heterogeneous sugar-alcohol sector is generally wedded to tradition, the long overdue cultural transformation is likely to be slow. Prospective policies to encourage change in the sector will need to be carefully framed to take account of this.

Barriers concerning access to capital. Specific financing lines provided by BNDES have existed for a number of years targeted at investments in cogeneration systems. Existing lines aim at boosting investments in more efficient power systems in a bid to harness existing potential more effectively. While potential investors continue to criticize the strict BNDES requirements and bureaucratic constraints, shortage of credit cannot be blamed for the few results that have been achieved to date. The potential embedded in cogeneration projects is nevertheless acknowledged by the bank and investors alike as being substantial and it follows that the required amount of investment is very significant. The most pressing need is for the BNDES financing programs to be reformulated in order to ensure that access to capital is not a barrier to further progress.

Financing is also required for investment in interconnection facilities. While financing lines need to aim at cost reduction in this area, regulatory support is needed to ensure that information on e.g. project technical requirements, reference costs etc. is unambiguous and readily available.

7.4 *Existing measures and proposals*

7.4.1 Policies and existing financing mechanisms

a) The National Climate Change Plan

The National Climate Change Plan (Brazil, 2008) outlines the potential for mitigating GHG emissions arising from the production of electricity using sugarcane biomass waste and to the opportunities for selling Reduced Emissions Certificates (CERS) within the context of MDL. However, the PNMC does not contain mention of specific policies or mechanisms to demonstrate the potential advantages of generating electricity from biomass. In practice the report provides no clear recommendations regarding the use of cogeneration with sugarcane biomass waste.

b) PROINFA

In recognition of the potential advantages (including reducing GHG emissions) of generating electricity from alternative renewable sources, a number specific programs have been created. The most important of these is the PROINFA (*Program for Providing Incentives to Alternative Sources of Energy*) created in 2002 (and subsequently modified). This program originally aimed at (i) the installation of 3,300 MW of capacity in production plants which would be brought into operation by the end of 2006, and (ii) the guaranteed purchase of electricity by ELETROBRÁS for a 20 year period. The basic generation capacity was to be distributed equally between wind farms, Small Hydroelectric Plants (PCH) and biomass thermal plants (Agência Brazil, 2008).

In early 2009, of the 144 plants contracted (approximately 3,300 MW total), 70 had not begun operations and works on 30 had not commenced[90]. Of the total capacity contracted under the PROINFA, plants aiming to produce 1,650MW are behind schedule (MME, 2009). The reasons behind the delays include problems with licensing and equipment suppliers, in addition to the low tariffs on offer.

Of the entire capacity contracted, 1,423 MW consists of wind development (456MW in operation at the beginning of 2009 and 325MW under construction). As for PCHs, the capacity contracted was 1,191MW and at the beginning of 2009 775MW were in operation, with a further 405MW under construction. The worst result concerned the biomass thermal plants, since the capacity contracted was well below that expected (685MW contracted). The number of these plants in operation in 2009 accounted for 504 MW, with 66MW under construction [91] (MME, 2009). The biomass thermal plants contracted are mainly cogeneration units powered by sugarcane biomass waste.

In the case of biomass-powered thermal plants the poor start-up rate was mainly due to the low financial returns on electricity marketed given that the basic tariff failed to ensure adequate

90 The deadline for starting operations was 31 December 2008. However according to Law 11.943 of 28 May 2009 this deadline was extended to 30 December 2010.

91 Five contracts are *sub judice* and/or being cancelled, totaling over 100 MW. This capacity will not be brought into service.

expected profitability. In a number of cases the potential developers were reluctant to commit themselves to 20 years at low tariffs in the expectation that perhaps these would increase in due course. It is also alleged that high prices in the equipment market on account of expansion in the sugar sector over the last few years made it impossible to meet the percentage of Brazilian-made components required under PROINFA rules.

In short, from the point of view of boosting electricity generation using renewable alternative sources, PROINFA was relatively successful with regard to wind energy but a disaster in the biomass generation sector. Developers claim that out the outset the returns on biomass-generated electricity were too low to motivate investors.

c) Reserve Energy Auctions

In the regular auctions designed to contract additional capacity for generating electric energy that have been held since December 2005, the amount of bio-electricity (electricity generated from biomass) contracted was minimal, as can be seen in Table 73 (251 MW average contracted since 2005 out of a total of 13.9GW average- i.e. a mere 1.8% of the total).

Table 73 – Results of the auctions for purchasing (new) electric energy expressed in terms of capacity contracted (average MW)

Capacity (MW average)	Auction 1	Auction 2	Auction 3	Auction 4	Auction 5	Auction 6	Auction 7	Total
Year	2005	2006	2006	2007	2007	2008	2008	
Class of auction	A3[1]	A3	A5[2]	A3	A5	A3	A5	
Hydroelectric	1.006	1.028	569	0	715	0	121	3.439
Thermoelectric (others)	2.212	596	474	1.304	1.597	1.076	2.969	10.228
Biomass generation[3]	97	58	61	0	0	0	35	251
Total contracted	3.315	1.682	1.104	1.304	2.312	1.076	3.125	13.918
Biomass/Total	2,9%	3,4%	5,5%	0,0%	0,0%	0,0%	1,1%	1,8%

Notes: [1] A-3, for new plants, with sale foreseen for the third year following the auction .
[2] A-5, for new plants, with the sale foreseen for the fifth year following the auction.
[3] Mainly sugarcane bagasse but also including other biomasses.

It can be seen that expanding generation capacity for the next five years through the 'auctions' procedure has mainly benefited fossil fuel-driven thermal plants, with 73.5% of the capacity contracted in seven regular auctions and 68.4% of the capacity contracted in all the auctions in which biomass generation was effectively represented (including the auctions for 'Alternative Sources' and 'Reserve Energy' (the latter exclusively for bio-electricity). Bearing in mind the non-competitiveness of renewable alternative sources compared with the traditional technologies and sources of electricity generation (principally the oil-fired, diesel-fired and mineral coal-fired plants) the *First Alternative Sources Auction* [92] ('A3') was organized in mid-2008. In this auction 639 MW were contracted, of which 542MW related to biomass-driven thermal plants (396 MW from sugarcane biomass waste). Analysts consider that the result fell far short of the MW capacity expected, given that biomass thermal plants and PCHs capable of producing 1165 MW had registered to participate in the auction.

92 Decree 6.048, of 27 February 2007, provided a regulatory framework for Auctions for Energy from Alternative Sources, paving the way for marketing energy generated by PCHs, wind farms and thermoelectric plants using biomass and biogas.

The most recent strategy has been the organization of Reserve Energy Auctions specified by energy source type. In the case of biomass, at the only auction that has taken place to date (in August 2008), 548 MW average representing the spare capacity of 31 generating units were contracted (30 bagasse plants and one using elephant grass), at an average price of 58.84R$/MWh, for a period of 15 years (CCEE, 2009). The auction also led to the contracting of two plants which would commence generating in 2009 or 2010; in both cases maximum capacity was required to be available within three years (2011 or 2012 respectively).

This auction, which was delayed several times throughout 2008, created unrealistic expectations. Initially the EPE claimed to be able to offer 7, 811 MW in 118 plants (Silvestrin,2008). Subsequently the EPE claimed that 96 plants were technically registered with a total installed capacity of 5,235 MW and a physical guarantee of 2102 MW average. However at the time of the auction 44 companies provided guarantees for generating around 1,160 MW average, with 39 of them being sugarcane plants (*Valor Econômico*, 2008).

The Reserve Energy Auctions in practice involve purchasing a kind of insurance policy to ensure better functioning of a national electricity system which is predominantly hydro-powered[93]. The form of purchase of this 'reserve' energy by the Electric Energy Marketing Chamber (CCEE) is equivalent to the *merchant plant* contracts which enable plants to operate as and when required. In the case of sugarcane plants this occurs during the harvest months with no leeway permitted (i.e. highly inflexible contracts). This kind of inflexible procedure requires the use of systems possessing extraction and condensation turbines in preference to counter pressure turbine systems which could lead to thermodynamic breakdowns and/or losses in the production process of both sugar and ethanol. The inflexibility rule also requires a stock of waste biomass to be kept in reserve or alternative fuel to be on standby. A further problem: the value to be paid to the plants is based upon a practically zero variable unit cost. This would appear to be reasonable in the shorter to middle term but not when opportunity costs arise for the sugarcane biomass waste (e.g. for production of ethanol by hydrolysis from bagasse)[94].

According to the CCEE (2009) the average annual fixed return of the contracted plants amounts to around 1360-1380 R$MW average, or something in the region of 550 R$MW installed, assuming an annual capacity factor of 40%. The database consulted in the course of the present study reveals that this involves a return of 15% a year over 15 years on the total capital invested (including the costs of interconnection) for new plants with 28MW of installed capacity.

In the auctions that have already taken place, in which biomass energy generating plants participated (7 regular auctions plus one targeted at alternative energy sources and one restricted to 'reserve' energy) 939MW average of biomass-related generation were contracted out of a total of 14,652MW average (i.e. 6.4% of the total). Note however that the capacities contracted with biomass plants at the Reserve Energy auction were a significant advance compared with the outcomes of the regular auctions.

The Reserve Energy Auctions were the result of a process of negotiation between the Federal and state governments (e.g. Civil Household, SMA/CETESB in São Paulo), the energy and electricity sector (EPE, ANEEL, the Electrical Energy Marketing Chamber) and practitioners from the sugarcane growing sector. The latter acknowledged the efforts being made to construct an appropriate environment but claimed that the auctions should be carried out on a regular basis in order to provide continuity to the investments. On the other hand, it was admitted that the attractions are that (i) existing plants are eligible to bid at auctions provided they are modernized; (ii) a

93 Given that this is a kind of insurance for ensuring the operations of the electricity system all consumers will foot the bill.

94 At the time of giving the go-ahead to the Reserve Energy Auction Maurício Tolmasquim, president of EPE, affirmed that electricity generated by sugarcane biomass and marketed in these conditions could greatly reduce the price of electricity on the spot market (basically defined by the variable costs of the last plant to start operations) (*Agência Brasil*, 14/08/2008).

fixed revenue is guaranteed for 15 years; and (iii) plant owners can sell energy in the open market[95]. The barriers obstructing the award of preliminary licenses and permits for water capture were resolved in the state of São Paulo by SMA/CETESB adopting simplified procedures.

An important question is to ask to what extent the total potential will fail to be harnessed as the result of systematically adopting the Reserve Energy Auctions procedure, given that the inflexible nature of the entire operation (involving contracted generation capacity) could significantly inhibit progress on expanding the generation system.

d) Cogeneration rating

The success of cogeneration in the United States, which began between the end of the 1970s and the first half of the 1980s, is to a great extent attributed to the rating of cogeneration plants which led to easier access to credit, tax exemptions, guaranteed sales of electricity etc. The rating procedures required a number of conditions to be fulfilled such as the existence of a minimum ratio between thermal and electrical energy produced (to avoid the benefits being attributed to thermoelectric plants), minimum standards of efficiency (from the thermodynamic point of view) and the majority ownership of plants by independent producers.

In Brazil, the idea of rating cogeneration plants was put on the agenda with a view to reproducing the US successful experience. The rating procedure was given regulatory status in 2000 in Brazil. The first experience with rating was a disaster because of (i) the unnecessarily strict requirements demanded under the rating instrument´s rules; and (ii) the incentives offered to potentially 'rated' co-generators were ineffectual and failed to provide sufficient motivation.

In November 2006 ANEEL modified the regulatory measure. Since then the biomass-driven cogeneration units are automatically rated [96]. This has reduced the number of restrictions on biomass cogeneration but questions are still being raised about the limited benefits of the whole issue of so-called "cogeneration incentive policies".

7.4.2 Measures for overcoming barriers

The text in this section is based on suggestions presented by the representative of UNICA who has dealt specifically with the interests of the members of the association regarding cogeneration using sugarcane biomass waste[97]. Four main aspects are described below: connection, marketing, financing and regulation. The author's observations are presented immediately after the comments and/or the claims made by the UNICA representative.

a) Connection

The current position of the majority of the sugarcane growing sector players is not to cast doubt on the regulatory measure which determines that interconnection costs should be assumed by the plant requiring access to the grid (in this case the 'co-generator'). The main problem is that these costs can be extremely high and that the sale of the electricity generated should provide a suitable return on investment. Specific lines of credit are required to incur this scale of investment.

95 Such plants could be much more competitive in the free market since, as the fixed cost has already been amortized, only the variable costs would need to be remunerated and the variable cost would be very low over the short to medium term.

96 According to article 8 of the ANEEL Normative Resolution 235 of 2006: " The thermoelectric plants which exclusively employed biomass as a primary source of do not need rating in order to benefit from the provisions of the legislation, providing the respective conditions are applied."

97 Souza, ZJ (2009): *The importance of bioelectricity for the sugarcane industry*. Presentation at the Ethanol Summit on 18 June 2009.

The above aspects are particularly pertinent. Firstly, the question of lines of credit specifically targeted at investments in interconnection provides an opportunity to suggest cost reductions and greater symmetry of information: in this respect the electrical sector (e.g. the ONS) should be obliged to calculate and disseminate reference costs for the interconnection of cogeneration plants with the grid. The financing projects would need to be carefully analyzed by the financial agent(s) in the light of these reference costs.

A second important aspect is that the new distilleries, which are likely to be subject to higher interconnection costs, should have their localization correctly defined in order to take into account a variety of key factors, including the cost of delivering surplus electricity. Policies and regulations need to be elaborated to ensure that (i) the expansion of the distilleries is undertaken from a 'locational' point of view; (ii) any environmental impacts are minimized (e.g. change of land use); (iii) the units are planned to optimize electricity generating potential; and (iv) the expansion of sugar growing activity is closely watched so that the requirements for constructing 'Shared Electrical Connection Installations' can be identified and dealt with in advance.

b) Marketing of surplus electricity

The first issue is a demand for specific and regular auctions for energy sources. The second is that the prices in the auctions according to the ACR (*Regulated Marketing Environment*) should reflect the so-called positive externalities of electricity generation produced from biomass (e.g. the higher generating capacity during the hydraulically unfavorable period and the nil/low emissions of CO_2).

An important aspect of these two questions is that the current vicious circle needs to be broken. On the one hand, participation in auctions for sugarcane biomass waste cogeneration is weak because the reference values are too low. On the other hand, since participation is weak the organizers probably calculate that no call exists for more 'specific' targeted auctions. The need for more attractive prices also calls for a change in the present paradigm of the Brazilian electric sector, given that to date encouragement for renewable sources of energy leading to reduced CO_2 emissions in the entire sphere of electricity generation has been more rhetorical than practical. In this sense, rating the cost of avoided emissions in the present study can serve for putting a price on one of the positive externalities.

Marketing of surplus electricity generated by cogeneration from sugarcane biomass waste under the ACL (*Free Marketing Environment*), still a novelty in the sugar growing sector, needs to find its way onto the sugarcane industry´s agenda.

c) Financing

In addition to the above-mentioned aspect (financing investments in interconnection) the sugar growing sector requires specific and regular lines of credit to help implement more efficient technology for generating electricity.

An adequate supply of credit is essential to the success of programs devoted to encouraging the expansion of energy sources and related technologies. Credit procedures need to be simplified and genuinely helpful financial assistance should be offered to appropriately rated cogeneration businesses.

One of the questions to be analyzed is whether the 'cogeneration investments' in the case of new enterprises should be packaged together with the financing of industrial plants and investments at the 'agricultural' stage of the cane growing operation. It is important to to provide financial underpinning for businesses which have produced overarching positive externalities.

d) Regulatory aspects

Brazil's electrical sector was and remains conceived and managed with a focus on hydroelectric generation. The sugarcane sector is pressing for more attention to be given to generation alternatives such as bio-electricity.

As already noted in this report, the logic of the electric sector is the prioritization of hydroelectricity generation, which is understandable (and even justifiable) given the still untapped potential and the Brazil´s notable technological expertise in constructing hydro plants. However the sector needs to adapt its approach since the construction of new hydroelectric plants tends to be expensive and increasingly fraught with difficulties.

On the other hand this kind of adjustment also needs to be made in the sugar growing sector which is known to be relatively conservative and reluctant to adopt modern management techniques and encourage technological innovation. Specifically in the area of electricity generation from sugarcane biomass waste we also need to seek a new paradigm, possibly involving participation by new business players with a greater understanding of the electricity sector, more informed risk perceptions and a forward view of opportunities for expanding and diversifying the activity. In theory at least, a more flexible approach could produce electrical energy cogenerator-distributor partnerships.

The sugar growing sector reckons that in less than a decade electricity could be much more important than sugar for several firms operating in the sector. For this to happen it is necessary that the above mentioned set of problems is duly addressed. It is also vital that the sector should understand that the future sugar industry cannot remain a "food" industry but, probably simultaneously, an "energy/chemical" industry. It is clear that different strategies and attitudes are needed.

Finally, with respect to boosting the investments needed for developing the sector it is worth remembering that throughout the world programs targeted on cogeneration have been successful in cases where incentive packages have been offered to investors (e.g. the USA during the 1970s and 1980s and Spain in the 1980s and 1990s). In this way clear advantages were identified and risk perceptions significantly attenuated. The potential barriers need to be confronted simultaneously. Piecemeal programs have not proved to be effective. On the contrary these tend to act as a disincentive to the agents involved.

8 Energy Supply - Electricity Production Sector: Wind Energy

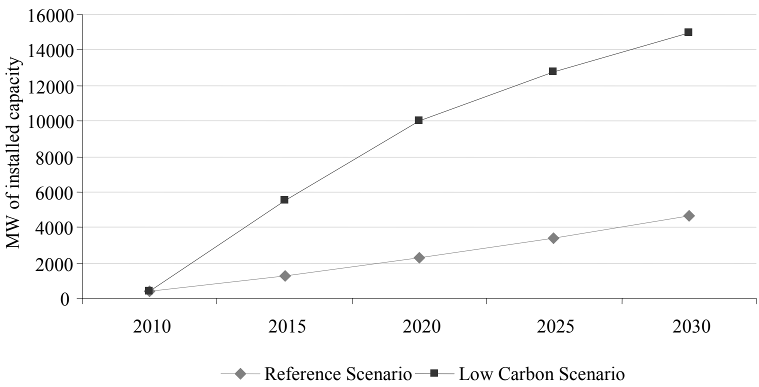
8.1 Mitigation Options

According to Granovskii, Dincer and Rosen (2007), substituting natural gas and the fuels used for producing electrical energy by renewable sources such as wind and solar energy is likely to produce a significant reduction in greenhouse gas emissions. In Brazil's case the introduction of wind energy into the national electricity generation system has the potential to reduce the geopolitical risks associated with importing natural gas.

Despite the substantial wind potential and the benefits of using this renewable energy source in Brazil, the amount of wind energy generated in the country is marginal: it is basically used for complementing the Brazilian electrical system in places where favorable winds blow at times of low rainfall.

Increasing the total supply of wind energy in Brazil up to 2030 (in addition to that proposed in the National Energy Plan, 2030) was considered in the Low Carbon Scenario as an option for encouraging the development of wind power in Brazil and maximizing its contribution to the reduction of greenhouse gas emissions. Projections for the supply of wind energy in the PNE 2030 forecasts an expansion of 4.7GW power up to 2030. Based on the wind potential estimated at 143.5GW by the *Brazilian Wind Energy Potential Atlas* the Low Carbon Scenario proposes an accumulated expansion of 15.0GW up to 2030 - in other words, an increase of 10.3GW of wind energy supply up to 2030 between the reference and low carbon scenarios. The choice of 15.0GW by 2030 was based on the proposal put forward by the Brazilian Wind Energy Association (ABEEólica) in its *10 -10 Program* aimed at promoting installation of 10GW of wind capacity within a period of 10 years (*Noticias ABEEólica*, 2009). The 5GW remaining up to 2030 would represent an increase with a reducing return of investment of the sector, as illustrated in Graph 13.

Graph 13 - Forecast for installed wind capacity up to 2030: Reference and Low Carbon Scenarios



The increase in the supply of wind energy in the Brazilian electrical system will contribute zero emissions of CO_2 to the atmosphere. The substitution of primary fossil sources for generating electricity such as mineral coal or natural gas for wind energy can avoid emissions of approximately 1,800 and 2,900 tons of CO_2 per day [98] respectively (Carvalho and Sauer, 2009).

8.2 Potential for reducing emissions and Marginal Abatement Cost

Unlike the sources of fossil energy, the process involving generating wind energy does not emit CO_2e into the atmosphere. Each unit of wind energy produced is substituted by the same unit of fossil fuels for the production of electricity and counts as "avoided" (or negative) emissions of $CO_2$2 equivalent.

According to the results presented in Table 74, the total investment cost in the Low Carbon Scenario would be US$8.6 billion in 2030 (current value in 2009). This estimated value was based on the average costs of expansion of a medium to large wind farm (see Table 4 below). The investment costs were reduced with the increase of turbine production, with a learning rate of 10% between 2010 and 2030 and the expected technological advances in the sector, benefits of scale and lower costs of the aerogenerator components. To estimate the cost of operation and maintenance (O&M) of a wind farm installation we assumed a value of US$10/MWh considering that a wind farm functions with a capacity factor of 25%. The O&M costs include insurance, land rental, regular maintenance, administration, spare parts and other administrative costs.

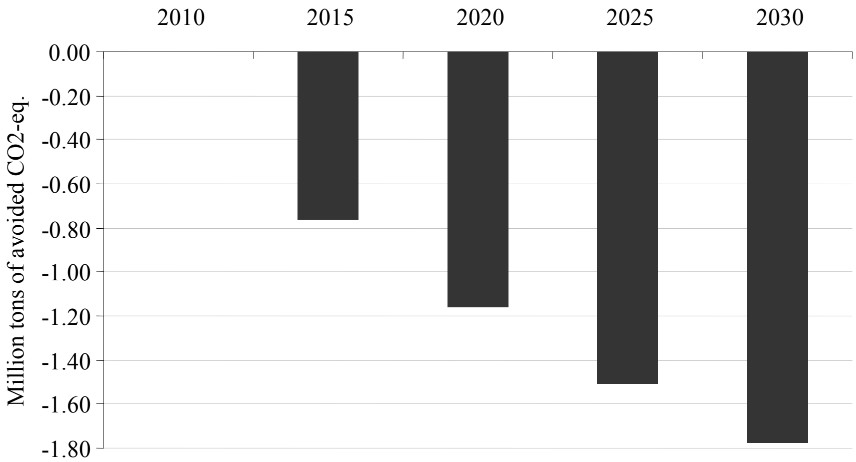
Table 74 - Overview: Low Carbon Scenario (accumulated values)

Low Carbon Scenario	2010	2015	2020	2025	2030
Average cost of expansion per year (US$/MW)	1,500,000	1,140,430	1,072,252	1,045,066	1,02,687
Installed capacity (accumulated values) (MW)	405.5	5,550	10,000	12,780	15,000
Current cost value (US$ million in 2009)	0.00	4,458	6,978	8,020	8,565
Sale of electricity (GWh)	888	36,914	127,623	256,603	410,884
Current value of revenue (US$ million in 2009)	90	887	1.989	2,897	4,347
CO_2e emissions (millions of tons of CO_2e)	0.00	0.00	0.00	0.00	0.00

Through using the investment cost and emission reductions model, it was possible to establish year to year estimates of the gross emission reduction potential by substituting the energy sources projected in the PNE 2030, the Reference Scenario, for wind energy in the Low Carbon Scenario. Graph 14 illustrates the gross emission reduction potential for each five year interval in the Low Carbon Scenario. The quantity of emissions accumulated between 2010 and 2030 for the Reference Scenario is 19.3 million CO_2e, reduced to zero emissions in the Low Carbon Scenario. Therefore, the gross emission reduction potential is 19.3 million CO_2e.

98 Assuming a mineral coke-driven electricity generation plant with an operating capacity of 350 MW and with a capacity factor of 50% and a plant using natural gas operating with a capacity factor of a 80%.

Graph 14 – Gross Emission Reduction Potential (CO2e)



Source: Theme M Report

According to the results of the cost model, the contribution by the wind sector to reducing CO_2 emissions is expressed by the gross accumulated potential of 19.3 million tons of CO_2e between the years 2010 and 2030. This potential represents an average abatement cost during the period of -7.6 US$/t CO_2, considering a discount rate of 8% a year. If the sectoral discount rate of 15% were adopted, the *break even carbon price* would be 98.5 US $/ CO_2 (Table 75).

Table 75 - Avoided emissions of CO_2-eq and abatement costs

Potential for gross reduction between 2010-30 ($MtCO_{2}$-eq.)	Cost of average abatement (US$/$tCO_2$) Discount rate of 8% per annum	Break-Even Carbon Price (US$/$tCO_2$) Sectoral discount rate 15% per annum
19.3	-7.6	98.5

8.3 Barriers to implementing low carbon options

At present the barriers and impediments for implementing the Low Carbon Scenario are of a market-related, technological, regulatory and financial nature.

8.3.1 Market related barriers

The competitivity of wind production as a primary source of electric energy is undermined by the high cost of generating electricity from this source compared with other non-hydroelectric sources, even in critical hydrological conditions. The average cost of generating electricity in wind farms is 75 US$/MWh, while the average cost for generating the second most expensive option (imported mineral coal) is 56.8 US $/MWh. (Table 76). The high cost of wind-generated electricity is due to the low economy of scale and the need to use imported equipment.

Table 76- Average cost of electricity generation (US $/MWh)

	Hydrological conditions	
Generation source	Critical	Average
Natural gas	56.4	40.4
Brazilian coal	44.4	40.5
Imported coal	56.8	49.3
Nuclear	51.8	50,1
Urban waste[1]	22.0	22.0
Sugarcane biomass[1]	23.0	23.0
PCH	36.0	36,0
Wind farms	75.0	75.0

Source: EPE, 2007

[1] Excluding costs of fuel

8.3.2 Regulatory barriers

During its first phase, PROINFA boosted the development of the Brazilian wind sector. Between 2006 and 2009 the wind sector increased from 10 to 33 wind farms, with an increase in the installed capacity from 28.5MW to 415MW. However, according to Dutra and Szklo (2008), the reforms in the electrical sector in Brazil in 2003 affected the second phase of PROINFA. This reform placed special emphasis on the use of public 'reserve' energy auctions in order to control excessive increases in electrical energy charges. These auctions were structured with a view to ensuring that the three renewable sources of energy (wind, PCH and biomass) would compete among themselves. In reality this practice tends to penalize the option of generating energy with the highest production costs (i.e. the case of wind energy). In order to overcome this basically market-related barrier, the Ministry of Mines and Energy published in February 2009 a proposal to design specific auctions for wind energy where the modality for contracting wind energy would have a decisive influence on return on investment risk perception ('*Proposal for expanding wind generation in Brazil'*, MME, 2009).

A further problem faced by the wind sector is the high cost of equipment. The requirement to use equipment made in Brazil (70%) has proved to be a bottleneck, given that few manufacturers of wind equipment currently exist in Brazil and the greater part of local production is for export. However to purchase equipment in Brazil, apart from paying a high price, investors normally experience long delivery delays. In principle these cirmstances should provide an incentive for developing Brazil's aerogenerator and related equipment industry, but in reality wind equipment projects financed by PROINFA have also suffered delays. The result is that much of the equipment installed in Brazil´s wind farms is imported.

8.3.3 Technological barriers

According to Jannuzzi (2003), the technology for generating wind power is relatively well-developed as a result of investments made in R&D and policies directed to opening markets in countries such as Germany, Denmark, the United States and, more recently, Spain. At present research institutions exist in Brazil which study the potential for wind power and experiment with technological innovations for wind farm components. These institutions include the

Brazilian Center for Wind Energy (CBEE), the Reference Center for Solar and Wind Energy (CRESESB) and the Studies and Development of Energy Alternatives Group (GEDAE-UFPA). In short, it is clear that improved technology and more investment in R&D by the public and private sectors in the wind sector are needed for reducing costs and improving the efficiency of wind energy as a viable source.

8.3.4 Financing barriers

BNDES provides financing through PROINFA for investors interested in the wind sector. However the associated loan contracts require investors to assume a minimum of 30% of the total initial investment value for implementing a project. The initial cost is considered to be high compared with the investment schedule.

8.4 Existing and proposed measures

At present the most attractive incentive for promoting the development of wind energy in Brazil is the *Program for Providing Incentives for Alternative Sources* (PROINFA) established by Law Number 10.438 of April 2002. This program was planned in two separate phases. The first phase of PROINFA concerns promoting the installation by 2008 of 3300 MW of interlinked electric power, to include 1300 MW produced by wind farms, 1192 MW from small hydroelectric plants (PCH) and 685MW from biomass (National Energy Plan 2030, 2008). The idea of the program is to provide incentives for independent and autonomous producers with businesses that cannot be controlled by, or associated with, any generating, transmission or distribution concessionaire to generate wind electricity. Purchasing the energy produced from these sources is guaranteed by ELETROBRÁS for a period of 20 years at a tariff fixed by the Ministry of Mines and Energy. According to the PNE 2030, the producers that are unable to meet this requirement can participate in the program providing that their portion of the contract is less than 25% (50% for producers using wind energy during the first phase of the program) and that no autonomous producer would be disqualified as a result. The Federal government still insists on wind farm equipment being 70% Brazilian manufactured.

As part of the program there will be for tender for each of the different types of energy, with priority given to the plants that have already obtained *Environmental Installation Licenses* (EIL), followed by the plants that possess a *Prior Environmental License* (PEL). In the event of excess capacity offered, the plants with environmental licenses that will expire soonest will be chosen.

The second phase of PROINFA foreshadows that electricity production from wind energy, PCH and biomass should make up 10% of Brazil's electric energy in the period between 2008 and 2022 (Ruiz, Rodriguez and Bermann, 2007). The PROINFA contracts are to be administered by ELETROBRÁS, with a duration of 20 years and with a price equivalent to the economic value corresponding to the generation of competitive energy, defined as the average weighted cost of generation of new hydraulic installations of over 30,000 KW and natural gas-powered thermoelectric plants, calculated by the government.

As for financing, the Program for Financial Support for Investments in Alternative Sources of Electric Energy under the aegis of PROINFA was created by the BNDES in March 2004 with an allocation of R$5.5 billion for financing projects to be contracted by 30 December 2006. According to ELETROBRÁS, the total investment earmarked for PROINFA is of the order of R$10.14 billion, with borrowings amounting to around R$ 7 billion.

A further source of financing for wind-related projects and associated works is the Growth Acceleration Program (PAC) launched in January 2007 by the Federal Government. In the area of electrical energy generation, investments of around R$59 billion are foreshadowed in a bid to guarantee the country's supply of electric power. It should be emphasized that these investments include those supplied under the aegis of PROINFA, plus an additional R$11 billion to be invested by the private sector.

Given that the wind energy occupies a small share of the electrical energy market in Brazil, an appropriate set of public policies and financing sources could drive development of the Brazilian wind sector beyond the scenario proposed by the PNE 2030 and increase the contribution by the sector to the mitigation of GHG emissions. The following are a number of public policy options and proposals for financing which might help to overcome the barriers and impediments identified above.

- *Specific auctions for purchase of wind energy*. Auctions are an effective instrument for developing the sector by guaranteeing the financial stability of the wind farms on the basis of long-term contracts with pre-fixed rates. Moreover, auctions encourage competition between the producers of wind energy and stimulate price reductions;
- *To reduce the "national" component in wind-related equipment* from 70% to 50%. As already discussed, one of the main drawbacks affecting the total cost of investment in wind projects is the high price of equipment. This equipment is supplied by a limited number of local suppliers and supplemented by imported equipment. The low level of wind production in Brazil does not provide incentives for new equipment manufacturers to compete in the market. The lack of competition between local suppliers and the high rates of tax levied on the equipment are the main reasons for the high cost of wind farm equipment.
- *To lower tariffs on imported components* for wind turbines (lower than the import taxes on entire turbines). While lowering the Brazilian-made component of equipment could help to reduce the costs of wind farms this could also serve as a disincentive to further development of the local wind farm equipment sector. One way of creating incentives for local industry would be through modifying the import taxes to favor turbine components over whole turbines. This would create a favourable market for local turbine manufacturing or assembly companies (including foreign firms manufacturing in Brazil) given that they would pay lower tariffs than those applied to turbines manufactured wholly abroad. The costs and effects of both measures need to be studied in greater depth.
- *To provide subsidies to assist with the cost of connections to the public electricity grid*. One alternative for providing incentives to, and reducing the costs of, investing in wind projects would be to make financial assistance available for assisting with connection of the energy produced in the wind farms to the public electricity grid. At present this cost falls on the investor or plant owner. Note that the different costs of connection, often depending on geographical location of separate wind farms can cause a degree of competitive distortion in the reserve energy auctions.
- *To offer carbon credit incentives*. The international carbon market could be a significant attraction for stakeholders in Brazil´s wind energy sector. Brazil possesses significant potential for issuing mitigation and sequestration certificates which can be traded on the international market. In the international carbon market the term for CO_2 credit is 21 years and the price per ton of CO_2 avoided is €15. A further option would be to develop projects through the *Clean Development Mechanism* (MDL) with a view to receiving dividends in the form of carbon credits.
- *To provide resources for research and development (R&D)*. Public and private investments in research and development programs could contribute significantly to developing specific equipment for the wind sector in Brazil as well as to improving the

efficiency and consolidation of data on wind energy potential, drawing attention to opportunities for mitigating CO_2 emissions and presenting proposals for linking up the wind farms to the national electricity energy sector (Jannuzzi, 2003).

Table 77 – Summary of policies proposed for deploying the Low Carbon Scenario

Proposed policy	Category	Type of instrument	Funding source	Sources of financing
To hold auctions specifically for the wind energy sector	Rectification	Regulation	Federal	Federal
To reduce compulsory national component in equipment from 70% to 50%	Rectification	Regulation	Federal	Federal
To lower taxes on imported turbine components to less than the taxes on complete imported turbines	Incremental	Regulation	Federal	Federal
To provide subsidies for the costs involved in connection to the public electricity network	Rectification, incremental	Program	Federal, state	Federal, state
To offer carbon credit incentives	Incremental	Law, Program, Regulation	Federal	Federal, market
To offer R& D funds	Incremental	Law, Programs	Federal	Federal, market

9 Additional Options for Mitigation-Substitution by Biomass: Ethanol

We considered two additional mitigation options which would assist reduction of carbon dioxide emissions from the energy sector in other countries (with implementation costs incurred in Brazil). One option concerns using the transmission lines connecting hydroelectric plants in the north of Brazil with plants in Venezuela in order to take advantage of the 'river basin complementarity' existing in that region. The second option would be to increase ethanol exports to a level of 85 billion liters in 2030, in other words 72 billion liters more than the amount considered in the PNE 2030 Reference Scenario.

9.1 Mitigation option

One of the most important options for mitigating or sequestering GHG indicated in the National Climate Change Plan is to substitute fossil fuels by renewable energy sources, given that the transport sector in Brazil is the principal emitter of CO_2 equivalent of all the activities that are not related to burnings and land use change. Since the Reference Scenario already foreshadows a significant increase in the use of ethanol for the Brazilian vehicle fleet, it is difficult to increase this forecast of fossil based fuel in the translport sector without causing negative impacts on the already distorted profile of our refineries. Brazil is increasing its efforts both at government level and in the ethanol producing sector to create a significant international market for ethanol and other biofuels, taking advantage of its high level of competitivity in this area and benefiting from the long-term sustainability for ethanol production from sugarcane. The LCCS project therefore selected the option of exporting large quantities of ethanol in order to replace part of the gasoline consumption in other countries. Despite the fact that this is not a direct mitigation/ sequestering of GHG emissions in Brazil it is nevertheless a powerful and efficient way of reducing global emissions of GHG. Exporting ethanol also contributes to the development of the country in terms of the significant socio-economic impact of this agro-industrial activity.

a) Technical description

A recent study by the *UNICAMP Interdisciplinary Nucleus for Energy Planning* (NIPE / UNICAMP showed that Brazil possesses excellent capacity to produce volumes of ethanol for export over the medium to long-term. We established a scenario in our study in which Brazil would reach 2025 producing ethanol for export amounting to 205 billion liters a year. This amount would involve substituting 10% of the world´s total gasoline consumption forecast for 2025. Our scenario also included an estimate of sugar production for both the internal and external markets.

The NIPE study demonstrated that Brazil has the capacity to reach this scenario in terms of availability of land suitable for sugarcane production, investment capacity for the required amount and the possibility of improving and expanding storage and transport infrastructure to cope with the estimated demand. The study however was not restricted to examining the potential of the external market for absorbing this quantity of export ethanol. For the export targets established the paper produced by Walter et al.(2008) was used as a reference. This paper contained a detailed analysis of the potential for growth of the use of ethanol fuel in the main gasoline consumer countries throughout the world, based on targets and legislation covering the obligatory use of biofuels. Two scenarios were constructed: in *Scenario 1* the volume of gasoline to be displaced in 2030 was 10% of forecast consumption and in *Scenario 2* the percentage of gasoline forecast to be economized in 2030 rose to 20%, amounting to an ethanol consumption of 272 billion liters and 566 billion liters respectively. Taking into account

Brazil's capacity for producing first-generation ethanol (NIPE study) and the countries with the greatest potential of large-scale production, it was assumed that a target for Brazilian ethanol exportation of 69 billion liters was reasonable. This amount would amount to around 25% of that forecast in Scenario 1 estimated by Walter et al. (2008) or approximately 2.5% of projected world demand for gasoline (in Scenario 2: 12% of world ethanol demand and 2.5% of gasoline economized). The Low Carbon Scenario proposed is summarized in Table 78.

Table 78 - Low Carbon Scenario

	2010	2015	2020	2025	2030
Cane for sugar (Mt)	277.3	301.6	315.2	337.5	362.2
Cane for ethanol (Mt)	406.0	595.2	823.4	1,136.7	1,369.1
Total production of sugarcane (Mt)	683.3	896.8	1,138.6	1,474.2	1,731.3
Conventional ethanol (ML)	34,408	51,900	73,866	104,913	130,009
Ethanol from hydrolysis (ML)	130	1,276	4,503	8,959	17,337
Total ethanol (ML)	34,538	53,176	78,369	113,872	147,346
Ethanol exported (ML)	8,760	22,124	38,846	58,261	69,668
Total sugar (Mt)	38,196	42,733	45,953	50,616	55,585
Productivity of sugarcane (t/ha)	81.8	86.5	91.3	95.9	100.3
Área of cane for ethanol and sugar (Mha)	8.35	10.37	12.47	15.37	17.26

It is possible to verify that there will be a substantial increase in ethanol and sugarcane production by comparison with the Reference Scenario (Table 25) basically due to greater demand for exported ethanol, given that the total production of sugar and ethanol for domestic consumption is equal in the two scenarios. The area needed for sugarcane cultivation would be 17 million hectares in 2030, amounting to little more than the area planted with corn and less than the area planted with soyabean at present. This would be perfectly compatible with the results of the NIPE study and with the 'Agroecological Zoning' for sugarcane. The production of ethanol by hydrolysis was adjusted to show an increase more in line with world expectations, especially those of the International Energy Agency (IEA).

In the Reference Scenario the EPE has made a highly modest projection for ethanol exports: 13.1 billion liters in 2030 - or scarcely 8 billion liters more than was exported in 2008.

The impact of reducing emissions by displacing gasoline with ethanol in the volumes suggested in the Low Carbon Scenario is significant even when considering very conservative hypotheses such as those employed here. It is worth emphasizing the use of the substitution factor of 1 liter of ethanol for 0.66 liters of gasoline, which is the amount recommended by the European Union (EU), but it should be born in mind that this does not correspond to Brazil's experience with using a mixture of ethanol/gasoline, nor the tests undertaken in other countries such as the USA (USDOE, 2005). A more appropriate value, albeit still conservative, would be 1 liter of ethanol for 0.80 liters of gasoline, as suggested by Macedo et al (2008), which would greatly reduce the cost of mitigation referred to below. With mixtures of up to 10% anhydric ethanol in gasoline the experience of both Brazil and the United States has indicated an equivalence of 1 liter of anhydric ethanol to 1 liter of gasoline.

Sugarcane ethanol is acknowledged as the biofuel with the best energy balance (the ratio between renewable energy of products and the fossil energy consumed in the productive chain) and with the best potential for reducing GHG emissions when substituting transport fossil fuels such as gasoline. Given the conservative assumptions of the present report, the emissions of the whole productive chain of ethanol are included, together with the emissions resulting from transporting the product from the producer plants in Brazil to the appropriate plants abroad, the potential for abating emissions would be between 1.2 to 1.3kg CO_2e/liter of ethanol during the scenario time frame. If the more reasonable substitution factor of 1.2 liters of ethanol per liter of gasoline were used, this value would increase to between 1.6 and 1.7kg CO_2e/liter. The emissions due to variation of the stock of soil carbon are not considered here. A very significant potential for improving these properties of ethanol for abating emissions by reducing GHG emissions in the productive chain and the better yields of co-products, mainly from the recovery and use of sugarcane straw (generation of surplus electrical energy) is considered, as well as the intensive use of direct planting, improvements in the collection system and mechanized planting/harvesting, optimizing fertilizer use and a series of new upgraded irrigation techniques. Using genetically modified sugarcane could produce a series of economic and environmental benefits such as significant productivity gains, better use of fertilizers and herbicides, resistance to disease, infestations and hydric stress. Among the negative effects of expanding ethanol production for export, the possible competition with food production must be mentioned, as well as the possible negative impacts on biodiversity and the environment. These effects will be greatly minimized when the Agroecological Zoning of sugarcane recently submitted to the government for approval comes into effect (every effort has been made in this to minimize negative impacts). It is important to reiterate that the area under sugarcane cultivation, according to the forecast in the Low Carbon Scenario, will be only 17 million hectares in 2030, or 6.5 million hectares more than the Reference Scenario. The positive socio-economic impacts will be substantial enough to justify this project as an important item in the national development agenda.

b) Assumptions and variables considered

i) Evolution of the area planted and the productivity levels of sugarcane, ethanol and sugar

The criteria adopted by ICONE (*Modeling Soils - Competition between the Agricultural, Livestock and Silviculture Activities*) were used in this study to simulate the growth of sugarcane production together with the other crops considered by the LULCUF study. Production data for sugar and ethanol were compared with the total production scenarios of sugarcane developed by the ICONE, which took into account the use of cane for other purposes ('rapadura', 'cachaça' and animal feed) in addition to the demand for sugar and ethanol. In this way it was possible to ensure the consistency of the data. For the Reference Scenario we used data provided by the BME 2030, slightly modified by the ICONE in order to conform to the results already obtained for the years up to 2008.

For each scenario we estimated the year-on-year production of sugar and ethanol forecasted to satisfy domestic and external market demand for both products. Using the data referring to the development of *Total Recoverable Su*gars (TRS) (one kilogram of TRS per ton of sugarcane), the sugarcane productivity (tons of cane/ha) and the efficiency of industrial conversion of ethanol and sugar (kg of sugar/kg of TRS and liters of ethanol/kg of TRS) for a specific "mix" of products, the need for sugarcane and the area for sugarcane cultivation was calculated on an annual basis.

The ethanol produced by second generation technology (hydrolysis) was considered as a ethanol productivity gain in terms of liters of ethanol per ton of sugarcane, thereby contributing to reducing demand for more growing area.

Table 79 - Yield of sugarcane products

Item	2010	2015	2020	2025	2030
Ethanol yield (l/tc)[1]	82.3	85.9	90.0	91.2	92.1
Sugar yield (kg/tc)[1]	140.3	145.3	149.7	150.2	150.4
TRS (kg/tc)[2]	144	148	153	157	162
Ethanol yield (l/tc)[2]	84.6	87.0	89.9	92.2	95.2
Sugar yield (kg/tc)[2]	137.5	141.3	146.1	149.9	154.7

Sources: PNE 2030 (1) and ICONE (2)

[1] PNE 2030 data for the Reference Scenario ; tc = ton of cane

[2] ICONE data for Low Carbon and Reference Scenarios; tc = ton of cane

The ethanol and sugar yields of the ICONE (Institute for International Trade Negotiations) data were obtained by using the average conversion rates below, which also served as a basis of calculating the total demand for sugarcane:

1 kg of sugar= 1.0474 kg TRS

1 L of ethanol = 1.702 kg TRS

Sugarcane productivity varied as can be seen in Table 18 below:

Table 80 - Variation of sugarcane productivity during the period 2010-2030

Productivity of sugarcane (t/ha)	2010	2015	2020	2025	2030
PNE 2030	77.0	78.1	80.1	80.8	82.1
ICONE	81.8	86.5	91.3	95.9	100.3

In the above table the data refers to averages for Brazil. In the ICONE study it was necessary to divide the country into six regions and to estimate productivity in each of them. The values defined were based upon the opinions of experts and utilized in the two scenarios in order to obtain a degree of uniformity for ease of comparison.

The productivity of ethanol by hydrolysis was estimated based upon the data produced by the ethanol project developed by NIPE/UNICAMP (NIPE, 2007) for the Low Carbon Scenario. For the Reference Scenario the productivity data in the PNE 2030 were used. The data is listed at Table 81.

Table 81 - Productivity of ethanol by hydrolysis

Productivity of hydrolysis	2010	2015	2020	2025	2030
PNE 2030 (L/t, d.b.)	210	240	255	265	275
NIPE, 2005 (L/tc)[1]	10	17,1	20,4	37,4	37,4

Note: d.b. = dry base and tc = ton of cane

[1] Includes biomass per ton of cane and hydrolysis productivity in L/tc

In the EPE data the evolution of productivity was considered to possess a very high value in 2010 and evolved very slowly between 2010 and 2013. In the case of the values taken from the NIPE study we took into account not only the technological development of hydrolysis but also the increased availability of biomass in view of the upsurge in bagasse waste and straw recovery.

The evolution of in the two scenarios shown in Figures 15 and 16 below

Figure 15 – Production of ethanol by hydrolysis in the two scenarios

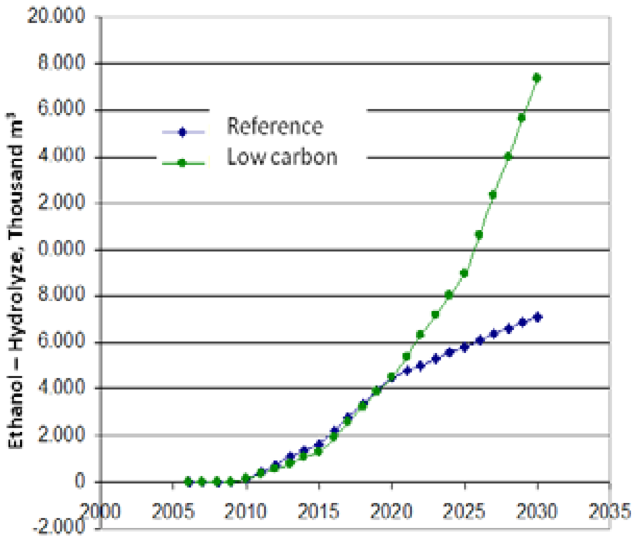
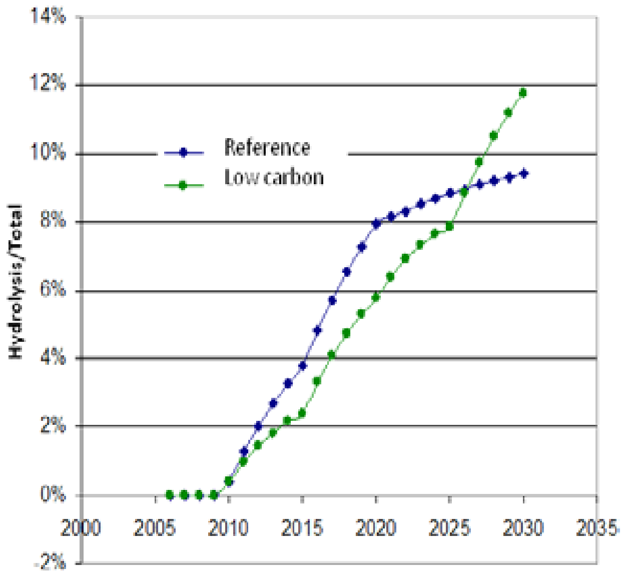


Figure 16 – Share of ethanol by hydrolysis in total production in the two scenarios



In the Reference Cenario the production of ethanol by hydrolysis grows rapidly up to 2020 and thereafter decelerates (contrary to the expectations of area specialists). The Low Carbon Scenario thus follows the PNE 2030 curve in its initial phase and from 2020 onwards the curve is one of slightly accelerated growth reflecting the competitivity gain expected.

ii) Evolution of the rate of mechanization involved in harvesting sugarcane

The evolution of mechanization for harvesting sugarcane is closely linked to the timetable of the end of cane burning in the sugar plantations. Other mechanized agricultural activities such as planting follow the same rhythm. An end-of-burning scenario was developed on the basis of Federal Law No. 2661 of 1998 which established the end of the burning phase in the so-called mechanized areas which for legal purposes are the areas with a declivity equal to or less than 12% and an area greater than 150ha. The Environmental Protocols signed by the state governments of São Paulo and Minas Gerais and by the majority of sugarcane producers of these two states were taken into account in this scenario. The Protocols are of key importance given the fact that São Paulo and Minas Gerais together produce over two thirds of all sugarcane in Brazil.

Table 82 - Rough timetable of the evolution of sugarcane harvesting (without burning)

Year	% of cane harvested w/o burning	
	SP/MG[1]	Brasil[2]
2010	55	45
2014	75	65
2017	100	85
2020 +	100	90

Notes: 1. Environmental Protocols of the states of São Paulo and Minas Gerais.
2. Federal Law Nº 2.661 for the remaining states
Source: Leal, 2009

Note that in the purely legal scenario mechanization will grow rapidly to around 100% in 10 years time. It is estimated that for social and topographical reasons around 10% of the sugarcane will continue to be harvested by hand (principally in the northeast) but in the long term this percentage tends to diminish or disappear altogether. In our study it was maintained at a (conservative) constant rate after year 2020.

iii) Evolution of the fixed and variable unit costs of operating and maintaining sugarcane production

The way in which sugarcane production costs are calculated by the sugar-alcohol sector made it difficult (or almost impossible) to itemize costs in the same way as would be done in industry (i.e. fixed costs, variable costs, investment costs, return on capital etc). The most common way of identifying production costs of sugarcane is by estimating the cost of each type of agricultural operation undertaken during the production cycle: establishing the plantation, fertilizing, ratooning, harvesting and transport, administration etc. The cost of equipment used either by the hour or by the 'area covered', together with the cost of fuel, agricultural inputs, maintenance, labor and other items are all included in the same package. For these reasons it was not possible to itemize the cost of sugarcane production as required by those responsible for the Synthesis Reports. Sugarcane was treated as an input for producing ethanol with its costs estimated and employed as a total value, variable throughout the period of the analysis.

The value determined in the *Ethanol Project* (NIPE, 2005) was used to indicate the reference cost of sugarcane production, given that at the time it was exhaustively assessed with the help of external consultants and members of the Project Team. This was R$33.16/ton of sugarcane at January 2005 and subsequently corrected by IGPM for December 2008. Table 83 below provides details of cost distribution as normally done in the sector.

Table 83- Details of sugarcane production costs

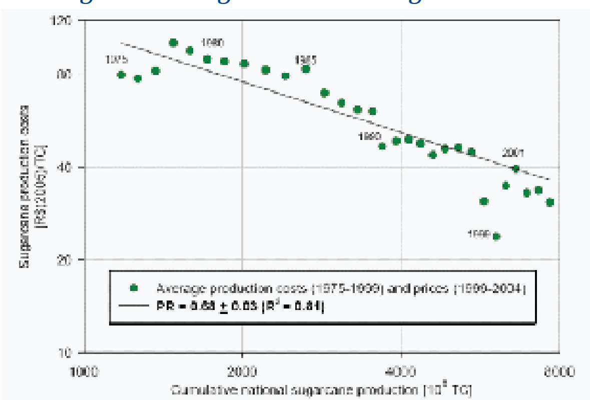
Item	R$/tc	%
Planting	5,56	17
Sugar cane handling	1,07	3
Rootstock handling	8,79	27
Harvesting and transport	11,10	33
Agric. Administration	1,33	4
Land remuneration	5,31	16
Total	33,16	100

Source: NIPE, 2005

In order to estimate the variation of this cost over the period under study the progress or learning curve methodology was employed as developed by van den Wall Bake (2006) who took the PROALCOOL period (1975 to 2005) as the benchmark for collecting data on sugarcane and ethanol production costs. For sugarcane the costs were totaled but for ethanol they were divided between the costs of raw material (i.e. sugarcane), and the costs of processing. This methodology (Nakicenovic et al, 1998) assumes that with every doubling of installed capacity or of production volume the investment or production cost is reduced by a percentage of the initial cost, and the 'progress factor' is defined as being a number between zero and one which multiplies the initial cost of the period in order to obtain the cost after the period of doubling of the volume produced. In other words C2 = C1xPR, where C1 is the cost of the product at the reference moment, C2 is the cost of the product after the period of time where the volume of accumulated production is double the value accumulated up to the reference moment and PR is the 'progress factor'. According to van den Wall Bake, the progress factors in the case of Brazilian ethanol for sugarcane and ethanol, PRc and Pre, are the following:

- PRc = 0.68 ± 0.03 (R^2 = 0.81) shown in Figure 17
- Pre = 0.79 ± 0.02 (R^2 = 0.77)

Figure 17 - Sugarcane learning curve



For the sugarcane we examined the period from 1941 to 2005 in order to calculate the accumulated reference production (2005) where the reference value of the sugarcane production cost is available (R$33.16/t). Based on this, the years in which the accumulated production doubled were determined and the 'progress factor' of 0.68 applied.

For the accumulated production of sugarcane by 2005 (from 1941 to 2005) of 8,183 million tons (Mt) the cost reduction over the period 2005-2030 was calculated in each scenario, determining the years where accumulated production doubled and making an adjustment to the curve at specific points.

iv) Evolution of the average unit investment costs of sugarcane production

As explained above, the capital costs involved in producing sugarcane could not be evaluated with the information available nor separated from the total production cost, obtained by the most frequently-used methodology in the sector. The only values available are those indicated for 2005 (NIPE, 2005) amounting to R$37.5 per ton of sugarcane per year in the case of a distillery with totally mechanized harvesting (machinery and equipment) and processing 2 million tons of sugarcane per harvest. The PNE 2030 also indicated values for 2005 in the region of R$58,00 to R$ 63,00 but these also included the costs of establishing the cane field and tending the nursery. The sugar cane was included in the evaluation of the ethanol production cost purely as a raw material.

v) Evolution of utilization of straw

Part of the straw is used for producing ethanol by hydrolysis in both scenarios. The remainder is used as a fuel, supplementing bagasse in the generation of energy surpluses for sale. The availability of straw was estimated based upon sugarcane production, a percentage of the unburnt straw and the average quantity of straw per ton of sugarcane (assumed as being 0.140 kg of straw (dry base) per ton of sugarcane throughout the timeframe of the two scenarios).

In the Reference Scenario the EPE presents the increased use of straw for these two purposes, but the PNE 2030 does not provide details of the criteria used for this.

vi) Technological evolution of the sugar mills and distilleries

In the Reference Scenario the PNE 2030 devides the sugar processing plants (mills) into three categories: old mills, old mills that have been modernized and new mills, without clearly identifying which were modernized nor the criteria governing modernization. The old mills are those in existence in in 2005. Table 84 below summarizes the proportions of sugarcane ground by the three types of sugar mills according to PNE 2030.

Table 84 – Grinding in three types of plant – Reference Scenario (Mtc/year)

Type of sugar mill	2010	2015	2020	2025	2030
Old	115	83	42	31	19
Modernized old plants	316	349	390	401	412
New	87	284	418	564	710
Total	518	716	850	996	1,141

Source: EPE, 2007

For the Low Carbon Scenario we considered a similar structure, but with the basic difference that the new mills were divided into (i) new mills without the hydrolysis process and (ii) new mills with hydrolysis. 'Old' mills were considered to be those existing in 2009. Table 85 provides a summary of the evolution of many distribution divided between these all types of sugar mills.

Table 85 – Milling in four types of plant – Low Carbon Scenario (Mtc/year)

Type of sugar mill	2010	2015	2020	2025	2030
Old	115	83	42	31	19
Modernized old plants	521	553	594	606	617
New without hydrolysis	46	249	462	769	061
New with hydrolysis	1	12	40	69	134
Total	683	897	1,139	1,474	1,731

The sugarcane and ethanol mills in Brazil are already extremely efficient and there is little margin for reducing the sugar losses in the course of sugarcane processing. The areas of energy generation and the possibilities of saving process steam could however perhaps be substantially improved. The technologies for this are already commercially available and only economic incentives are lacking for them to be utilized on a broader scale. Overall productivity, taking into account improvements in the quality of the sugarcane and industrial efficiency in terms of liters of ethanol per ton of sugarcane, varied in the study from between 84.6 in 2010 to 95.2 in 2030.

Modernized older sugar mills are taken into account only from the point of view of the energy component of the mills, with old mills generating up to 10 kWh/tc of surplus electricity and the modernized older mills generating around 50 kWh/tc. The new mills using straw generate as much as 140 kWh/tc.

The following data were examined for estimating investments and calculating production costs:

- Scale factor of the distilleries: data produced by Dedini (Olivério, 2007) were used for the capacity range 120kl - 1000 kl of ethanol/day (240,000 to 2, 250,000 tons of sugarcane per harvest) for adjusting the regression curves which allowed extrapolation for larger capacities. The average capacity of the new distilleries was taken as varying linearly from 2.0 million tons of sugarcane per harvest in 2010 to 4.5 million tons in 2030. The results of the adjusted curve is shown in abbreviated form in Table 86 below.

Table 86 – Scale factor of the new distilleries

Production (kl/day)	Milling (1000t/yr)	Investment (MR$)[1]	Investment adjusted (MR$)[2]	Unit Investment (R$/t/ano)[2]
120	270	90	99,9	370
240	540	110	122,1	226
500	1,125	150	166,5	148
1,000	2,250	210	233,1	104
1,500	3,375		266,0	79
2,000	4,500		298,6	66
2,200	5,000		311,6	62

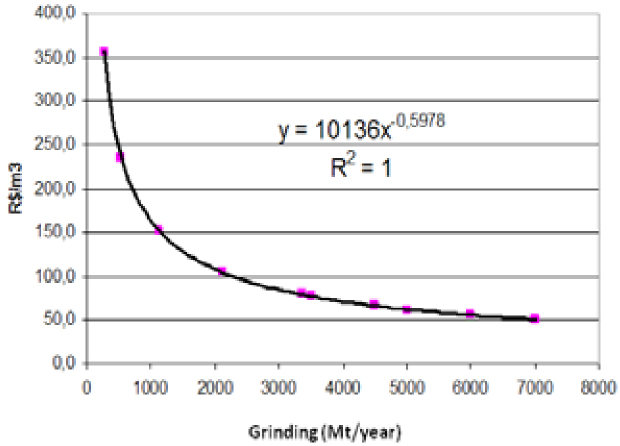
Notes: [1] Source: Olivério, 2007
[2] Adjustment curve and monetary correction

Using this data it was possible to identify the investment projections per sugar mill during the period 2010 to 2030. In the case of existing mills it was considered that the average mill has a milling capacity of 1.4 million tons of sugarcane per harvest and a value of $154 million. 60% of the milled cane goes for ethanol, corresponding to 840,000 tons of cane and an ethanol production of 71.4 m liters.

The reference date for the investments was December 2008. The investment values were calculated by Olivério (2007) and the sugarcane and ethanol production costs (NIPE, 2005) were corrected by the IGPM to this date.

The scale of the distillery has a powerful effect on capital return, mainly the distilleries with annual milling capacities of below 2 million tons of sugarcane per harvest, as can be seen in Figure 18 below.

Figure 18 – Influence of the scale of the distillery on capital return (IRR=15%)



The cost structure of ethanol was based upon data available in NIPE, 2005, estimated by specialists for a distillery with a capacity of 2 million tons of sugarcane per harvest.

Table 87 - Basic structure of the cost of ethanol

Independent distillery processing 2 Mtc/year- 2005		
	R$/m³	R$/m³
Regular operation		390,12
Industrial		132,71
Depreciation	26,50	
Maintenance materials	20,97	
Chemical products	21,63	
Salaries and charges	28,86	
Outsourced services	8,74	
Lubricants	3,43	
Other	22,58	
Administration		46,87
Salaries and charges	15,66	
Outsourced services	6,41	
Social assistance	8,96	
Others	15,84	
Total		569,70
O&M	114,66	

Source: NIPE, 2005

Based on this data we sought to develop a methodology which would allow the total costs of ethanol production to be divided into three sections (i) raw materials; (ii) return on capital; and (iii) O&M. The methodology for estimating the return on capital in new distilleries is set out in detail in Table 88 in the case of IRR=15%. The raw material cost segment was calculated by dividing the cost of sugarcane (based on van den Wall Bake´s curve method as described above) by the estimated productivity of ethanol (liters of ethanol/ton of sugarcane). The O&M costs were arbitrarily defined as 10% of the total cost for new distilleries, reducing from 10% (2010) to 8% (2030).

Table 88 – Return on capital in the new distilleries (IRR=15%)

Year	Milling (000tc/yr)	Investment (MR$)	Annual cost of capital (000 R$/yr)	Productivity (l/tc)	Production (m3/yr)	Portion of capital (R$/m3)
2009	2000	215	32818	84.0	167.944	195,4
2010	2000	215	32818	84.5	169.000	194,2
2011	2125	221	33628	85.0	180.685	186,1
2012	2250	226	34410	85.6	192.501	178,8
2013	2375	231	35167	86.1	204.450	172,0
2014	2500	236	35900	86.6	216.530	165,8
2015	2625	240	36611	87.1	228.743	160,1
2016	2750	245	37303	87.7	241.087	154,7
2017	2875	249	37975	88.2	253.564	149,8
2018	3000	254	38631	88.7	266.172	145,1
2019	3125	258	39271	89.3	278.913	140,8
2020	3250	262	39895	89.8	291.785	136,7
2021	3375	266	40505	90.3	304.790	132,9
2022	3500	270	41102	90.8	317.926	129,3
2023	3625	274	41686	91.4	331.195	125,9
2024	3750	277	42258	91.9	344.595	122,6
2025	3875	281	42819	92.4	358.128	119,6
2026	4000	285	43370	92.9	371.792	116,7
2027	4125	288	43910	93.5	385.589	113,9
2028	4250	292	44440	94.0	399.517	111,2
2029	4375	295	44961	94.5	413.578	108,7
2030	4500	299	45474	95.1	427.770	106,3

In the case of new distilleries and an IRR of 15% the evolution of the component portions of the total cost of ethanol production is detailed in Table 89 below.

Table 89 – Evolution of the components of the total costs of producing ethanol in new distilleries (IRR=15%)

Year	Cost of ethanol (R$/m3)	Capital + O&M (R$/m3)	Cost of sugarcane (R$/m3)	Components of the total costs projected in study		
				Cane	Capital	O&M + administration
2009	709,06	266,32	442,74	62.4%	27.6%	10.0%
2010	689,53	263,14	426,38	61.8%	28.2%	10.0%
2011	663,09	252,42	410,67	61.9%	28.1%	10.0%
2012	638,14	242,57	395,57	62.0%	28.0%	10.0%
2013	614,56	233,46	381,10	62.0%	28.0%	10.0%
2014	592,24	225,02	367,22	62.0%	28.0%	10.0%
2015	571,10	217,16	353,94	62.0%	28.0%	10.0%
2016	551,07	209,83	341,24	61.9%	28.1%	10.0%
2017	532,08	202,98	329,11	61.9%	28.1%	10.0%
2018	514,09	196,54	317,54	61.8%	28.2%	10.0%
2019	497,03	190,50	306,52	61.7%	28.3%	10.0%
2020	480,86	184,81	296,05	61.6%	28.4%	10.0%
2021	465,56	179,45	286,11	61.5%	28.5%	10.0%
2022	451,07	174,39	276,68	61.3%	28.7%	10.0%
2023	437,38	169,60	267,78	61.2%	28.8%	10.0%
2024	424,45	165,08	259,38	61.1%	28.9%	10.0%
2025	412,26	160,79	251,47	61.0%	29.0%	10.0%
2026	400,78	156,73	244,05	60.9%	29.1%	10.0%
2027	389,99	152,88	237,11	60.8%	29.2%	10.0%
2028	379,86	149,22	230,64	60.7%	29.3%	10.0%
2029	370,39	145,75	224,64	60.6%	29.4%	10.0%
2030	361,55	142,46	219,09	60.6%	29.4%	10.0%

Ethanol by hydrolysis: estimates for ethanol by hydrolysis vary greatly in the literature but for the present study we considered only the data produced by the National Renewable Energy Laboratory (NREL) and the International Energy Agency (IEA) in an effort to find a balance between the significantly different data produced by these key institutions. For the calculation of the investment necessary for a hydrolysis plant we used as a reference the NREL (2002) Report which contained a detailed economic analysis of a future plant (designed by NREL) - with acid pretreatment and enzymatic hydrolysis with simultaneous sacarification and co-fermentation, using as raw material the waste corn stalks collected by bundling to provide all the energy necessary for the functioning of the plant, for process steam and for electricity. Table 90 shows the main estimated investment items.

Table 90 – Itemization of projected investment for a future reference ethanol by hydrolysis plant producing 2000 t/day (US$ at year 2000)

Item	1000US$
Total equipments	133,700
Storage	1,700
Construction site	5,900
Total instalment costs	121,200
Indirect costs	
Expenditure on construction site	24,300
Office and construction fees	30,300
Project contingencies	3,600
Total investment capital	179,400
Other costs (start-up, permits, etc.)	17,900
Total investment in project	197,400

Source: NREL, 2002

The main performance data of this plant using 2000 tons of biomass (dry base) per day (7000 tons/year) were estimated as follows:

- Productivity: 374 liters of ethanol/ton of biomass (dry base)
- Annual production: 262 million liters
- Period of operation: 8400 hours/year (350 days/year)
- All the wastes used in the production of steam and electricity for the plant.

The principal costs identified :

- Raw material: US $33/t (dry base)
- Inputs (non-raw material) : US $12.7 million/year
- Treatment of effluents: US $2.0 million/year
- Fixed costs: US $7.5 million/year
- Surplus electricity: US $0.602kWh/liter of ethanol
- Minimum selling price for ethanol: US $0.2827/per liter

The design of the plant met optimal requirements principally from the point of view of energy balance and excellent use of effluents and wastes. The study indicated a strong scale factor (0.70) which would make plants with capacities of less than 2000 tons of biomass per day (dry base) unviable. It is important to note that even the costs of raw material is a future projection (as with the major part of the costs identified in the study) given that real values at today's prices are well above those considered in our calculations.

The IEA (2008) forecasts of the costs of ethanol by hydrolysis for 2030 are considerably more conservative than the values indicated in the NREL (2002) Report, as can be seen below:

- **2010**: US$0.80 to US$0.90/liter of gasoline equivalent (US$0.53 to US$0.5 9/liter of ethanol).

- **2030**: US$0.55 to US$0.65/liter of gasoline equivalent (US$0.36 to US$0.4 3/liter of ethanol).
- **2050**: US$0.55 to US$0.60/liter of gasoline equivalent (US$0.36 to US$0.40/liter of ethanol).

Iin order to arrive at the costs of ethanol by hydrolysis in the short and medium-term, projections for 2030 were used and an inverse learning curve (from 2030 to 2010) and with a Progress Factor PR = 0.85. The value considered for 2030 in the case of the IRR = 15% was R$0.9 1/liter (US$0.41/liter) and the cost of biomass (bagasse) remained constant at R$26.6/ton (value determined in the PNE 2030). The adjustment for the reverse curve provided the results as summarized in Table 91.

Table 91 – Variations in the production costs of ethanol by hydrolysis (R$/L)

	2010	2015	2020	2025	2030
IRR=8%	2,83	1,78	1,22	0,84	0,70
IRR=15%	3,72	2,33	1,59	1,10	0,91

c) Example of the project for implementing the mitigation or sequestering option

For the economic analysis two options were considered for the same project described in the Low Carbon Scenario:

- **Option** 1: the costs of ethanol by hydrolysis weighted by the costs of the ethanol with internal rates of return (IRR) of 8% and 50%.
- **Option 2**: the costs of ethanol by hydrolysis are not weighted by the costs of the ethanol and with internal rates of return (IRR) of 8% and 50%.

The basic difference between Options 1 and 2 is that in the latter a financial component is assumed (government investment, tax differentials etc) which increases the cost of hydrolysis production to the level of the average cost of production of conventional ethanol. In this way, an incentive would be provided for the private sector to invest in new technology in order attain a minimum level of competitiveness during the learning period common to all new technologies.

This process has a significant impact on the abatement costs of GHG omissions by substituting gasoline abroad with Brazilian ethanol. The investment costs in the two options are equal, although in Option 2 part of these costs would come from outside the plants in the form of donations, nonreimbursable resources, tax breaks etc. Table 92 below presents the values of the investment. No calculation was made of the receipts since the methodology used concerns only the differences between production costs in the two scenarios.

Table 92 – Share of Investments in the Production of Ethanol between the External and Internal Markets, 2010-2030 (million R$)

Scenarios	Reference	Low Carbon	Difference
Total Accumulated Production (ML)	1,159,424	1,760,888	601,464
Internal Consumption	861,740	934,254	72,514
Export	297,684	826,634	528,950
Performance, from 2010 forward[1]			
Former production[2]	641,655	667,443	25,788
Projected Production[3]	517,769	1,093,445	575,676
Former Internal Consumption[2]	497,679	523,467	25,791
Projected Internal Consumption[3]	364,061	410,787	46,726
Former Exports[2]	143,976	143,976	0
Projected Exports[3]	153,708	682,658	528,950
% Projected Exports of the Projected Production	29.68	62,43	-
Investments for Export (million R$)[4]	9,016	54,717	45,701

Notes:
1. Takes into account only units constructed from 2010 forward. 2. Value in 2009 (production, internal consumption, exports) multiplied by 21 (number of years between 2010 and 2030). 3. Value (production, internal consumptions and exports) from new units constructed from 2010 forward. 4. Total investment in new units multiplied by the percent of exports of total production from the new units. These values are those that should be used to represent the total investments for ethanol production for export between 2010 and 2030. Source: Theme F Report

The total investments accumulated for each type of technology are shown in Table 93 below.

Table 93 – Accumulated investments in each production technology in the two scenarios (R$ million)

Technology	Reference Scenario	Low Carbon Scenario
Conventional	26.367	65.564
Hydrolysis	4.012	22.081
Total	30.379	87.645

9.2 Potential for reducing emissions and Marginal Abatement Cost

The gross potential of the mitigation/sequestering option considered is 667 million tCO_2e in the period 2010-2030. The emissions avoided increase year on year between 2010 and 2030, effectively from 1.0 million tCO_2e to 73 million tons of CO_2e per annum.

In order to facilitate interpretation of these results referring to the marginal abatement costs of GHG associated with the gross potential of the options considered, the main assumptions and parameters employed are summarized here.

Objective: Transport Biofuels-Ethanol was to identify the mitigation potential of GHG emissions and/or carbon sequestration on the basis of exporting large volumes of ethanol to partially replace gasoline consumed in other countries, as well to estimate the costs of mitigation and/or sequestration by comparing a Low Carbon Scenario with a Reference Scenario.

Sugarcane production costs: the method used is the one normally employed in the sector (dividing sugarcane production costs by agricultural operations and not as Investment and O&M). The costs presented in the NIPE Ethanol Project (2005) were used as a baseline (values referring to 2005) and the projection for the period 2010 to 2030 was done on the basis of a learning curve methodology with a Progress Factor PR= 0.69, on the basis of the study by van den Wall Bake (2006). The 2005 value was R$33.16/t (NIPE, 2005). With the IGPM corrections up to 2008 and with a learning curve, the cost of sugarcane per ton delivered to the plant varied from R$37.18 to R$20.83 from 2009 to 2030 (at December 2008 values).

Costs of ethanol production: the estimates of ethanol production costs were divided into three categories and the weighted average was calculated by the amount of production of each modality. The three types are the following:

Old sugar mills: plants already constructed in 2009. Their production costs were calculated on the basis of the cost of sugarcane and productivity (liter/ton) with the cost of capital at a constant rate and based on present investments in an average-sized plant with a 1.4 million ton sugarcane capacity and on a reduction factor of 0.6 (arbitrary) in order to account for the fact that around 60% of the cane goes for ethanol, and the costs of O&M arbitrarily fixed at 10% (based on an evaluation of current values) at the beginning of the period and declining to 8% in 2030.

New sugar mills: the cost of the raw material component was calculated on the same basis as old sugar mills and the investment was estimated based on a curve adjusted by the values presented by Olivério (2007), considering a linear growth of average capacity of 2 million tons of sugarcane per harvest in 2010 up to 4.5 million tons in 2030. The cost of O&M were arbitrarily fixed at 10% of the total, constant throughout the period.

Hydrolysis plants: based on the production cost projections of the IEA (2008) for 2030 (R$0.79 to R$0.94 per liter of ethanol) in the investment structure for the reference plant presented by the NREL (2002) and the learning curve with a Progress Rate PR= 0.85, we made projections for the period 2010-2030. In this case, we started with an estimated value for 2030 and calculated backwards to 2010. In these conditions the cost of ethanol by hydrolysis turned out to be above that produced by conventional ethanol production throughout the entire period of the scenario. In order to verify the impact of the higher costs of ethanol by hydrolysis in the global abatement cost, we analyzed two options: **Option 1** considering the costs of ethanol by hydrolysis in the weighting of the cost of ethanol and **Option 2** where the effect of the hydrolysis was segregated.

A summary of the results is shown at Table 94.

Table 94 – Economic results of the options for emissions abatement of GHG

Mitigation options	Potential for gross reduction between 2010-2030 ($MtCO_2e$)	Cost of average abatement in the period with IRR=8% (US$/t CO_2e)	Break even carbon price wih IRR=15% (US$/$tCO_2e$)
Option 1	667	1,61	37,64
Option 2	667	-20,67	6,45

9.3 Barriers against implementing low carbon options

Despite Brazil's recognized experience and competitivity in ethanol production from sugarcane, implementing a project of this magnitude will face a number of barriers that need to be identified and addressed well beforehand. Some of the main barriers that are likely to emerge are discussed below (the list is not exhaustive).

1) Protectionism by countries with the most potential to be substantial importers of Brazilian ethanol

Ethanol, currently classified as an 'agricultural' product, is faced by a powerful farm lobby in many developed countries with structured biofuel programs. This is particularly true of the USA and the EU. These both levy heavy import duties on Brazilian ethanol (US $0.14/liter plus 2.5% *ad valorem* in the case of the United States, and €192/m3 for non-denatured ethanol and €102/m3 for denatured ethanol by the EU). In addition to the obvious customs barriers against the product, more subtle barriers such as requirements for certification involving a series of highly complex matters such as indirect land use change, emissions caused by land use change and various other issues related to substitution of fossil fuels. Orchestrated campaigns against ethanol suggesting a direct link between ethanol production and Amazonian deforestation, the use of slave and child labor, the destruction of biodiversity and pressures brought against small farmers can also be considered to be 'barriers'.

2) Opposition from sectors affected by the expansion of biofuels (e.g. the oil and food industries)

The loss of part of the traditional markets for fossil fuels by the oil industry and competition for raw materials from the food industry have contributed to these important sectors of the world economy to regard themselves as 'penalized' by the growth of the ethanol sector. These industries are motivated to undertake actions intended to make widespread acceptance of biofuels difficult, such as linking increased ethanol production to higher food prices, even when other factors are responsible.

3) deficient infrastructure to meet the needs of internal transportation, storing, quality control and organizing external transport of large volumes for exportation. The lack of adequate infrastructure in the importing countries is also an important consideration.

4) a shortage of qualified manpower to deal with the rapid growth of ethanol production and, most importantly, lack of familiarity with the new mechanical techniques involved in sugarcane planting and harvesting activities.

5) difficulties of adjusting, in an environment of rapid growth, to producing ethanol in anticipation of higher demand for the fuel as well as to the high costs of maintaining a regulating stock.

6) negative social impacts caused by increased sugarcane production affecting areas occupied by small farmers and other traditional crops in the region. Some regions are already imposing limits on the amount of land that can be used for sugarcane growing.

7) in the case of ethanol by hydrolysis, considered a priority in the PNMC, the existence of economic and technological problems concerning penetration of this new technology which has not yet reached the commercial stage. The high costs of production compared with conventional ethanol will inhibit its implementation on a bigger scale.

9.4 Existing measures and proposals

Throughout its long history in Brazil the sugar-alcohol sector has been submitted to a series of policies, regulations and laws aimed at controlling and directing its development. In the case of ethanol this situation was particularly noticeable at the beginning of the 20th century, when efforts to introduce ethanol as an alternative fuel for 'Otto Cycle' engines began to emerge. In the 1920s the Brazilian National Institute of Technology devoted much effort to developing a engine that would be better adapted to this renewable fuel and a number of sugar processing interests tried in vain to promote its use. In the 1929 financial crisis the international sugar market suffered serious price setbacks and Brazilian producers had difficulty to control supply and demand, which resulted in substantial problems for the sector. The Brazilian government decided to intervene more objectively in 1931 by making the use of 5% ethanol in all imported gasoline consumed in the country compulsory, with the aim of using up part of the country´s sugarcane production. This was eventually extended to all gasoline sold in Brazil.

The Sugar and Alcohol Institute (IAA) was established in 1933. This was made responsible for controlling the entire production of sugarcane, sugar and ethanol, the domestic market and export prices. The Institute was also responsible for expanding the sector. Moreover, the IAA also established a total separation between the agricultural and industrial sides of the activity, but this regulation was undermined by legal devices that enabled much of the sector to continue controlling its own activities. In 1971 the modernization program for the sector was launched with the aim of increasing its competitiveness. As a result sugar-alcohol producers in São Paulo began to take the lead in growing more sugar than their competitors in the northeast. In 1972 the *Planalsucar* was created with the aim of developing different varieties of sugarcane and introducing new agronomic technology to upgrade the technical level of the sector. The next major step forward in respect of ethanol was undoubtedly the launching of the PROALCOOL (the National Alcohol Program) with the approval of Decree Law Number 76.593 of 14 November 1975. This Government Directive was substantially motivated by: (i) the abrupt rise in oil prices in 1973 and the (ii) falling sugar prices in the international market. The program was highly successful in helping to resolve both problems and, despite a series of setbacks, has since continued to contribute significantly to reducing Brazil´s dependence on oil while at the same time boosting the competitivity of the sector as a whole The main instruments were the creation of the *National Alcohol Commission* to manage the program, the provision of special financing arrangements aimed at facilitating expansion of production, the establishment of sugar/ethanol price parity to encourage producers to produce either, the introduction of compulsory rules for mixing anhydric ethanol with ordinary gasoline and the efforts to maintain favorable prices of ethanol compared with gasoline to ensure a market to absorb the new raised levels of production.

In the mid-1980s oil prices regained their pre-shock levels and PETROBRAS by then had succeeded in reducing dependence on imported oil. This led to an increasing need for subsidies and a resumed lack of government interest in the ethanol program. However support continued in view of the economic and social importance of the sector despite the fact that differentiated financing was not available for funding the expansion needed to make ethanol competitive with gasoline. As a result the ethanol market began to face serious problems. The 1988 Federal Constitution prepared the way for deregulation of the sector, beginning with sugar. The IAA was extinguished in 1990 and in 1991 Law Number 8.178 launched the process of price liberalization. In 1996 sugar/ethanol price parity came to an end, and in 1996 the prices of sugar, anhydrate and hydrate were freed at producer level and by 1999 at the pumps.

A key problem concerns the strategic or regulatory stock designed to reduce price fluctuations during and between sugar harvests with the aim of preventing fuel shortages. This led to various laws being passed but the problem is still unresolved. Law Number 88.626 of 16 August 1983, for example, a stock of anhydrate equivalent to one month's consumption should compulsorily exist together with a stock of two months´ consumption of hydrate. PETROBRAS was given the responsibility to acquire the amount necessary to form the stock. Meanwhile Law No. 94.541

(1987) increased the sector stock for two months consumption of both types of ethanol, to be financed with resources produced by a tax of 2% on the purchse price of ethanol. These laws in effect were never adhered to and have been forgotten, despite the persistence of the problem.

While the sector is totally deregulated today, the obligatory requirement to mix 20%-25% of ethanol with all the gasoline consumed in Brazil (under Federal Law, 1993) remains. The percentage of ethanol is defined by the government based on monitoring supply of and demand for anhydrate ethanol. Consumption of hydrate is regulated by the market in competition with gasoline. This competition has increased given the growth of the number of "flex" vehicles (FFVs) in the country which enables drivers to opt for either of the two fuels at the pumps. Managing the national fuel ethanol market is the responsibility of the National Agency for Oil, Natural Gas and Biofuels (ANP) established in 1997. This agency controls ethanol quality and is charged with monitoring the balance between supply and demand.

The laws and regulations impacting on the sugar-alcohol sector are too numerous to discuss here. It is worth noting however two key advantages for the image of the sector vis-à-vis the international and domestic communities: the end of sugarcane burning (Federal Law Number 2.661 of 1998, the São Paulo State Law No. 11.241 of 2002 and the Forest Code governing areas of permanent preservation, legal reserves and ciliary vegetation. The Federal Law prohibiting burning establishes that by the year 2018 this practice will cease in areas that have access to mechanized harvesting (areas with declivity equal to or less than 12% and an area equal to or greater than 150ha). No forecast yet exists for stopping burning in the 'non-mechanized' areas. The São Paulo state law rules an end to the burnings in the 'mechanized' areas in 2021 and in the non-mechanized areas in 2031.

In the state of São Paulo and Minas Gerais environmental protocols have been signed between representatives of the sugar-alcohol sector, the state government, rural workers, NGOs and environmental bodies bringing these dates forward to 2014 and 2017 for mechanized areas and non-mechanized areas respectively. The environmental preservation areas on the other hand represent an enormous legal liability of the sector and require a solution to be found.

The special financing mechanisms for expanding the ethanol sector created by the Pro-Alcohol program ceased to exist from the mid-1980s onwards and since then only the normal credit for all the sectors of the economy has been available (with, admittedly, certain favorable arrangements to benefit agriculture in general). The National Social and Economic Development Bank (BNDES) is the main financier of large-scale projects such as those involving the new distilleries and sugar mills that are at present under construction. The repayment terms are generally negotiable. In the case of BNDES credit is extended for eight years following completion of plants. Financing from this source consists of the following:

Direct operations: financial cost + BNDES remuneration+ credit risk rate;

Indirect operations: financial cost + BNDES remuneration + financial intermediation fee + remuneration of the financial institution registered).

The financial cost includes one or more of the following: long-term interest rates (TJLP), currency basket charges depending on variation of the US$ or of the UMBNDES (BNDES Monetary Unit) and IPCA (National Extensive Consumer Price Index) plus fees.

BNDES remuneration depends on the financing line being 0.9% per annum for renewable energies. In this case the financial cost would be a maximum of 80% of the TJLP.

Major foreign groups also apply resources to projects involving the construction of distilleries and processing plants. Participation by foreign capital in the sugar-alcohol sector grew from 7% (at the beginning of the expansion project) to 12% in 2007.

The investment requirements in the Reference and Low Carbon Scenarios are estimated at R$422 million and R$829 billion respectively for expanding ethanol production throughout the entire sugar-alcohol sector during the period 2010 to 2030. These figures should not constitute a problem for the Brazilian financial sector and it is likely that a growing segment of investment will continue to come from abroad.

In the case of ethanol by hydrolysis (2nd generation) that has not yet reached the commercial stage and which is not yet able to compete with conventional ethanol (1st generation) assistance will be required for it to compete with the latter. Brazil has two basic options for dealing with this problem: to wait for the appropriate technologies to be developed abroad and acquire user rights or to participate actively in the development of the technologies, adapting them to local conditions (e.g. in the sugar plants) while meeting the high costs of start-up.

The various barriers affecting the sector can also be overcome by the stakeholders involved in expanding ethanol production undertaking joint or autonomous actions in a planned and coordinated manner. Possible ways of overcoming the barriers outlined at 9.3 above are suggested as follows.

l) Protection of the countries with the most potential to be substantial importers of Brazilian ethanol

This would appear to be the main barrier for moving from the Reference Scenario to a Low Carbon Scenario. This barrier has been in place for a number of years - effectively since the countries interested in using ethanol instead of gasoline became aware of the remarkably competitive posture of Brazilian ethanol (as with the sugar market). Agriculture in developed countries is one of the most protected sectors of the world economy: import taxes are raised against foreign competitors, subsidies of various types are provided to local producers and non-tariff barriers are common, such as sanitary criteria, allegations of environmental degradation etc. It is extremely important that Brazil should continue to take forward its current anti-protectionist measures and explore others that are likely to emerge in future.

- *International specification of combustible ethanol*: this issue is being discussed in an international commission formed by representatives of the USA, the EU and Brazil (represented by INMETRO). The aim is to find a consensus regarding a specification for ethanol fuel that can be internationally accepted. Most of the parameters have been agreed but a number of important sticking points remain.
- *Certification of sustainability*: this is probably the most serious barrier that Brazilian ethanol will encounter for penetrating the American and European markets on a large-scale. The methodology used for analyzing the life cycle of greenhouse gases emissions, principally those emissions caused by change of land use, including the so-called 'indirect' land use changes, is a critical issue. Representatives of Brazil´s sugar-alcohol sector such as UNICA (Sugar Agroindustry Union of the State of São Paulo) liaise with bodies abroad interested in the question such as the US Environmental Protection Agency (USEPA), the California Air Resources Board (CARB) and the European Commission basically to ensure that the 'life cycle analyses' made of Brazilian ethanol employ the correct data to reflect Brazilian conditions. Other bilateral efforts are being made by the firms themselves such as case of SEKA (Swedish) and 7 São Paulo ethanol-producing firms (the Verified Sustainable Ethanol Initiative). The Brazilian government needs to create a 'national sustainability agenda' with a view to identifying competent interlocutors, establishing reliable data banks and organizing a world-wide publicity campaign to inform about the reality of Brazil´s ethanol production. In parallel, the Brazilian government should take steps to punish abuses by local producers regarding labor legislation, environmental protection, compensation for small farmers etc. Finally, it is important to ensure that sugarcane expansion is directed to the areas indicated by the 'Agroecological Zoning' initiative as appropriate for growing sugarcane in order to avoid impacting sensitive biomas or food production.

- The government should seek bilateral agreements with other key countries and take action within the World Trade Organization (WTO) to reduce import tariffs on ethanol. In this respect it is important to try to change the WTO description of the product from an 'agricultural' product to an 'energy' product.
- The government should produce evidence of the real causes of deforestation in the Amazon in order to absolve ethanol of the blame for deforestation attached to by its opponents.

2) Opposition from sectors affected by the expansion of biofuels (e.g. the oil and food industries).

The government and ethanol producers should prepare public awareness-raising campaigns both in Brazil and abroad to draw attention to the social and environmental advantages of ethanol. These advantages include better performance of light vehicle engines using a mixture of ethanol and gasoline (higher octane value of gasoline, quicker and cleaner combustion, fewer polluting emissions etc). As for problems such as the increase in high evaporative emissions, corrosion and phase separation, explanations should be given and solutions proposed in order to counterbalance attacks by opponents. The phenomenon of global warming should be explained in a simple and understandable way drawing attention to the differences between fossil fuels and renewable fuels. One of the key points to be pressed home most forcefully is the minor impact of ethanol production in Brazil on food production. In this respect attention needs to be drawn to the fact that sugar is not, and will not be, in short supply for the domestic or export markets.

3) Deficient infrastructure to meet the needs of internal transportation, storage, quality control and organizing external transport of large volumes for exportation. The lack of adequate infrastructure in the importing countries is also an important consideration.

This barrier is being addressed by both the public and private sectors. PETROBRAS is expanding its pipeline network to transport light fuels and improving port installations. Meanwhile the traditional producers of ethanol such as COPERSUCAR, GRUPO COSAN, CRYSTALSEV and others have projects underway to construct ethanol pipelines, storage facilities, improvements to major waterways (*hidrovias*) and port installations with a view to speeding up and cheapening the transport of ethanol to the main exporting ports. Several ports exist in Brazil that could become major ethanol exporting terminals in the event of the sugarcane "frontier" moving into their regions of influence.

Importing countries are gradually investing in infrastructure to improve distribution of biofuels that are already being imported.

One idea that would help to rationalize and cheapen the logistical costs of ethanol would be to establish 'clusters' of distilleries and sugar pricessing plants in Brazil. Clustering production facilities would provide the economies of scale necessary for centralizing fuel storage and would make pipeline construction more economically viable (NIPE, 2005).

4) A shortage of qualified manpower to deal with the rapid growth of ethanol production and, most importantly, lack of familiarity with the new mechanical techniques involved in sugarcane planting and harvesting.

Ethanol and sugar producers are currently investing in personnel training for the new units that are being constructed, but apparently there is still a shortage of qualified technical and administrative staff to keep in step with increased production. If the sector expands quickly the staffing problem could deteriorate. If training is not appropriately addressed serious economic problems could arise owing to the lack of skilled operatives.

5) Difficulties of adjusting, in an environment of rapid growth, to producing ethanol in response *to higher demand for the fuel and to the high costs of maintaining a regulating stock.*

Government authorities and producers are aware of the serious problem of the absence of a 'regulatory supply and demand stock' of ethanol aimed at lessening price volatility during and between sugar harvests. Strategies are also lacking to guarantee to future ethanol importers that the product exists in appropriate quantities and quality. In this respect, according to the *Revista Canavieiros* (May 2008) resources to the tune of R$2.3 billion have been earmarked for warranties underwritten by BNDES and the Bank of Brazil.

6) Negative social impacts caused by increased sugarcane production affecting areas occupied by small farmers and other traditional crops in the region. Some regions are already imposing limits on the amount of land that can be used for sugarcane growing.

The rapid replacement of traditional crops such as soya and corn by sugarcane in the Center-South region is causing a degree of dislocation in local economies normally dependent on these traditional crops. It is also giving rise to negative reactions from some municipal authorities which have succeeded in banning sugarcane planting. NGOs defending small farmers who have been moved from their properties to make way for sugarcane have also created much negative publicity for ethanol. This problem should be resolved when the government publishes its Agroecological Zoning initiative. Negotiations at local level are also expected to mitigate the problem. In short, data needs to be honestly presented about the negative and positive impacts of sugarcane cultivation with a view to showing that the positive impacts outweigh the negative. Socio-economic studies also need to be developed in order to give a more balanced view of the problem and to suggest acceptable solutions.

7) In the case of ethanol by hydrolysis, considered a priority in the PNMC, the existence of economic and technological problems concerning penetration of this new technology which has not yet reached the commercial stage. The high costs of production compared with conventional ethanol will inhibit its implementation on a bigger scale.

The use of second-generation technologies for producing biofuels typifies the problems associated with the deployment of technologies that have not yet reached the commercial stage. If Brazil proposes to use this technology on a large scale, as suggested by the PNMC, investments in its development need to be made which will provide opportunities for selecting and adapting the best local processes and securing the appropriate quantity and quality of raw materials required for operationalizing the process. Sugarcane is in an exceptionally favorable position to become a major energy-producing raw material given its ability to be used both in first generation technologies (employing raw sugar) and second-generation technology (using the fibres). The estimated investments needed for developing and expanding ethanol by hydrolysis amount to around R$47 billion in the Low Carbon Scenario and R$19 billion in the Reference Scenario during the period 2010 to 2030. The additional cost for producing ethanol by hydrolysis as compared to conventional ethanol is high over the short term but should level off after 2020.

Differentiated lines of credit and nonreimbursable loans will be necessary for developing this technology to an economically viable stage. The resources needed for achieving this objective are in fact less than those presented in the present study given that these were estimated assuming that the technology would only be developed in Brazil. The idea of sharing resources for developing hydrolysis jointly with other countries is difficult to evaluate without a deeper and more complex analysis. It is important at this stage however to reiterate that the technology for using cane straw in boilers or in advanced thermochemical routes has not yet been thoroughly mastered. For the present, preference is still being given to the use of bagasse for hydrolysis, while straw supplies the basic energy for the sugar processing plants.

10 Additional Mitigation Options-Electricity Production of Sector: Hydroelectricity

10.1 Mitigation Option

Hydroelectric 'complementarity' aimed at increasing the total amount of hydroelectricity produced in two hydroelectric plants situated in different river basins was evaluated on the basis of connecting the Tucuruí hydroelectric plant in the Amazon basin in Brazil to the Simón Bolívar plant on the Guri Reservoir in the Caroní Basin (Bacia do Caroní) in Venezuela. We also examined the construction of the new Belo Monte plant in the Amazon basin and the prospect of interlinking it with Venezuela.

The link between the two existing hydroelectric plants could increase the supply of renewable energy as a viable alternative for reducing greenhouse gas emissions. The two regions are complementary in view of the seasonality of their hydrological regimes (average monthly flow of the river based on historic records from previous years), particularly if we consider the flow in the tributaries on the right bank of the Amazon. A definite 'firm' energy gain from an interlinked scheme could in effect be interpreted as an expansion of the system.

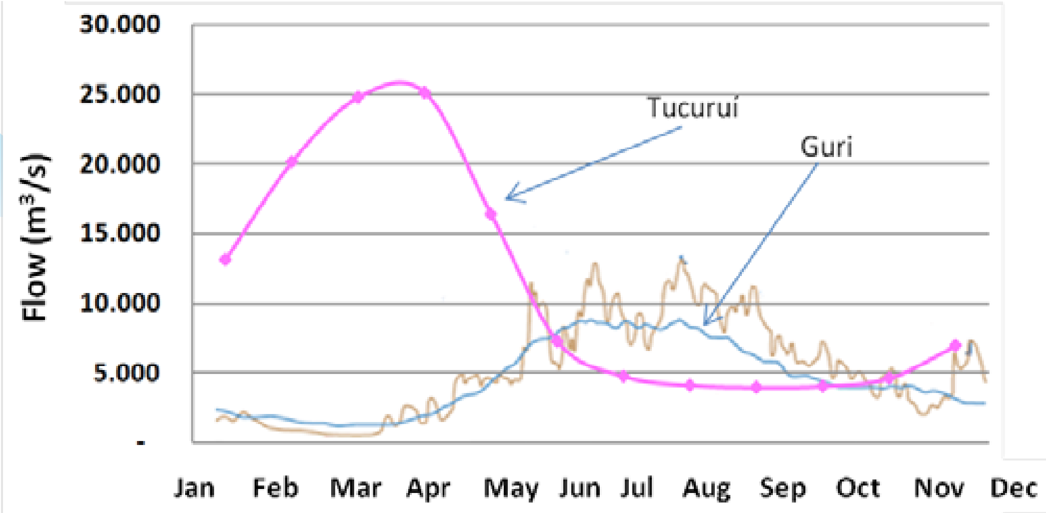
This type of scheme known as 'hydrological complementarity' increases the total amount of hydroelectricity produced in two hydroelectric plants located in different river basins. In order to do this it is necessary for the plants to be connected so that power can circulate between them on a seasonal basis. Since considerable hydro potential exists in the northern region of South America the scheme for linking the two river basins possesses major advantages.

We evaluated (i) the feasibility of the connection between the existing 'Tucuruí' hydroelectric plant in the Amazon basin in Brazil and the 'Simón Bolívar' hydro plant at Guri, in the Bacia do Caroní in Venezuela; and (ii) the future hydroelectric plant at Belo Monte and the prospects for connecting it with the Simón Bolívar plant. Complementarity in these two cases is based upon the location of the hydro plants in the northern 'half sphere' (Simón Bolivar) and the southern 'half sphere' (Tucuruí and Belo Monte.) Between January and June the energy produced in the Tucuruí could be sent to the Simón Bolivar and between July and December the latter could dispatch energy to the Tucuruí (Muniz, 2007).

In 2007 the Simón Bolivar plant at Guri produced 51,029 GWh with a average production factor of the plant of 2.94m^3/kWh. Between August and October it was necessary to drain off 3076m^3/s in order to achieve the correct height of the operation of the reservoir (EDELCA, 2007). Bearing in mind the average production factor of the plant, around 3.6GW of power were wasted between August and October.

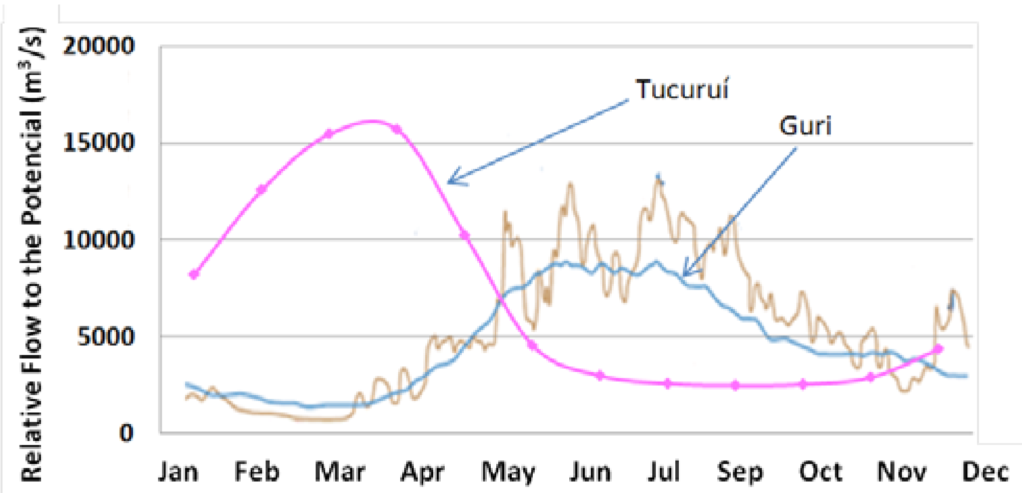
A more detailed analysis of hydrological complementarity between the Tucuruí on the Tocantins River (a large tributary of the Amazon) and the Simón Bolivar plant can be done by comparing the hydrological regimes of the two rivers. Figure 19 was constructed with data provided by the HYDROWEB of the Brazilian National Water Agency and Venezuela's EDELCA (*Electrificación del Caroní, C.A*). In this figure we can observe the average long term flows of the Tocantins river and the average flows feeding the Guri reservoir in Venezuela (blue line). Between January and May the flows into the Tucuruí reservoir are much higher than those into the Guri, while between June and October the flows into the Guri are higher than those into the reservoir on the Brazilian side. The water retention capacity in the two reservoirs could lead to the two above-mentioned periods being extended in order to maximize the energy generated during periods of highest water availability.

Figure 19– Average long-term flows into the Tucuruí and Guri reservoirs



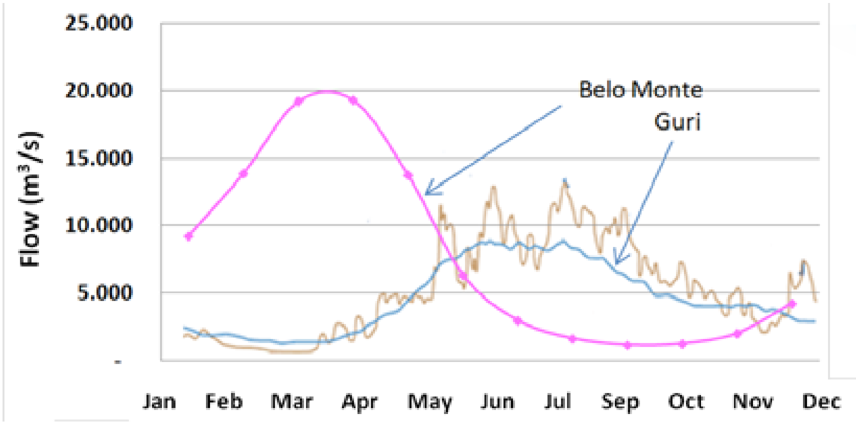
The peak power in the Tucuruí hydroelectric plant was 6,474MW, observed on 24 January 2009. The installed power of the plant is 8370 NW and its head height 78 m. Therefore around 4.71 m^3/kWh need to be generated in the Tucuruí plant. The same ratio for the Simón Bolivar plant is 2.94 m^3/kWh (EDELCA, 2007). Therefore the ratio between the capacity for transforming the flow into power between the Tucuruí and the Simón Bolivar is 1:6. In short, each unit of volume produced in the Simón Bolivar plant produces a quantity of energy corresponding to 1.6 units of water volume produced in the Tucuruí plant. In Figure 20 we can see the superimposed flows adjusted on the basis of the energy potential by volume of water from the two hydro plants. It is possible to verify that energy complementarity can indeed work.

Figure 20– Adjusted flows based on the energy potential by volume of water in the hydroelectric plants at Tucuruí (Tocantins River) and Simón Bolívar (Guri Reservoir)



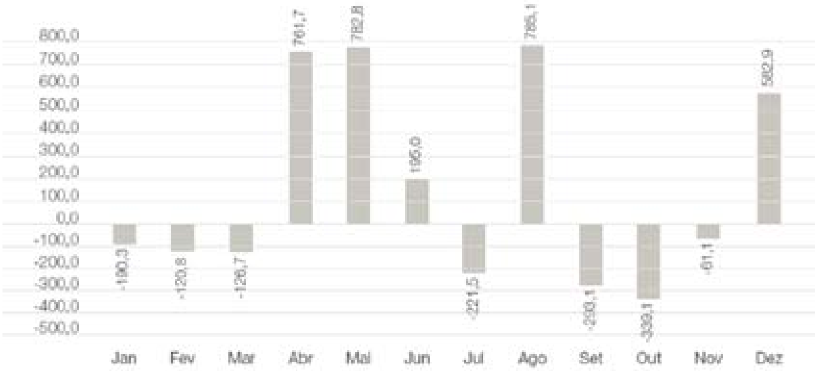
The same type of analysis can be done by examining the data for the Xingú River in Brazil where the Belo Monte (GW) hydro plant will be constructed and data produced by EDELCA (Figure 21). Figure 21 shows that between August and October the surplus energy from the Simón Bolivar plant could be imported to Brazil and that between February and April the energy produced in Belo Monte could be transferred to Venezuela. The connection between the two hydroelectric plants would help to optimize the water reserves in the two reservoirs, providing a constant source of energy throughout the year.

Figure 21– Long term flows into Belo Monte (Brazil) and Guri (Venezuela)



Brazil´s north region exports a total net amount of 1229.90 GWh. to the northeast region (connected to the national interlinked system). However, the prospect of the north region receiving energy from Venezuela for Brazil's north region is of interest given that in the months of July, September, October and November the north currently has to import power from the north-east (Figure 22).

Figure 22–Interregional transfer from the north to the northeast (MW average)



Source: ONS, 2008

In addition to the Simón Bolivar hydroelectricity plant other hydro plants exist in the Caroni Basin. The Macagua plant produces 13,220 GWh/year. The Caruachi (11.350 GWh/year) and Tocoma (10,520GWh/year) plants are under construction. The Tayucai (8500 GWh/year), Aripichi (3700 GWh/year), Eutobarima (8300 GWh/year) and Auraima (3700 GWh/year) plants are at the planning stage (EDELCA). Table 95 shows the installed capacity, the number of generating units, the annual 'firm' energy production, the 'average' annual energy and the difference between average and firm energy in each of the installations in the Caroni basin.

Table 95 – Operational data of the Caroní Basin hydroelectric plants

Plant	Installed capacity (MW)	Generating units	Annual firm energy (GWh)	Annual average energy (GWh)	Difference (average-firm)
Macagua	3,140	20	13,220	15,220	2,000
Guri	10,000	20	40,710	48,220	7,510
Caruachi	2,280	12	11,350	13,040	1,690
Tocoma	2,250	12	10,520	12,140	1,620
Tayucay	2,450	6	8,500	11,600	3,100
Aripichi	1,200	4	3,700	4,800	1,100
Eutobarima	2,400	5	8,300	11,300	3,000
Auraima	1,200	6	3,700	5,400	1,700
Total	**24,920**	**85**	**100,000**	**121,720**	**21,720**

The difference between average energy and firm annual energy could represent the energy that could be 'exchanged' with Brazil. In other words, the same amount of energy could be produced in Brazil and exported to Venezuela between January and June. In this way the 'firm' energy available for each country would amount to the total shown in the table (around 22TWh per year).

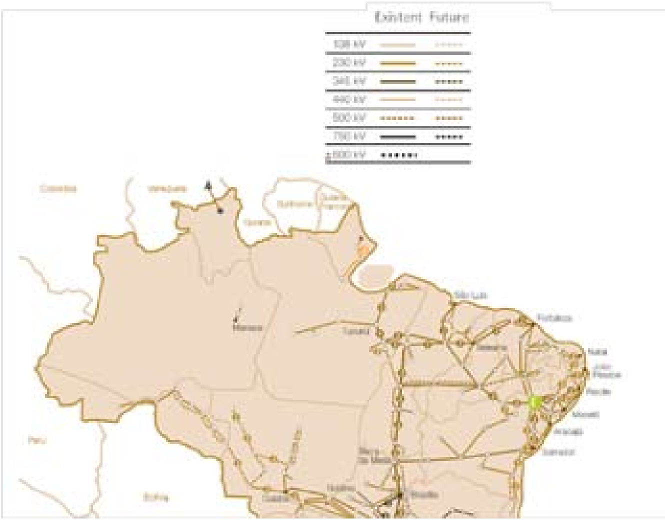
At present a connection exists between Boa Vista in the extreme north of Brazil (state of Roraima) and the Venezuelan system (the region covered by the Guri reservoir), while the rest of the Brazilian network is isolated (IRSA, 2009). EDELCA has provided electricity for Boa Vista since the construction in 1998 of a 695 km long transmission line (495km in Venezuela and 200 km in Brazil). At the time of construction it was estimated that an investment of US$180 million was required to install the transmission line on the Venezuelan side and an estimated cost of US $60 million on the Brazilian side. This line has a transmission capacity of 200 MW of firm energy for Roraima - the amount of energy expected to be needed in the region in 2020 (Federal Senate, 2001).

In 2007, Brazil consumed 536 GWh of energy produced in Guri. Transmission as far as the Venezuelan frontier is done with a 400 kVA line (EDELCA, 2007).

In short, the cost of extra hydroelectricity produced by the hydrological complementarity scheme is based on the cost of the interconnection between the hydroelectric plants, plus an additional quantity of firm energy that the region can benefit from.

The distance between Bacia Caroni and Boa Vista is around 700 km,. between Boa Vista and Manaus 700 km and between Belo Monte and Manaus 800 km (Muniz, 2007). Moreover a 500kW transmission line is planned for between Jurupari and Oriximiná (which is connected to the Tucurui) and approximately 300 km separate Jurupari from Manaus (Figure 23). The link between Venezuela and Boa Vista could be done with a continuous current line while the others would need an alternating current line with a capacity of 500 or 750 kWh. If the electricity were to reach Belo Monte then the energy will be available for the interconnected Brazilian grid. In short, around 1000 km of new transmission lines would be needed as far as Boa Vista in order to connect Venezuela's energy to Brazil´s interlinked system. A stretch of transmission line presenting a technical challenge would be that needed over the Rio Amazonas.

Figure 23 –Transmission line between Jurupari in the state of Pará and Boa Vista in the state of Roraima



The estimated investment needed for constructing a 500kW transmission line between Jurupari and Oriximina and the 230kW transmission line between Jurupari and Macapá is R$666.4 million (2007- 2010). The target is to construct 713 km of transmission lines at a total cost of R$999.7 million (PAC 5). The stretch between Jurupari and Oriximina forms part of the interconnection of the Tucurui with Manaus and the stretch between Jurupari and Macapá would include the Rio Amazonas.

The total investment foreseen for constructing the 506 km transmission line between Oriximina and Cariri is R$1.3 billion. This stretch also forms part of the interconnection between the Tucurui hydro plant and Manaus.

Assuming a cost of R$1 million per kilometre of transmission line, investments of the order of R$1 billion would be required for connecting Boa Vista to the Brazilian grid.

In order to produce estimates of potential emissions reductions in other 'interlinked' countries as the result of the Brazilian Electrical System exporting power (e.g. in the case of Venezuela), it is necessary to evaluate the energy mix of the Venezuelan generation system and estimate a CO_2 emission factor for the electricity generated in Venezuela. The emission factor for Venezuelan electricity is 0.283 tCO_2/MWh (Retscreen, 2009) or around 0.251 tCO_2/MWh (EIA/DOE, 2009). Considering that (i) the Simón Bolivar plant produces 7,510 GWh of electricity seasonably and that an equivalent amount of energy could be produced in Brazil - with half to be consumed in Venezuela and half in Brazil; (ii) the energy produced in Brazil would be a surplus which is not used at present; and (iii) the installed capacity of the hydroelectric plants in Brazil is already sufficient to produce energy - it would be possible to avoid around 1.4 2 million tons of CO_2 per year. Assuming a cost of R$1 billion for the connection, a useful life of 25 years and a discount rate of 8% a year, the cost of one ton of 'avoided' CO_2 would be minus R$477. In this calculation we also took into consideration the avoided costs of the expansion of the interlinked system amounting to US $56.89/MWh. We estimated that the emission factor of the interlinked system in Brazil would be 0.094 tCO_2/MWh up to 2014, 0.081 tCO_2/MWh up to 2019, 0.069 tCO_2/MWh to 2024 and, finally, 0.074 tCO_2/MWh by year 2030.

A further project of this kind would be to link up the Tortuba hydroelectric plant (1000 MW) in Guyana with the cities of Manaus and Boa Vista (IIRSA, 2009). The cost of construction of the hydroelectric plant and the transmission line is estimated at US $1,850 million.

11 Low Carbon Scenario 2010-2030 for the Energy Sector

11.1 Potential for reducing CO2 emissions

The potential for reducing carbon emissions arises from moving from a Reference Scenario to a Low Carbon Scenario. This involved examining the maximum potential of GHG abatement of each option considered in the energy area for the period between 2010 and 2030.

The maximum potential for reducing carbon dioxide emissions in the energy area is 1.8 billion tons in 2010-2030. The main reductions would result from substituting charcoal from deforestation by charcoal produced from renewable plantations (representing 31% of the total potential of the sector), foreshadowing the end of use of nonrenewable biomass by industry by 2030.

We estimated the marginal abatement costs of the options for mitigating carbon dioxide emissions for the period between 2010 and 2030 on the basis of two analyses (methodology presented in Chapter 2.1). Firstly, the abatement costs were based on the discount rate used in the PNE 2030 (8% a year). Secondly, we estimated the *break even carbon price* in accordance with the different sectoral IRR benchmarks sought by the economic players.

For the energy area the marginal abatement costs of the mitigation options at an annual discount rate of 8% varied between -248 US $/t$CO_2$ in the case of cogeneration with sugarcane bagasse and 516 US$/t$CO_2$ for the increased efficiency of air-conditioning equipment used in the residential sector.

The *break even carbon price* of the GHG emissions mitigation options in the energy area fall into the 10 US$/t CO_2 - 2.807 US$/t CO_2 range. Note that the cost of the carbon needed to make the proposed options viable is higher than the marginal cost of abatement of the options with a discount rate of 8%. In other words, additional financial support is needed to ensure that these options are made attractive for the real economic agents.

Table 96 – Potential for reducing CO_2 emissions (2010-2030)

Nº	Sectoral	Low carbon mitigation options	Reduction of emissions ($MtCO_2$)	Marginal cost of abatement (US$/$tCO_2$) (disc. rate 8%)	IRR expected in the sector	Break Even Carbon Price (US$/$tCO_2$)
1	Industrial	Combustion optimization	105.2	-44.1	15%	n/a
2		Heat recovery systems	19.0	-91.7		n/a
3		Steam recovery	37.3	-97.0		n/a
4		Heat recovery in furnaces	283.0	-25.6		n/a
5		New processes	135.4	2.1		173.6
6		Other energy efficiency measures	18.3	-13.5		n/a
7		Thermal solar energy	25.8	-54.7		n/a
8		Recycling	74.8	-34.5		10.4
9		Substitution for natural gas	43.7	-20.2		68.9
10		Substituting fossil for renewable sources of energy	69.2	2.8		41.8
11		Substitution of the nonrenewable component of biomass	567.0	2.9		41.8
12	Aeolic	Wind energy	19.3	-7.6	15%	98.5
13	Cogeneration	Cogeneration	157.9	-248.2	18%	34.0
14	Residential	Solar heating	3.0	161 8	79%	1,397.6
15		Air-conditioning units (MPES)	2.6	516.6		2,807.3
16		Lamps	3.1	-119.7		n/a
17		Refrigerators (MPES)	9.5	41.8		547.5
18	Commercial / Industrial	Engines	1.5	-49.8	15%	72.3
19		Industrial lighting	0.6	-65.0		n/a
20		Commercial lighting	1.5	-52.3		n/a
21	GTL	GTL	128.2	-1.5	25%	33.9
22	Refineries	Changing Design of New Refineries	51.8	19.1	15%	106.1
23		Improving Energy Use of Existing Refinery Units (Heat Integration)	52.3	6.6		74.8
24		Improving Energy Use of Existing Refinery Units (Fouling Mitigation)	7.0	72.9		208.5
25		Improving Energy Use of Existing Refinery Units (Advanced Control)	7.0	95.1		431.5
Total potential			**1,823**			

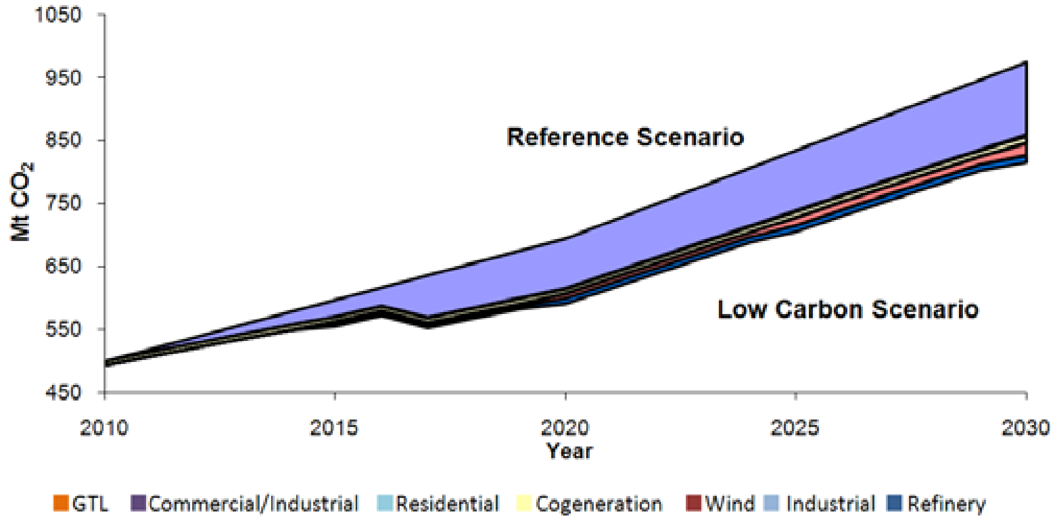
*Note: *Sequestered carbon is not taken into account in these plantations.*
In this table the mitigation options for hydropower and ethanol are not addressed given that they are 'additional' options

As discussed in Item 2.1.2. this study showed only the positive values of carbon that make the mitigation projects economically attractive (*break even carbon price*). In the case of negative values e.g. situations in which the mitigation measures are already attractive from an economic point of view (facing other barriers), the values are not shown.

11.2 Low Carbon Scenario

The final aggregated result of the reduction of greenhouse gas emissions was determined on the basis of the mitigation potential for the energy area. According to the Reference Scenario employed (PNE, 2030), Brazilian emissions in the energy area should increase from approximately 500 million tons of CO_2 in 2010 to 975 million tons of CO_2 in 2030.

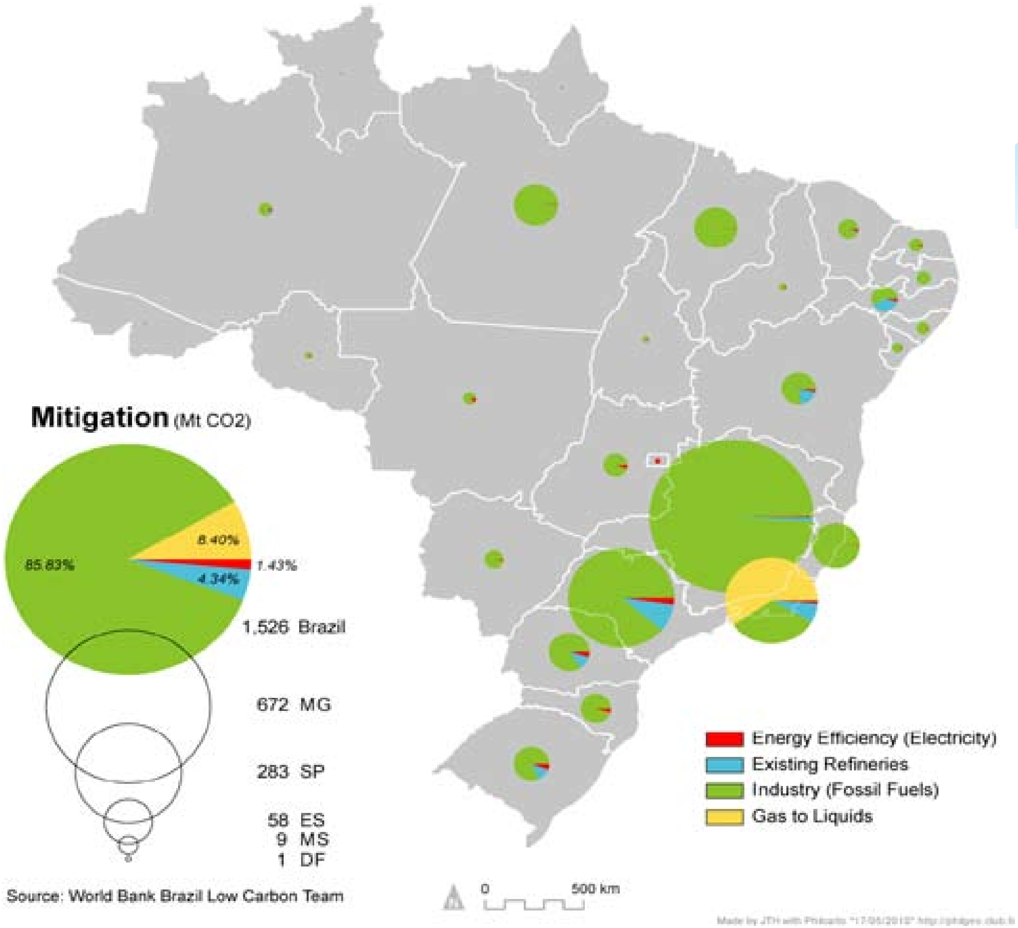
Graph 15 –Annual Reduction of CO_2 Emissions



Note: This graph does not include the mitigation options of hydroelectricity and ethanol given that they are 'additional' options.

Considering the 25 measures proposed by the study groups involved in this task covering 7 sectors in the energy area, the emissions in 2030 can be reduced to 815 million tons of CO_2. This reduction of 160 millions tons of CO_2 (the equivalent of 16% of all emissions in 2030) could be achieved mainly by the industrial sector which represents 72% of the reductions in 2030, as well as by the introduction of GTL in Brazil which would account for 12% of the reductions in 2030. Figure 24 shos mitigation by activity between 2010 and 2030.

Figure 24: Emission Mitigation by Activity, 2010-2030



11.3 Additional Options

Table 97 below summarizes the potential for reducing GHG emissions by developing the additional mitigation options proposed. These are measures which incur costs within Brazil but which seek to reduce GHG emissions in other parts of the world.

Table 97 – Potential for reducing CO2 emissions

Low Carbon Mitigation Option		Reduction of emissions ($MtCO_2$)	Sectoral
Nº	Name		
1	Exportation of ethanol	666.9	Ethanol
2	Interconnection with Venezuela	27.9	Hydroelectricity
Total potential		694.8	

According to the analysis, the avoided GHG emissions - taking into account the development of the two additional mitigation options - represent a potential saving of approximately 700 million tons of CO_2. The marginal abatement costs of the additional mitigation options for the period between 2010 and 2030 considering the 8% per year discount rate employed by the PNE 2030 are presented in the following table.

Table 98 – Marginal Cost of Abatement – discount rate of 8% per annum

Low Carbon Mitigation Option		Marginal abatement cost (US$/$tCO_2$)	Sectoral
Nº			
1	Exportation of ethanol	2.1	Ethanol
2	Interconnection with Venezuela	-30.5	Hydroelectricity

The marginal abatement costs of the additional options of enhanced ethanol exportation and the interconnection of the hydro plants with Venezuela at an annual discount rate of 8% are 2 and -31 US$/$tCO_2$ respectively. The total cost for implementing these measures would be US$549 million in 2030. This estimate of the marginal abatement cost for ethanol exports does not yet include the cost of the activities which would need to be implemented in order to achieve targets for increasing the productivity of livestock producers while avoiding the expansion of the 'agricultural frontier' into native forests.

11.4 Energy Impacts

From the energy point of view, the mitigating options considered in the low carbon scenario influence the national and international energy system (for the international energy system, only for two additional GHG emissions mitigating options: a transmission line connecting Brazil a Venezuela and ethanol exports displacing gasoline abroad) in three main ways: increase in energy supply (both electricity and fossil fuels), reduction in energy demand and the replacement of fossil fuel energy sources by renewable fuels.

Table 99 shows the impact on the (national and international) energy system, in tons of oil equivalent, of the mitigating options analyzed. The influence on the energy system of 26 amongst 27 mitigation options is shown. The impacts on energy as a consequence of the replacement of fossil fuels by natural gas were not considered (only the reduction in GHG emissions was reported here). This chapter only analyzes the replacement of fossil fuel energy sources by renewable fuels.

To better visualize the energy impacts, the mitigating options are shown divided into 5 groups: increase in electricity supply, increase in fossil fuels supply, reduction in electricity consumption, reduction in fossil fuels consumption and the replacement of fossil fuel energy sources by renewable sources. On this very last group, the Brazil-Venezuela electric power system interconnection is included, not meaning a complete substitution of fossil fuels by renewables but only an increase in the share of renewables in Venezuela's energy matrix.

Table 99 – Energy Impacts of Low Carbon Mitigations Options

MtEp	2010	2011	2012	2013	2014	2015	2016	2017
Electricity generation								
Sugarcane cogeneration	0,5	2,0	3,3	4,7	6,1	7,6	7,9	8,2
Wind	0,0	0,1	0,3	0,4	0,6	0,8	0,9	1,1
Total	**0,5**	**2,1**	**3,6**	**5,2**	**6,7**	**8,4**	**8,8**	**9,3**
Fossil fuels production								
Gas to liquid (GTL)	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,4**	**0,4**	**0,4**
Power energy conservation								
Solar heater - residential	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1
Air conditioning (MEPS)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1
Residential lighting	0,1	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Refrigerators (MEPS)	0,0	0,0	0,0	0,0	0,0	0,1	0,2	0,3
Commercial lighting	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Electric motors	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Industrial lighting	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Total	**0,1**	**0,2**	**0,2**	**0,2**	**0,2**	**0,4**	**0,5**	**0,7**
Fossil fuel energy conservation								
Combustion optimization	0,0	0,4	0,8	1,2	1,7	2,1	2,2	2,3
Heat recovery systems	0,0	0,1	0,3	0,4	0,6	0,7	0,8	0,8
Steam recovery systems	0,0	0,3	0,5	0,8	1,2	1,5	1,6	1,6
Furnace heat recovery system	0,0	0,4	0,9	1,4	2,0	2,6	3,2	3,9
New industrial processes	0,0	0,4	0,7	1,2	1,6	2,1	2,6	3,1
Other energy efficiency measures	0,0	0,0	0,1	0,1	0,2	0,2	0,2	0,3
Recycling	0,0	0,2	0,4	0,6	0,8	1,0	1,0	1,0
Existing refineries (energy integration)	0,0	0,0	0,0	0,0	0,0	0,8	0,8	0,8
Existing refineries (incrustation control)	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1
Existing refineries(advanced controls)	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1
New refineries	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,2
Total	**0,0**	**1,8**	**3,7**	**5,8**	**8,0**	**11,5**	**12,8**	**14,2**
Energy substitution								
Transmission line Brazil-Venezuela	0,0	0,0	0,0	0,6	0,6	0,6	0,6	0,6
Ethanol exports displacing gasoline abroad	0,4	1,3	2,0	2,8	3,6	4,6	5,7	7,0
Solar thermal energy	0,0	0,1	0,2	0,3	0,4	0,5	0,5	0,5
Biomass displacing other fuels	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3
Renewable charcoal displacing non renewable charcoal	0,0	0,0	0,0	0,0	0,0	0,0	0,0	10,6
Total	**0,4**	**1,4**	**2,1**	**3,7**	**4,6**	**5,7**	**6,8**	**18,9**

2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
8,5	8,9	9,3	9,7	10,1	10,5	11,0	11,8	12,0	12,1	12,3	12,7	13,0
1,2	1,4	1,5	1,5	1,6	1,7	1,7	1,8	1,8	1,8	1,9	1,9	1,9
9,8	**10,2**	**10,8**	**11,2**	**11,7**	**12,2**	**12,7**	**13,5**	**13,8**	**13,9**	**14,2**	**14,6**	**15,0**
0,4	**0,4**	**0,9**	**0,9**	**0,9**	**0,9**	**0,9**	**1,6**	**1,6**	**1,6**	**1,6**	**1,6**	**2,5**
0,1	0,1	0,2	0,2	0,2	0,2	0,2	0,3	0,3	0,3	0,3	0,3	0,4
0,1	0,1	0,1	0,2	0,2	0,2	0,2	0,3	0,3	0,3	0,3	0,3	0,3
0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
0,4	0,4	0,5	0,6	0,7	0,7	0,8	0,9	0,9	1,0	1,1	1,2	1,3
0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,2
0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,2	0,2	0,2	0,2	0,2	0,3
0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
0,8	**1,0**	**1,3**	**1,4**	**1,5**	**1,6**	**1,7**	**1,9**	**2,1**	**2,2**	**2,3**	**2,4**	**2,7**
2,4	2,5	2,6	2,7	2,8	2,9	3,0	3,1	3,2	3,3	3,4	3,6	3,7
0,8	0,9	0,9	0,9	1,0	1,0	1,0	1,1	1,1	1,2	1,2	1,2	1,3
1,7	1,8	1,8	1,9	2,0	2,0	2,1	2,2	2,3	2,4	2,4	2,5	2,6
4,6	5,4	6,2	6,4	6,6	6,9	7,1	7,4	7,7	8,0	8,2	8,5	8,9
3,7	4,3	5,0	5,7	6,4	7,2	8,1	9,0	9,9	10,9	12,0	13,1	14,3
0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,4	0,4	0,4	0,4	0,4
1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
0,8	0,8	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4	1,4
0,1	0,1	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
0,1	0,1	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
0,2	0,2	0,6	0,6	0,6	0,6	0,6	1,0	1,0	1,0	1,0	1,0	1,0
15,7	**17,2**	**20,1**	**21,2**	**22,4**	**23,7**	**25,0**	**26,8**	**28,3**	**29,9**	**31,5**	**33,2**	**35,0**
0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
8,0	9,2	10,5	12,3	14,4	16,7	19,1	21,6	23,1	24,5	25,9	27,3	28,7
0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
0,4	0,6	0,7	0,9	1,1	1,3	1,5	1,7	2,0	2,2	2,5	2,8	3,1
10,8	11,0	11,2	11,5	11,8	12,1	12,4	12,7	13,1	13,4	13,7	14,1	14,5
20,3	**21,8**	**23,5**	**25,7**	**28,4**	**31,2**	**34,1**	**37,2**	**39,3**	**41,3**	**43,3**	**45,3**	**47,4**

Electricity supply in Brazil could increase by 15 Mtoe (174 TWh) in 2030 with a larger share of wind energy and from surplus electricity generation from sugarcane biomass (cogeneration). Of the total, more than 85% stems from cogeneration, which considers three options in both the reference and low carbon scenarios. Two alternatives correspond to cogeneration systems with steam turbines: in the first case only counterpressure steam turbines are considered (operating only during the harvest), and in the other extraction and condensation turbines (capable of operating throughout the year). The difference between the two scenarios is the generated steam pressures and temperatures. According to this analysis, cogeneration can produce more than 150 TWh to exported to the national energy grid in 2030.

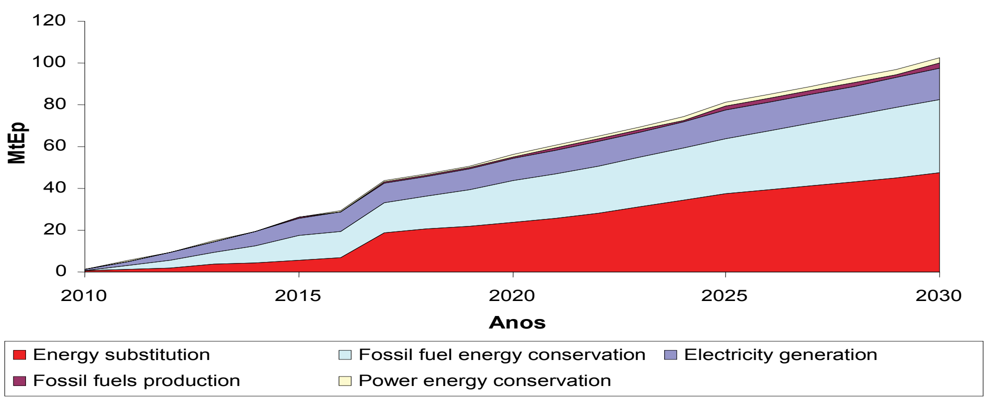
For wind power it is proposed an accumulated expansion of 15.0 GW up to 2030 in the low carbon scenario. That is, an increase of 10.3 GW of wind energy supply up to 2030 between the reference and low carbon scenarios.

The increased supply of liquid fuels stems from the implementation of GTL in Brazil which, according to the study, can generate additional 13.0 Mb / year of diesel and 5.6 Mb / year of gasoline in 2030, which is equivalent to an increased supply of liquid fuels of 2.5 Mtoe in 2030.

For the fossil fuel energy conservation the options included are for energy efficiency in the industrial sector and options for modification of existing refineries and for the foreshadowed expansion of the refinery sector seeking to reduce its self-consumption of fuels. Energy efficiency measures can be combined to reduce up to 32.3 Mtoe in 2030. The total estimated potential of this reduction (fossil fuel energy conservation) is 2.8 Mtoe in 2030.

Finally, as an energy substitution option in favor of more renewable fuels, there is the increase in the exports of ethanol, which would reduce the consumption of 37.3 billion liters of gasoline in 2030, and the replacement of all non-renewable biomass, represented by firewood and charcoal coming from biomass exclusively from plantations. Graph 15 shows the total energy impact of the five groups considered for the period of analysis here covered.

Graph 16 – Energy Impact of the Different Mitigation Options



If the mitigation options here analyzed were implemented in the comming years, the energy replacement and fossil fuel energy conservation would be responsible for the greatest impacts on the national and international energy sectors. Increased energy efficiency in fossil fuel consumption in the industrial sector would be particularly relevant. Table 2 shows a summary of the energy impacts of the different mitigation options here reviewed for the period.

Table 100 – Summary of the Energy Impacts of Low Carbon Options

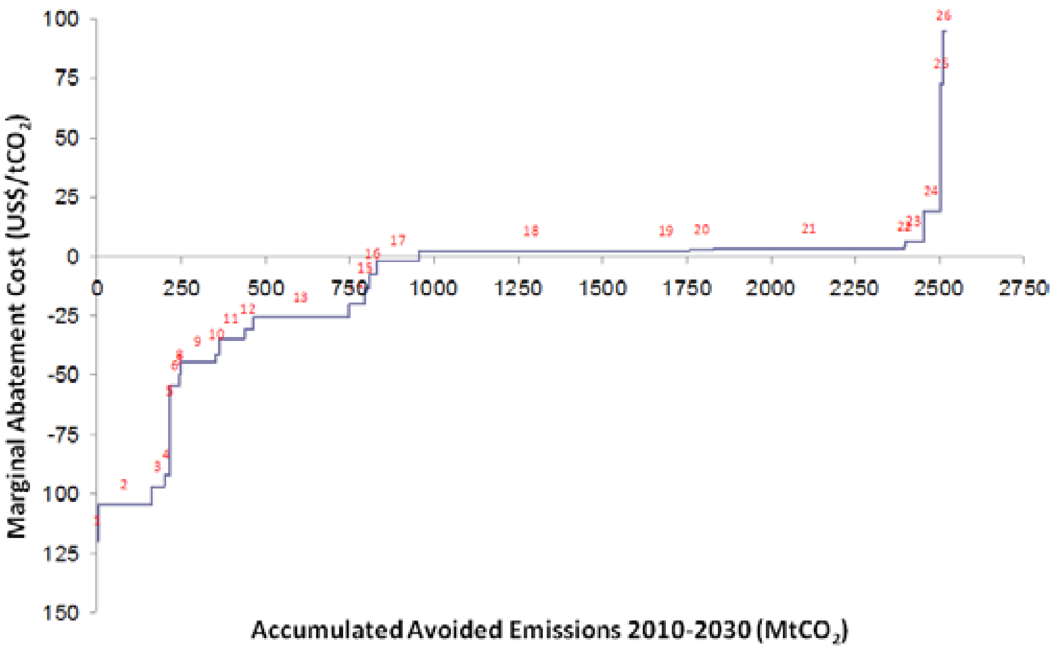
Mtoe	2010-2015	2016-2020	2021-2025	2026-2030	Total
Electricity generation	26.5	48.9	61.4	71.5	208.3
Fossil fuels production	0.4	2.7	5.1	8.7	16.9
Power energy conservation	1.3	4.3	8.1	11.6	25.2
Fossil fuel energy conservation	30.7	80.0	119.3	157.9	387.9
Energy substitution	18.0	91.4	156.7	216.5	482.6

During the 2010 - 2030 period, the total energy impact would be greater than 1.1 Gtoe for all mitigation options together. The increase of both electric power and fossil fuel production would reach 225.2 Mtoe in the 20 analyzed years, while energy conservation (electricity and fossil) would reach 403.6 Mtoe. The share of renewable energy sources, in turn, would increase by more than 480 Mtoe during the same period.

11.5 Synthesis of abatement costs

The costs involved in the mitigation initiatives in the energy area are summarized in the form of an Abatement Cost Curve which identifies the associated costs and potential for reducing GHG emissions in each option proposed. This type of curve enables identification of the total cost linked to the construction of the mitigation options proposed, which is given by the integer of the curve. The following graphs show only the 25 options analyzed in the study plus the two additional options (ethanol and hydroelectricity).

Graph 17 –Marginal Abatement Cost Curve – discount rate of 8% per annum (accumulated emissions reductions 2010-2030)



Key:

1	Residential lighting	14	Natural gas displacing other fuels
2	Sugarcane cogeneration	15	Other energy efficiency measures
3	Steam recovery systems	16	Wind
4	Heat recovery systems	17	Gas to liquid (GTL)
5	Industrial lighting	18	Ethanol exports displacing gasoline abroad
6	Solar thermal energy	19	New industrial processes
7	Commercial lighting	20	Biomass displacing other fuels
8	Electric motors	21	Renewable charcoal displacing non renewable charcoal
9	Combustion optimization	22	Solar heating - residential
10	Refrigerators (MEPS)	23	Existing refineries (energy integration)
11	Recycling	24	New refineries
12	Transmission line Brazil-Venezuela	25	Existing refineries (incrustation control)
13	Furnace heat recovery system	26	Existing refineries (advanced controls)

For a social discount rate the total cost for deploying the options for reducing carbon dioxide emissions in the energy area is -US$34 billion in 2030, equivalent to an average cost of -US$13 per ton of CO_2.

11.6 *Synthesis of Investment*

This item covers the synthesis of the investment requirements needed to set in train the greenhouse gas emission mitigation options in the energy area (i.e. the total additional investment during the period under analysis vis-á-vis the Reference Scenario, corrected for present values, which is needed to make viable the options that have still not been developed in Brazil). Note that the investment usually refers to the period 2010-2030 but the useful economic life of some mitigation measures extends beyond the period under analysis.

Table 101 – Present value of net investments in the energy area

Low Carbon Measure		Current value of net investments (US$)		Sector
Nº	Name	Rate 8%	Sectoral rate	
1	Combustion optimization	1,098	722	Industrial
2	Heat recovery systems	203	160	
3	Steam recovery	515	405	
4	Heat recovery in furnaces	4,746	3,375	
5	New processes	17,027	10,176	
6	Other energy efficiency measures	357	210	
7	Thermal solar energy	735	483	
8	Recycling	157	123	
9	Substitution for natural gas	1,832	1,095	
10	Substituting fossil for renewable sources of energy	1,367	801	
11	Substitution of the nonrenewable component of biomass	5,294	3,870	
12	Wind energy	6,724	4,350	Aeolic
13	Cogeneration	19,630	11,993	Cogeneration
14	Solar heating	1,474	70	Residential
15	Air-conditioning units (MPES)	2,321	23	
16	Lamps	182	58	
17	Refrigerators (MPES)	2,294	28	
18	Motors	388	173	Commercial/ Industrial
19	Industrial lighting	59	26	
20	Commercial lighting	163	73	
21	GTL	1,610	347	GTL
22	Changing Design of New Refineries	1,587	831	Refinery
23	Improving Energy Use of Existing Refinery Units (Heat Integration)	2,160	1,333	
24	Improving Energy Use of Existing Refinery Units (Fouling Mitigation)	480	296	
25	Improving Energy Use of Existing Refinery Units (Advanced Control)	800	494	
26	Interconnection with Venezuela	(855)	(634)	Hidroeletricidade
27	Etanol exportation	9,357	4,718	Etanol
Total		**73.202**	**41,514**	

It can be seen that at a social discount rate an investment of US$73 billion is required, in addition to the investment that would be made in the Reference Scenario, to deploy the mitigation options in the energy area. In the case of the *break even carbon price* this amount would be somewhere in the region of US$42 billion.

The following table presents the annual incremental financial support: the additional investment needed with regard to the Reference Scenario. In other words, this is the additional investment needed in present money. Given that real values would be spread over time this would make implementation of the measures during the period analyzed more viable.

Table 102 –Annual Incremental Investment Cost of Low Carbon Measures

Low Carbon Measure	Annual investment cost (US$ millions)									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Combustion optimization	146	151	157	163	169	0	0	0	0	0
Heat recovery systems	43	45	47	48	50	0	0	0	0	0
Steam recovery	110	114	118	123	127	0	0	0	0	0
Heat recovery in furnaces	580	602	624	647	671	696	722	749	776	805
New processes	1,316	1,365	1,415	1,468	1,522	1,578	1,637	1,697	1,760	1,825
Other energy efficiency measures	27	28	29	30	31	32	33	34	36	37
Thermal solar energy	98	101	105	109	113	0	0	0	0	0
Recycling	33	35	36	37	39	0	0	0	0	0
Substitution for natural gas	142	147	152	158	164	170	176	183	189	196
Substituting fossil for renewable sources of energy	72	83	96	109	123	139	156	157	165	175
Substitution of the nonrenewable component of biomass	798	813	827	842	864	886	909	135	144	154
Wind energy	0	770	837	941	1,188	1,077	853	736	926	701
Cogeneration	1,417	3,430	3,197	3,256	3,172	3,361	917	1,017	844	1,032
Solar heating	0	0	175	177	176	179	177	180	178	181
Air-conditioning units (MPES)	0	0	0	0	0	259	318	399	502	577
Lamps	121	-41	-41	124	-42	-42	127	-43	-43	129
Refrigerators (MPES)	0	0	0	0	0	416	424	417	403	393
Motors	0	0	0	0	0	123	0	0	0	0
Industrial lighting	0	0	0	0	0	13	0	0	8	2
Commercial lighting	0	0	0	0	0	33	0	0	27	13
GTL	0	0	0	0	0	850	0	0	0	0

Changing Design of New Refineries	0	0	0	0	0	1,172	0	0	0	0
Improving Energy Use of Existing Refinery Units (Heat Integration)	0	0	0	0	0	2,148	0	0	0	0
Improving Energy Use of Existing Refinery Units (Fouling Mitigation)	0	0	0	0	0	477	0	0	0	0
Improving Energy Use of Existing Refinery Units (Advanced Control)	0	0	0	0	0	796	0	0	0	0
Interconnection with Venezuela	114	114	114	-1,562	0	0	0	0	0	0
Etanol exportation	116	281	401	512	588	656	738	858	923	969
Total	**5,132**	**8,038**	**8,289**	**7,181**	**8,955**	**15,021**	**7,186**	**6,518**	**6,840**	**7,190**

Low Carbon Measure	Annual investment cost (US$ millions)										
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Combustion optimization	210	217	225	234	242	0	0	0	0	0	302
Heat recovery systems	0	0	0	0	0	0	0	0	0	0	90
Steam recovery	0	0	0	0	0	0	0	0	0	0	227
Heat recovery in furnaces	0	0	0	0	0	0	0	0	0	0	1,201
New processes	1,893	1,963	2,035	2,111	2,189	2,270	2,354	2,441	2,531	2,625	0
Other energy efficiency measures	38	40	41	43	44	46	48	50	51	53	55
Thermal solar energy	140	145	151	156	162	0	0	0	0	0	202
Recycling	0	0	0	0	0	0	0	0	0	0	69
Substitution for natural gas	204	211	219	227	235	244	253	263	272	282	0
Substituting fossil for renewable sources of energy	185	196	207	220	211	201	136	123	110	94	77
Substitution of the nonrenewable component of biomass	164	167	171	174	191	209	227	247	268	290	314

Wind energy	686	558	538	480	378	393	371	299	418	378	372
Cogeneration	1,244	1,110	1,193	1,262	1,353	2,328	1,034	751	1,025	1,285	1,278
Solar heating	179	181	180	182	181	183	181	183	182	184	182
Air-conditioning units (MPES)	590	559	482	385	290	224	206	220	250	289	338
Lamps	-43	-44	131	-44	-44	133	-44	-44	134	-45	-45
Refrigerators (MPES)	379	338	299	296	315	337	359	382	408	433	451
Motors	235	0	0	0	0	384	0	123	0	0	337
Industrial lighting	24	8	0	17	12	12	14	13	19	24	11
Commercial lighting	55	27	0	57	49	24	44	33	41	54	26
GTL	850	0	0	0	0	1,275	0	0	0	0	1,700
Changing Design of New Refineries	637	0	0	0	0	1,172	0	0	0	0	1,172
Improving Energy Use of Existing Refinery Units (Heat Integration)	1,880	0	0	0	0	0	0	0	0	0	0
Improving Energy Use of Existing Refinery Units (Fouling Mitigation)	418	0	0	0	0	0	0	0	0	0	0
Improving Energy Use of Existing Refinery Units (Advanced Control)	696	0	0	0	0	0	0	0	0	0	0
Interconnection with Venezuela	0	0	0	0	0	0	0	0	0	0	0
Etanol exportation	1,471	1,605	1,736	1,823	1,863	1,855	1,852	1,820	1,764	1,684	1,584
Total	**12,136**	**7,283**	**7,609**	**7,624**	**7,671**	**11,290**	**7,035**	**6,904**	**7,473**	**7,631**	**9,942**

From the point of view of financial support, the following table shows the additional total value for the period 2010-2030 that would be necessary for constructing the Low Carbon Scenario: US$172 billion by 2030.

Table 103 –Financial Support (without discount rate)

	Low Carbon Measure	Value (US$ millions)			Sector
		Reference	Low carbon	Additional	
1	Combustion optimization	0	2,215	2,215	Industrial
2	Heat recovery systems	0	323	323	
3	Steam recovery	0	819	819	
4	Heat recovery in furnaces	0	8,074	8,074	
5	New processes	0	37,995	37,995	
6	Other energy efficiency measures	0	827	827	
7	Thermal solar energy	0	1,482	1,482	
8	Recycling	0	249	249	
9	Substitution for natural gas	0	4,088	4,088	
10	Substituting fossil for renewable sources of energy	9,321	12,357	3,036	
11	Substitution of the nonrenewable component of biomass	0	8,794	8,794	
12	Wind energy	0	12,898	12,898	Aeolic
13	Cogeneration	16,756	52,264	35,507	Cogeneration
14	Solar heating	434	3,854	3,420	Residential
15	Air-conditioning units (MPES)	5,309	11,197	5,888	
16	Lamps	903	1,197	295	
17	Refrigerators (MPES)	42,734	48,785	6,051	
18	Motors	3,399	4,601	1,201	Commercial/ industrial
19	Industrial lighting	108	286	178	
20	Commercial lighting	265	748	483	
21	GTL	2,310	6,986	4,676	GTL
22	Changing Design of New Refineries	116,753	120,908	4,154	Refineries
23	Improving Energy Use of Existing Refinery Units (Heat Integration)	0	4,028	4,028	
24	Improving Energy Use of Existing Refinery Units (Fouling Mitigation)	0	895	895	
25	Improving Energy Use of Existing Refinery Units (Advanced Control)	0	1,492	1,492	
26	Interconnection with Venezuela	1,676	455	-1,221	Hydroelectricity
27	Etanol exportation	0	25,098	25,098	Ethanol
	Total	199.969	372,914	172,945	

12 Final Comments

Substantial potential exists for reducing the greenhouse gas emissions produced by the Brazilian energy system. For the 2030 time horizon and taking as our Reference Scenario the *National Energy Plan 2030* of the Energy Research Company (EPE, 2007), we estimated a potential abatement of 1.8Gt O_2 between 2010 and 2030. In 2030 the abatement amounted to 158.7 $MtCO_2$ or 16.3% of the greenhouse gas emissions produced by the Brazilian energy system in that year according to the Reference Scenario. The additional investment needed on a yearly basis to achieve the Low Carbon Scenario amounted on average to US$8.2 million? which at present values represents US$73.2 billion? in 2007 at a rate of 8% per year.

This result is even more important given that this study did not embrace all the supply and demand sectors of end-user energy of the Brazilian energy matrix although it did include the key sectors.

Some mitigation options (with a discount rate of 8% a year) involving negative abatement costs could be deployed, providing a number of market barriers against their implementation were lifted. Key examples are the mitigation options concerned with (i) cogeneration from biomass; (ii) a series of measures in the industrial sector (such as optimizing the combustion and recovery of steam); and (iii) energy-saving measures in the residential sector (substituting incandescent lamps for fluorescent lamps etc). The present study proposed ways of overcoming these barriers.

The industrial sector is responsible for 72.7% of avoided emissions of the Low Carbon Scenario during the period under consideration. In the industrial sector we assessed that the initiative with the highest emissions-abating potential was the reduction or elimination of nonrenewable biomasses represented by the fuel wood and charcoal originating from deforestation, and the substitution of these materials for biomasses grown exclusively in specialist plantations.

Another important option was the reduction of carbon emissions from the world energy matrix based upon Brazil exporting bio-ethanol. This option needs however to overcome a series of substantial barriers preventing its implemention such as the protectionist approach by countries which possess the most potential for importing Brazilian ethanol. Infrastructure problems for transporting large volumes for export also need to be overcome. The exportation of ethanol - providing these impediments can be overcome in due course - should produce considerable benefits for Brazil and the wider world. This option, at a rate of 8% per year, also represented negative abatement costs.

In summary, Brazil finds itself in the group of emerging countries where both supply and demand of energy is likely to grow over the coming years. The official government Reference Scenario points to a growth in the primary energy supply in Brazil of 3.9% per year. Although the country enjoys an energy system with a larger number of renewable energy sources than elsewhere, the many challenges cannot be ignored. The Reference Scenario of the Brazilian energy system indicates more end-use of energy as well as the predominance of petroleum as the country´s main primary source of energy.

Different options exist for mitigating carbon emissions in the Brazilian energy sector. This study undertook a comprehensive analysis of these alternatives in the form of the construction of a Low Carbon Scenario. This scenario points to the potential for abating greenhouse gas emissions in this country and reveals that part of its potential could generate co-benefits for the national energy system. The scenario also points to the need to fine-tune this study to include, for example, new sectors of energy supply and demand as well as suggesting new mitigation options for the various sectors. Hopefully this study will contribute to formulating alternatives for future energy scenarios in Brazil and will assist our country to consolidate and broaden its role in international efforts to avoid the impacts of Global Climate Change.

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