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**BIOMass-based Climate Change MITigation through Renewable Energy
(BIOMITRE)**

BIOMITRE Technical Manual

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APPENDIX A. BIOMITRE Tool User Manual

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1. Introduction

1.1 About this Manual

This **BIOMITRE Technical Manual** should be used in conjunction with the **BIOMITRE User Manual** (available separately, although a copy is included in Appendix A for completeness) and the **BIOMITRE Tool**, a software tool designed to allow the calculation of energy, greenhouse gas (GHG) and cost-effectiveness implications of a wide range of biomass energy technologies. The BIOMITRE Tool is not intended for the novice user, as some knowledge of Life Cycle Assessment and/or biomass energy technologies is required. However, this Technical Manual is designed to assist BIOMITRE Tool users by providing technical and conceptual underpinning to both biomass energy technologies and Life Cycle Assessment. Hence, it should allow the user to utilise the tool and to input their own data confidently, and also to provide confidence in the results.

The aim of this Technical Manual is to enhance the useability of the BIOMITRE Tool - a widely-applicable and generally-acceptable means for promoting the benefits of appropriate bioenergy energy technologies by assessing the greenhouse gas balances and cost-effectiveness of emissions savings of individual schemes, and communicating good practice and raising awareness amongst relevant developers, consumers and policy-makers within the context of the Kyoto Protocol and subsequent commitments to European Union targets for global climate change mitigation

1.2 Background to the BIOMITRE Tool

This software tool has been developed through an accompanying measure, referred to as "**BI**omass-based Climate Change **MIT**igation through **RE**newable **E**nergy" or the **BIOMITRE** Project (European Commission Contract Reference Number NNE5-00069-2002). The BIOMITRE Tool is available in downloadable form from www.joanneum.at/biomitre/softwaretool. The project was designed to allow production of a software tool which provides a standard means of analysing the GHG balance and emissions-saving cost-effectiveness of biomass energy technologies. The work has been undertaken with funding from the Directorate-General for Energy and Transport of the European Commission (EC) and co-funding support from the International Energy Agency (IEA) Task 38.

Diverse biomass energy technologies present considerable potential for the large-scale exploitation of renewable energy sources in the European Union (EU). Additionally, these technologies offer significant prospects for reducing greenhouse gas (GHG) emissions which are associated with global climate change. However, in order to assist the promotion of these important technologies, it is essential that there is a wide understanding and appreciation of their GHG emissions benefits - hence, this software tool, based on a standard methodology.

By virtue of its intended application, it is important that the BIOMITRE Tool provides a transparent means of calculation with an essential modular design which reflects the specific elements of biomass energy technologies and their diversity. Its preparation is based on a standard methodology derived from established methods, studies and models which have been reviewed accordingly. Established case studies supply basic data within the software tool which incorporate unified and documented

methodologies. This enables the software tool to be tested and used to generate further case study material. The main strength of the tool lies in its flexibility, allowing experienced Life Cycle Assessment (LCA) practitioners to input their own data for a particular technology, area, time, and/or specific project, in order to assist in GHG and cost effectiveness evaluation.

The development of the BIOMITRE Tool takes place against a background of considerable activity in the commercialisation of biomass technologies, assisted, amongst other agencies, by the European Commission. By way of examples, here are 5 current or very recent such projects:

- **Project For The Production Of 200 Million Litres Of *Bioethanol* En Babilafuente (Salamanca) From Cereals And Lignocellulose**
Project Reference: NNE5/685/2001
Project Acronym: BABILAFUENTE BIOETHA
- **Production Of Clean Hydrogen For Fuel Cells By Reformation Of *Bioethanol***
Project Reference: ERK6-CT-1999-00012
Project Acronym: BIO-H2
- **Integrated Biomass Utilisation for Production of Biofuels Target Action H and J**
Project Reference: ENK6-CT-2002-00650
Project Acronym: CO-PRODUCTION BIOFUE
- **Large *Bioethanol* / ETBE Integrated Project in China and Italy**
Project Reference: ENK6-CT-2000-80130
- **Biomass and gas integrated CHP technology**
Project Reference: ENK5-CT-2000-00111
Project Acronym: BAGIT.

1.3 Aims and Objectives

The main aim of the BIOMITRE Project has been to assist the widespread propagation of biomass energy technologies throughout the EU as a cost-effective means of providing commercial renewable energy supplies which mitigate global climate change through GHG emissions savings. In this context, the BIOMITRE Tool is designed to enable a wide range of users to conduct assessments with relative ease and to foster confidence in the results amongst a broad audience. The intended applications of the BIOMITRE Tool include:

- raising awareness of GHG emissions savings by deriving sound case study material on typical examples of biomass energy technologies,
- demonstrating good practice in the design and operation of biomass energy technologies,
- evaluating means for improving biomass energy technologies to maximise GHG benefits and to increase emissions-saving cost effectiveness,

- determining the consequences for biomass energy technologies of current and future mechanisms for promoting renewable energy technologies and reducing GHG emissions, and
- targeting research, development and technological demonstration effort on biomass energy technologies in terms of GHG emissions savings.

The Tool is designed to be generally-applicable to all major commercial biomass energy technologies, including agricultural and forestry residues, energy crops and wastes. Additionally, it encompasses all the important elements of these technologies, including production (cultivation, harvesting, recovery. etc.), processing (chipping, pelletisation, baling, etc.), transportation (by road, rail, waterways, etc.), conversion (direct combustion, co-firing, gasification, pyrolysis, digestion, etc.) and end-product utilisation (heat, power, combined heat and power, liquid biofuels, etc.). The tool consists of modules which reflect these elements and accommodate their diversity.

The Tool has been developed in compliance with a standard methodology based on existing work, studies and models developed by IEA Tasks 25 and 38, and by other researchers in this field. Existing work has been reviewed, specified and recorded in a systematic manner as part of the BIOMITRE project (see Appendices B and C), as a basis for producing the unified standard methodology outlined in Section 4.

1.4 Biomass Energy Technologies

The term "biomass energy technologies" in the context of the BIOMITRE Project refers to means of producing energy in a useful form from any organic material. Due to the diversity of biomass material and methods of converting it into a variety of forms of energy, there are a considerable number of biomass energy technologies. Indeed, the possible range of unique technology chains is multiplied further when the various possible combinations of biomass sources (whether annual crops, longer term crops, residues, wastes or trimmings, and so on) are comined with the various possible conversion technologies and end-products, such as combined heat and power, electricity, heat, liquid and gaseous fuels, respectively. A brainstorm exercise within the BIOMITRE research group produced 903 biomass energy technology chains, broken down as follows:

Combined heat and power	=	114
Electricity	=	114
Heat	=	169
Gaseous Fuels	=	333
Liquid Fuels	=	173

2. The Environmental Benefits of Biomass Energy Technologies

Biomass energy technologies have both 'immediate' and future potential. In fact, in some European Union (EU) member states, biomass energy sources ranging from forest wastes to annual crops have already been encouraged and promoted, through government policies and incentives. In such instances, national government support is frequently justified in terms of saving imported fossil fuels, reducing CO₂ emissions, improving urban air quality, and assisting diversification, re-orientation and innovation in farming and forestry.

In practical terms, biomass energy technologies can be utilised as direct replacements for existing fossil-based energy services, for example, to generate grid electricity or biofuels (diesel and petrol substitutes). They may also be utilised for heat, and/or in localised energy systems. As illustrated in Figure 2.1, while roughly the same amounts of CO₂ may be emitted from the stack of the biomass power station tailpipe or the biofuel vehicle as the equivalent current fossil technology, in the biomass cases, it has only recently been 'fixed' by the plant through photosynthesis. Hence, upon combustion, last year's atmospheric CO₂ is simply being returned to the atmosphere it came from. This contrasts with fossil fuel carbon, which is being taken from the earth and released, thus adding to the overall 'carbon burden' in the atmosphere. However, unfortunately, things are not this simple, for in order to utilise biomass energy technologies, varying amounts of fossil fuels are currently required, for example, during crop growing, harvesting, processing and distribution. Thus, biomass energy technologies are not currently 'carbon-neutral' in the sense that they require the use of fossil carbon in production. Therefore, the "net GHG benefit" of a given biomass energy technology can be calculated by measuring the GHG generated in producing the biomass energy biotechnology, and subtracting from it the GHG generated in providing the equivalent conventional (fossil) alternative.

In order to assess the total environmental benefits of biomass energy technologies, the benefits and impacts should be measured relative to each other and to current practice (i.e. the production and use of conventional fuels). However, it is not realistically possible to measure and combine all environmental aspects together in a simple manner. A more realistic aim is to concentrate on those benefits which are associated with prominent environmental issues. It can be argued that, in addition to emissions of CO₂, the most prominent issues for the UK are fossil fuel resource depletion and the release of other greenhouse gases (GHG), thus providing three key parameters (GHG being a grouped parameter).

A number of studies have already been carried out along these lines for various biomass production chains. Therefore, there is an existing literature to call upon, notwithstanding the fact that production methods for different biomass energy technologies vary locally and nationally, as do figures for agricultural methods, crop yields, and so on. Of critical importance, however, is the fact that there are not only real differences in biomass energy technologies, but there are also differences in the way in which energy and greenhouse gas assessments of biomass energy technologies have been undertaken, leading to potential bias and variations between results which are due to methodological variation rather than solely to differences in technological circumstances. Hence, there is a need for a standard approach in this emerging field, to provide confidence amongst users, practitioners, decision makers and the wider public, that decisions made regarding biomass energy technology utilisation are made on the basis of correct and properly comparable results.

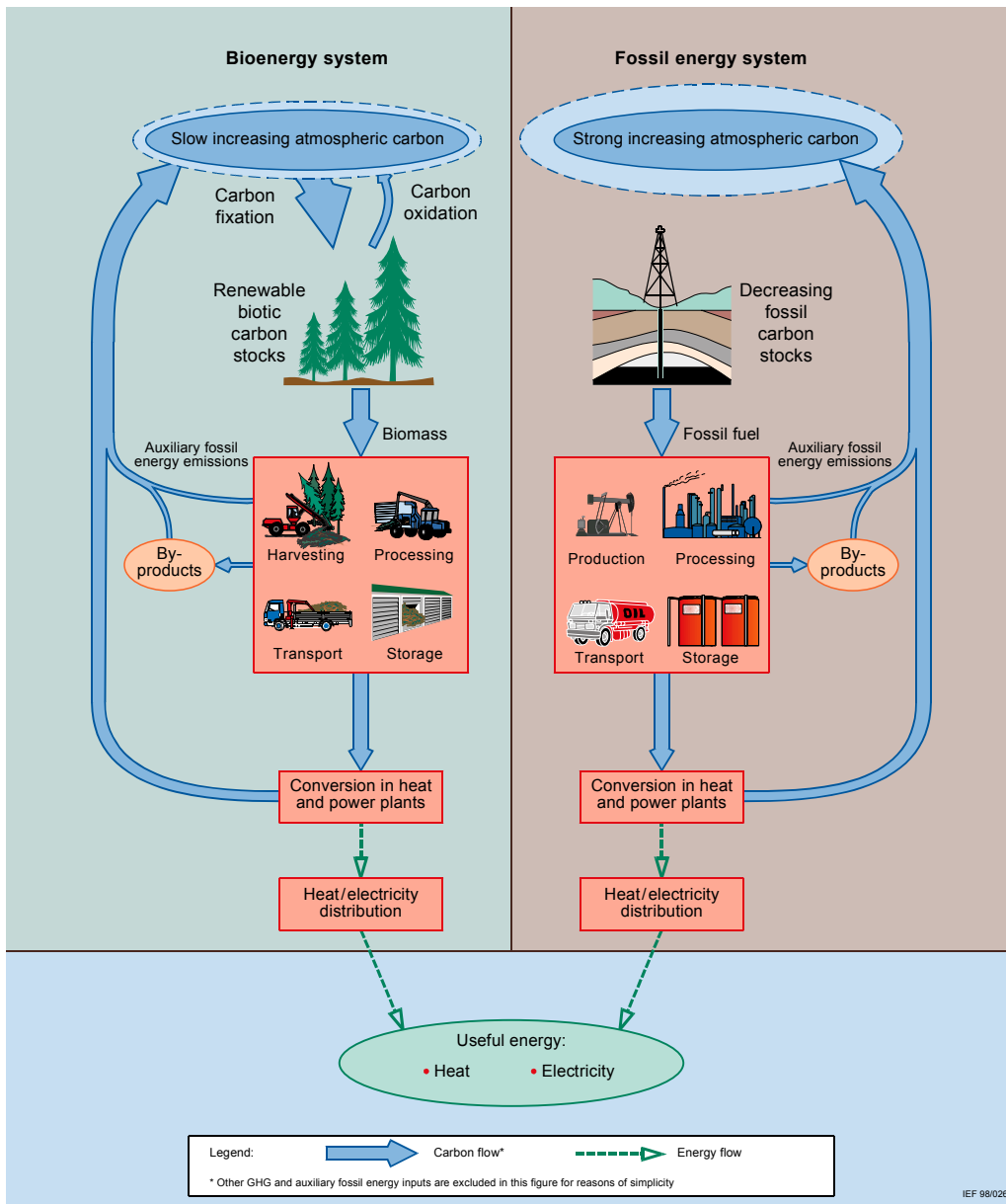


Figure 2.1 Comparison of Bioenergy and Fossil Energy Systems

3. Principles of Life Cycle Assessment for BIOMITRE

3.1 Overview

Having established that it is energy, CO₂ and GHG which are the main LCA parameters of interest (cost-effectiveness is considered separately in Section 6.7 below), these can be defined in more detail as; primary energy inputs, and net savings of CO₂ and GHG emissions, comparative to the use of current fossil fuel derived equivalents. These terms are further defined in Section 3.4.1. Other, more local environmental concerns, such as deterioration of air quality due to tailpipe emissions, are excluded from the scope of GHG accounting, but should be considered in a full-scale LCA (see Section 3.2 below).

The next step is deciding how measurement of each of these energy and GHG parameters is to be undertaken. Fortunately, there already exists a standard generic methodology for undertaking such measurements, in the form of the Life Cycle Assessment process. However, before examining this process, a short list of three main principles can be established which must be adhered to in order to ensure that the results of the measurements are accurate and meaningful. Firstly, if a difference is to be measured, then two measurements are needed; the 'new' and the 'old'. For example, both biodiesel and fossil diesel must be measured in order to see the difference between them. Secondly, all the measurements must be made using standard methods, to avoid methodological bias creeping into the results. For example, the method and approach used to identify CO₂ emissions from the production cycles of biodiesel and fossil diesel should be the same, to allow comparison to be possible. Thirdly, all the calculations, and any assumptions, must be transparent, so the reader can see clearly what has been considered and how. This is particularly important for new technologies and relatively new methodological approaches, where data and process are not always well-established and standardised. In a transparent study, if a part of the production process is updated at a later date, the reader can see the effect that this will have on the global calculations, so transparency makes results updateable as well as traceable.

3.2 Life Cycle Assessment

Life Cycle Assessment (LCA) is an established technique for quantifying the total environmental impacts of the provision of a product or service from original resources to final disposal, or so-called "cradle-to-grave". Its background can be traced back at least as far as the development of energy analysis in the 1970s. During this particular time, when concern about fossil fuel resource depletion was increasing due to the first oil shock, energy analysis emerged as a means of calculating the total energy required to provide products and services. Many of the approaches and conventions incorporated into LCA have their roots in the principles of energy analysis. Broader environmental concerns and implementation of environmental management have resulted in increased interest in LCA. Amongst numerous reasons for conducting LCA studies is the possibility of comparing the total environmental impacts of alternative products or services.

Although this is a laudable aim, the problems in achieving this, even for relatively simple production systems, is fraught with difficulty, not least in the problem of

comparing impacts which are measured in different and non-comparable units (e.g. human life or health, and financial losses to the economy from environmental damage). In order to avoid getting bogged down in such problems, the LCA methodological approach can be adapted to examine key comparable issues to be examined, rather than all environmental impacts. As indicated above, here, these key issues have been identified as fossil fuel depletion and contribution to global climate change.

3.3 LCA Standards and Practice

The practical use of LCA has been considerably enhanced by the adoption of an official framework for LCA in the form of the International Standard ISO 14040 series (ECS, 1997, 1998, 1999, 2000a, 2000b). This framework establishes the definitions and conventions of LCA, and provides practical advice on methods of calculation.

LCA involves six major stages:

1. Goal and scope definition
2. Life cycle inventory analysis
3. Life cycle impact assessment
4. Life cycle interpretation
5. Reporting
6. Critical review.

Setting the goal and scope of an LCA involves establishing the intended application of results and the reasons for generating them. The second stage, life cycle inventory analysis, involves quantifying relevant inputs and outputs of the life cycle of a product or service. This usually requires considerable data collection and analysis, since various life cycle inputs and outputs must be quantified, including energy resources, such as fossil fuels, and emissions to atmosphere, such as CO₂ and other greenhouse gases. Life cycle impact assessment uses the inventory data as a starting point for evaluating the significance of potential impacts from the life cycle of the product or service. This is achieved by "classification", which involves assigning life cycle inputs and outputs to impact categories, "characterisation", where results are combined within impact categories, and "weighting", which incorporates further aggregation of results. All the findings are brought together in life cycle interpretation prior to reporting and critical reviewing, which are the final major stages of the exercise.

3.4 Energy and Greenhouse Gas Accounting

When energy and Greenhouse Gas (GHG) accounting is undertaken using LCA principles and practice, it is mainly concerned with the first two major stages outlined above; Goal and scope definition, and Life cycle inventory analysis. These are discussed further as they relate to biomass energy technologies in the following subsections. In addition, more detailed definitions of key terms are incorporated into goal and scope definition.

3.4.1 Goal, Scope and Definitions

3.4.1.1 Goal and scope

As explained above, the BIOMITRE Tool is intended to achieve a comparison between a chosen biomass energy project and the conventional equivalent. This is intended as a basis for policy makers to determine the relative benefits of biomass energy projects and technologies and thus, the extent to which they warrant promotion and development. Another key aspect of LCA scoping is establishing the "functional unit" which is being investigated, which enables subsequent results to be interpreted correctly and in a meaningful manner. For example, the functional unit could be a kilogram or litre of biofuel or conventional fuel, or a joule of useful energy.

Also, it is essential to identify the general limits of the study and carefully define the key parameters to be investigated. Since energy, and CO₂ and other GHG emissions are the principal considerations here, it is necessary to provide related definitions.

3.4.1.2 Defining Energy

The appropriate measure of fossil fuel resource depletion is **primary energy**, which consists of the amount of energy available in resources in their natural state, such as coal, natural gas and oil deposits in the ground. As such, it is an indicator of energy resource availability which is greater than the energy provided by fuels and electricity used by consumers, known as **delivered energy**, and the energy services required by these consumers, referred to as **useful energy**.

If the product or service under investigation is specified in physical terms, then the energy result is referred to as the **energy requirement**, which is equal to the total amount of primary energy involved in the provision of a given product or service. Depending on the nature of the product or service, the energy requirement can be measured in different physical units, such as weight (MJ/kg), volume (MJ/l) or energy (MJ/MJ). The total amount of primary energy consists of the sum of the direct energy due to the use of fuels and electricity, the indirect energy associated with the production of materials, equipment, etc., and the energy contained in any feedstocks, such as chemicals and materials derived from fossil fuels. The energy requirement of a fuel can also include its calorific value, in which case the result is referred to as the gross energy requirement.

Therefore, the energy content of an energy product reflects either its total calorific value, in which case it is generally referred to as **gross energy content**, or the total available energy obtainable from the product, generally referred to as the **net energy content**. Hence, the net energy content reflects the necessary losses involved in utilising the product arising from the need to vaporise any moisture within it.

3.4.1.3 Defining Greenhouse Gas Emissions

There are essentially four types of greenhouse gas emissions, according to the nature of the emission and the point at which it takes place. First, there are the direct emissions, such as those which leave the stack or exhaust pipe at the point of energy

conversion or utilisation. However, generally, in the case of biomass technologies, the most significant GHG emissions occur upstream, as the indirect result of using fossil fuels for energy to create the biomass energy product. In other words, GHG accounting in this area is based, principally, on the evaluation of emissions from the use of fuels and electricity in producing the product under investigation. This is achieved by means of suitable combustion emission factors, which indicate the GHG emissions produced per unit of energy available when a fuel is burnt or electricity is generated (such as kg CO₂/MJ). Although such carbon and other GHG coefficients include CO₂ and other GHG emissions from electricity generation, they usually exclude CO₂ and other GHG emissions from other fuel cycle activities, such as the construction, operation and maintenance of infrastructure for processing fuels. Hence, this provides a third source of GHG emissions. In order to clarify the basis of subsequent calculations, the term gross carbon coefficient can be adopted to represent the total CO₂ emissions produced per unit of energy available from fuels or electricity (also measured as kg CO₂/MJ), and so on, for other GHG emissions.

Finally, there is the matter of feedstocks in GHG calculations. This is more complicated than in primary energy calculations. Whether any GHG emissions arise from feedstocks which store potential GHGs originally derived from fossil fuels depends on the ultimate fate of these constituents. If the carbon always remains stored in the feedstock, then it is excluded from calculations. However, if the feedstock is eventually burnt or decomposes naturally, the CO₂ released must be included. For example, since natural gas is used routinely as a feedstock from which inorganic nitrogen fertiliser is manufactured, the fate of the potential GHGs within the fertiliser product and associated by-products or waste products must be included as it contributes to global climate change (note that if other products are produced in the process, **allocation** may be required, as discussed below).

Using these measurements, coefficients and factors in LCA, for each of the potential GHGs (principally, CO₂, CH₄ and N₂O), it is possible to derive the total GHG requirement of a product or service, which consists of the total GHG emissions associated with the provision of a physical unit of the product or service.

3.4.2 Life Cycle Inventory Analysis

Life cycle inventory analysis is based, primarily, on systems analysis, which treats the process chain as a sequence of sub-systems that exchange inputs and outputs. The starting point is, therefore, to define the system(s) under study. There are essentially two types of systems of interest to the BIOMITRE Tool; the biomass energy technology production system, and the current alternative system(s) for comparison.

3.4.2.1 Drawing the System Boundary

Each complete system and sub-system has a boundary drawn around it, and materials and energy which cross each boundary are relevant to the inventory. A simple, general flow chart is sufficient to illustrate this approach when applied to biomass energy technologies (see Figure 3.1). Hence, the application of systems boundaries might, at first, seem like a self-evident and simple exercise. However, even for quite uncomplicated process chains, the issue of systems boundaries is an important and potentially complex consideration. The reason for this is that almost any activity requires inputs, ranging from raw materials to sophisticated machinery. These must be provided by other activities or, from the perspective of systems

analysis, other systems. In an industrial economy, there are links, immediately or remotely, between any one activity and all the other activities in the economy. Hence, when preparing a life cycle inventory, it is, in theory, necessary to trace all these connections in order to account for all the accumulated inputs and outputs.

The sum total of inputs and outputs to be included in the study must then be linked together in the process chain, which reflects the life cycle of the product or service from the original natural resources, or "cradle", through actual use, and on to eventual disposal, or "grave". In the case of a biomass energy technology, the product is invariably entirely consumed (combusted) during its use. However, disposal does effectively occur, since most of the combustion products (e.g. stack/exhaust gases), are released into the environment. Fortunately, LCA recognises these as outputs, which are accounted, along with other outputs and inputs, to the process chain. For example, the process chain for biodiesel production consists of oilseed rape cultivation, transportation from farm to mill, drying, storage, solvent extraction of rapeseed oil, refining, esterification, and transportation to points of distribution and sale.

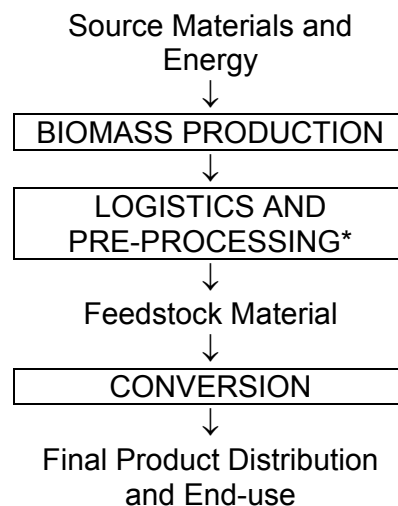


Figure 3.1 General Flow Chart for Biomass Energy Technologies

*Note: This may involve several steps, including transport, drying, etc., and may result in one or more by-products or waste products.

3.4.2.2 Reference Systems

Linked to the process chain, one aspect of LCA which needs to be considered for biomass energy production is the matter of reference systems, which are used to determine credits for alternative activities that are avoided or displaced. These essentially fall into two categories; alternative land use activities, and alternative energy products and services.

Regarding land use reference systems, the land which is used for growing a biomass energy crop could be used for another purpose, or maintained as fallow. A credit will be appropriate where the use of the land for biomass production results in the cessation of other activities which would cause primary energy use and climate change, for example, the regular mowing and maintenance of fallow set-aside land, where the credit given to the biomass system should equal the primary energy/GHG

avoided by the cessation of maintenance. On the other hand, a negative credit is due where the change of land use would lead to a release of carbon from the soil which otherwise would not have happened. This is a contentious area, although it should be noted at this point that such a debit/credit is a 'one-off' event, whereas avoided maintenance is ongoing for the lifetime of the biomass production system. When selecting an appropriate reference system, it is important to use that which is most likely in practice and which reflects current/expected economic reality.

Energy service reference systems credits are the primary energy and GHG which would be emitted if conventional energy services were provided instead of those provided by the biomass energy system. Hence, an essential comparison needs to be made between the primary energy and GHG implications of production (the energy/GHG requirement of the biomass energy product) and the primary energy and GHG input to conventional fuel production (the gross energy/GHG requirement of the conventional fuel). For example, for the biomass energy system cited in the preceding section (biodiesel production from oilseed rape), the relevant energy service reference system in the EU might typically be conventional ultra low sulphur diesel, which involves exploration and extraction from crude oil deposits, transportation from oilfield to refinery, refining (including hydro-cracking), and transportation to points of distribution and sale.

3.4.2.3 Allocation Procedures

Process chains which involve the provision of more than one product or service present a further important issue for LCA, because inputs and outputs then need to be divided between them. The various methods of division are called allocation procedures, and there is no single procedure which is appropriate for all circumstances. Indeed, there are three main ways to allocate primary energy/GHG implications between main products, co-products (which involve similar revenues to the main product), by-products (which result in smaller revenues), and waste products (which provide little or no revenue).

According to ISO14040, the preferred allocation procedure uses a substitution approach, where the main conventional process for producing a co-product, by-product or waste product is used to generate comparative effective credits, which are then subtracted from the life cycle inventory of the process chain under investigation. This allocation procedure is fundamentally sound, but clearly increases the scope of the LCA to include process chains of main methods of production of the relevant by-products and co-products. Also, the substitution approach cannot necessarily be used when co-products, by-products or waste products are not normally produced by any main process. There are numerous co-products, by-products and waste products generated by biomass energy production, including, variously, straw, soil, meal, bran and glycerine. Invariably, these are produced mainly as by-products of other process chains. Although this apparent conundrum may be solvable mathematically, using simultaneous equations, it does not necessarily make practical sense to expand the system boundary in such a way, for reasons which may vary from resources and data availability to the actual substitutability (in detail), to the potential availability of the substitution product in the quantities expected, produced by the current conventional means.

Hence, it is sometimes necessary to revert to simpler allocation procedures, of which allocation by market price and subsequent revenue is often the most appropriate. This is invariably not an 'ideal' solution, since market prices often fluctuate, and in such cases the results of the LCA will change. However, the market price should

reflect the value of the by-product in proportion to the main product as far as the producer is concerned, and thus, it is a valid measure of the proportional value society places on each, and therefore the same proportion of primary energy/GHG implications can be used in calculating allocation credits.

The third means of achieving allocation is by using more fixed physical relationships between the main product and by-products. The mass, volume or calorific value of products can be used, although such simple bases for allocation need to be justified satisfactorily, and this is only likely to be a logical and valid option in specific circumstances. For example, in cases where all the products are fuels, such as petroleum products produced by an oil refinery, allocation by relative output and calorific value can be regarded as appropriate. However, allocation by this means for products which might have calorific values but are not, in fact, used as fuels, is quite tenuous and not suitable.

3.5 Other LCA Software Tools

The ISO standard for life cycle assessments has been incorporated in computerized tools, developed for increased user-efficiency, and with suggested applicability to a range of assessment situations, including biomass energy systems.

GEMIS is a modular tool which evaluates environmental impacts of energy, material and transport systems for a given energy system (Fritsche, 1999, 2002). GEMIS software and databases are public domain software and can be downloaded from a web site, free of charge (currently available from Öko-Institut, Darmstadt, DE). Representing a major step forward in comprehensive, standardised assessments of energy systems, it was developed to illustrate efficiency, emissions, waste, pollutants, land-use and costs (investment costs, fixed and variable annual costs and externality factors for air and GHG).

SimaPro is a computerized LCA-tool, designed to collect, analyse and monitor environmental information for products and services, with integrated databases and impact assessment procedures (Goedkoop and Oele, 2002: SimaPro is currently marketed by Pré Consultants, Amersfoort, NL). Each step is clear and the process tree can be used to display results, showing a high degree of transparency, since calculations are shown alongside each process box. It is possible to view parts of the life cycle at different scales, and to display their contributions to the total score. Functional units definition is incorporated, as is sensitivity analysis, although SimaPro is not specific to biomass energy systems and has no function for calculations of costs. Also, transparency is somewhat reduced in SimaPro as algorithms are not immediately obvious in results compilation, and incorporation of allocation and reference systems is not explicit. There is no means of checking the completeness of the process chain, or data fitness or quality.

4. The BIOMITRE Standard Unified Methodology

4.1 Development

The BIOMITRE Standard Unified Methodology (BIOMITRE Methodology) has been developed following completion of the following Work Packages within the BIOMITRE Project:

- **Work Package No.1 Review of Existing Methodologies**, which is the responsibility of Mid-Sweden University, and confirms the basic nature and any deficiencies of the main existing methodologies for evaluating GHG balances and emissions-saving cost-effectiveness of prominent biomass energy technologies relevant to the EU (see Appendix B).
- **Work Package No.2 Collation of Existing Data**, which is the responsibility of VTT Processes, and brings together, evaluates and summarises case study material for evaluating GHG balances and emissions-saving cost-effectiveness of prominent biomass energy technologies relevant to the EU (see Appendix C).

Further theoretical and scientific underpinning for the BIOMITRE Methodology is contained within these two Appendices, in particular, the reader in search of further detail in this regard is referred to Appendix B. This also provides the basis for the unified methodology for evaluating GHG balances and emissions-saving cost-effectiveness of prominent biomass energy technologies relevant to the EU. The methodology is outlined in this section, although further detailed documentation of the technical issues are provided in proceeding sections for each of the three main work stages respectively, as follows; Process description (Section 5); Data input (Section 6), and; Summary results (Section 7).

4.2 Process Description

Given that the BIOMITRE Tool is designed specifically to examine primary energy, GHG and cost-effectiveness of different biomass energy technologies, the first step is to identify the main product(s) - invariably, these will either be in the form of electricity, heat or biofuel (or a combination). The Tool operates in Joules, the basic fundamental unit of energy, so the user will need to specify output(s) in terms of net calorific value. Working back up the chain from a unit of product(s), the systems boundary can then be drawn around each distribution/end-use, conversion, logistics, and biomass production step, to include the consumption of fuels and electricity for all these main process steps, the provision of these fuels and electricity, the production of major agricultural supplies and processing chemicals from natural resources, and the manufacture of all plant and machinery and its maintenance. As a result, a biomass energy system flowchart is produced by the user, showing the flows of energy and materials through the production system, and points at which wastes and by-products are produced (and so materials/energy leaves the system and may require a credit as necessary).

Once the biomass energy system flowchart is generated and key flowchart parameters are set, the inventory of system processes can be generated. For each stage in the production chain, data are required, and the sum of these data forms the

inventory. Further details of flowchart creation, setting basic parameters, and making the inventory are included in Section 5, with examples.

4.3 Data Input

It is a good idea to assemble key data before inputting using the BIOMITRE Tool is commenced. This enables the user to become conversant with the key parameters and familiar with the basic LCA aspects of the project being studied. It also allows the decision to be taken over what level of data entry is to be used (the Tool allows for a range of detail from basic (level 1) to highly detailed (level 3)). Further information on this is contained in Section 6.1 and in the User Manual (Appendix A).

It should be noted at the outset that it is the users responsibility to ensure that data inputted is consistent, for example, they all apply on an annualised time frame, they all apply to the same period, and they all apply to a representative plant/process, of a given size and in a given location. Also of critical importance, is the selection of data sources. Where data is required from previous studies, these should be examined to ensure that they meet the requirements of transparency, and that they are likely to present data which is appropriate (or can be adjusted to make it appropriate) to the specific case being studied. Further guidance is contained in Section 6.

The user must also use the advice laid out in ISO14040 (see also Section 3.4.2 above) to carefully and as accurately as possible select reference system data and choose appropriate allocation rules, and there should be consistency across the energy, GHG and cost-effectiveness data. Other issues of importance include timing, multiple outputs, and vegetation carbon stock changes, and these issues are all considered further in relevant parts of Section 6.

4.4 Summary Results

The BIOMITRE Tool is designed to automatically generate results tables and some graphical output relating to demonstration of energy and GHG balances and relative cost-effectiveness of the project being studied. It also allows for the user to conduct multiple runs in order to investigate the effects on the bottom line outputs of altering key values, either to assist project design, or to carry out rudimentary sensitivity analysis to assess the effects of data ranges where there is uncertainty. These issues and reporting are considered further in Section 7.

5. Process Description

5.1 Making a Biomass Energy System Flowchart

As outlined in Section 4.2, the first step is to identify the main product(s). To illustrate the flowchart generation process, we can use the example of biodiesel production from oilseed rape.

The starting point in developing the flowchart is therefore the (in this case) single product, biodiesel. Figures could be normalised to a tonne of biodiesel, or a number of km travelled, although, since the fundamental unit the Tool operates in is Joules, the user will need to know the net calorific value of the biodiesel. Working back up the chain from the biodiesel at the point of use, the next step back is distribution, which is a logistics step. Prior to this is the main energy conversion step, in this case, the esterification of the rapeseed oil into Rape Methyl Ester. Therefore, in creating the flowchart, the two boxes prior to end-use are distribution and esterification. However, between these steps a by-product is produced, since glycerine is a product of the esterification process, so on the flowchart, the exit of this by-product from the system should be noted.

Working backwards further, there is oil refining, preceded by extraction of the oil from the rapeseed. There are two main commercial processes for this; mechanical crushing, and solvent extraction; in this example, the latter technology is advocated. Hence, we add boxes for these two steps, and another note to reflect the exit of the by-product rape meal during solvent extraction.

Prior to this is rapeseed transport from the field, and drying and storage in preparation for solvent extraction, each of which require logistics steps. Prior to this is cultivation of the oilseed rape crop, although again it should be noted the potential for the production of rape straw as a by-product of crop production and harvesting. Finally, the input of seed provides the first point of the main biodiesel production chain flowchart. Hence, the basic flowchart is now complete, and this is illustrated in Figure 5.1.

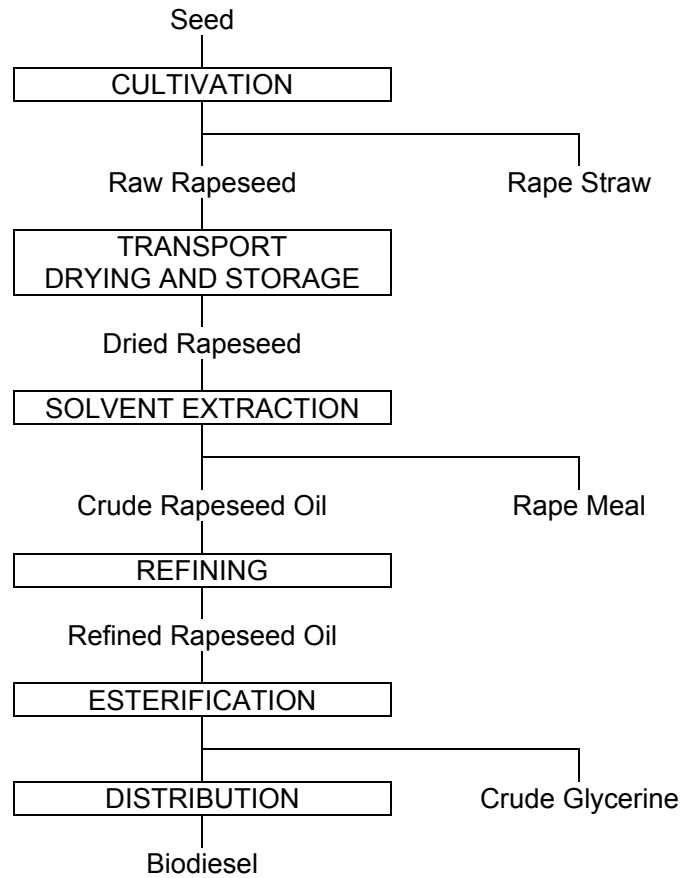


Figure 5.1 Basic Flowchart Example for Biodiesel Production from Oilseed Rape.

5.2 Setting Basic Flowchart Parameters

Once the biomass energy system flowchart is generated, key flowchart parameters can be set. Amongst these is a mass and/or energy flow, which describes the way in which raw materials/energy flow through the system to create a given amount of end-product. Hence, continuing with the example of biodiesel production from oilseed rape, Figure 5.2 shows in mass terms how an given amount of 1 tonne of biodiesel is produced from constituent relative amounts of and intermediate raw materials through the flowchart. This could also be illustrated in terms of joules of energy, in terms of net calorific values.

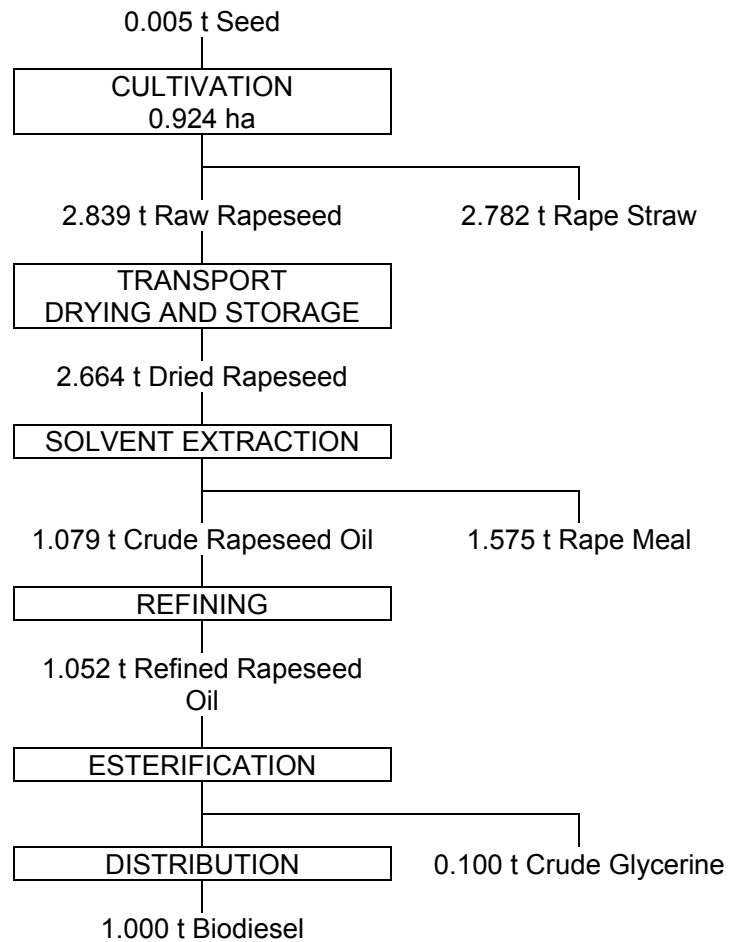


Figure 5.2 Basic Flowchart Example for Biodiesel Production from Oilseed Rape Showing Main Mass Flows.

5.3 Making an Inventory of System Processes

Once the flowchart with main mass flows is produced, this can be used as a basis to produce the inventory of system processes. For each stage in the production chain, data are required, and the sum of these data forms the inventory. For example, in the case of biodiesel from oilseed rape, cultivation must include consideration of all of the inputs, including the farm machinery manufacture and maintenance, as well as the fuel used by these machines. Primary energy is consumed as a result of the fuels and electricity used in the factories which manufacture agricultural equipment. Such factories also require raw materials, such as steel, which itself involves the consumption of further primary energy through the fuels and electricity used in the steelworks.

This process continues up the supply chain, and it may seem to present insurmountable problems for the calculation of total primary energy inputs and CO₂ and other GHG outputs. Fortunately, there is a practical solution to this which, in effect, involves checking the relative contribution of successively removed systems in the process chain. In general, successive contributions diminish in relative

magnitude, and it is often possible to draw the systems boundary around a fairly small group of systems connected to the main process chain. For example, it might be found that the primary energy inputs of fuels and agrochemicals used in cultivation are very important, whereas those of farm machinery manufacture and maintenance are considerably less significant. The method for tracing and accounting for each connected system within a process chain is referred to as process analysis, whereas another method called statistical analysis, which is based on input-output analysis of complete economic systems, provides a way of deriving approximate results that incorporate the effects of all the connections. As a result, an inventory can be produced which is complete enough to encompass those parameters for which significant results in terms of primary energy use may be obtained, and an example for the biodiesel from oilseed rape example is given in Table 5.3

CULTIVATION	Reference Land Use	ESTERIFICATION
Main Land Use	Diesel Fuel for Mowing	Natural Gas
Diesel Fuel:	Machinery for Mowing	Electricity
- subsoiling	Maintenance for Mowing	Heavy Fuel Oil
- ploughing	Labour for Mowing	Light Fuel Oil
- harrowing	TRANSPORT	Caustic Soda (50% concentrated)
- sowing	Diesel Fuel	Methanol
- fertiliser application	Vehicle	Equipment
- pesticide application	Maintenance	Maintenance
- harvesting	Labour	Labour
- or all operations	Other Items	Other Items
Machinery:	DRYING	
- subsoiling	Fuel Oil	DISTRIBUTION
- ploughing	Equipment	Diesel Fuel
- harrowing	Maintenance	Vehicle
- sowing	Labour	Maintenance
- fertiliser application	Other Items	Labour
- pesticide application	STORAGE	Other Items
- harvesting	Electricity	
- or all operations	Equipment	
Maintenance:	Maintenance	
- subsoiling	Labour	
- ploughing	Other Items	
- harrowing	EXTRACTION	
- sowing	Natural Gas	
- fertiliser application	Electricity	
- pesticide application	Hexane	
- harvesting	Equipment	
- or all operations	Maintenance	
Labour:	Labour	
- subsoiling	Other Items	
- ploughing	REFINING	
- harrowing	Natural Gas	
- sowing	Electricity	
- fertiliser application	Heavy Fuel Oil	
- pesticide application	Light Fuel Oil	
- harvesting	Phosphoric Acid	
- or all operations	Smectite	
Land	Equipment	
Seeds	Maintenance	
N Fertiliser	Labour	
P Fertiliser	Other Items	
K Fertiliser		
Lime		
Sprays:		
- pesticides		
- herbicides		
- fungicides		

Figure 5.3 Inventory of System Processes for Biodiesel Production from Oilseed Rape

6. Data Input

6.1 Levels of Data

The BIOMITRE Tool allows the input of three levels of data. For all levels, a range of basic data is required, which covers both the basic parameters discussed above, and key information about reference systems and allocation. An example for Biodiesel is presented in Figure 6.1.

The level of detail of the input data for the primary energy and GHG emissions required for the three levels are:

Level 1:

- Totals of primary energy and GHG emissions for each stage of system processes.
- Prices are used for cost data.

Level 2:

- More detailed inputs of primary energy and GHG emissions. Logistics and pre-processing stages can be broken down into more steps (up to 9 steps).
- Cost data can be entered as total costs for the different stages e.g. 'total cost for biomass production' or 'total cost for fuel distribution'.

Level 3:

- In this most detailed level, the biomass production stages can be broken into more steps within each of the selected biomass production systems (e.g. perennial crops, annual crops or forestry and waste).
- Detailed cost data for each step is required for this level.

For further details on inputting data at different levels the reader is referred to the BIOMITRE User Manual (Appendix A).

Description of Functional Unit:	Biodiesel at point of distribution from oilseed rape using solvent extraction		
Final Unit of Measurement:	1 tonne of biodiesel (bd)		
Relevant Location:	United Kingdom		
Relevant Period:	1996		
Allocation Procedures:	Cultivation:	Land Requirement (ha.a/t bd)	0.924
		Amount of Main Output - raw rapeseed (t/a)	2.839
		Price of Main Output - raw rapeseed (Euro/t)	185.44
		Amount of By-Product - rape straw (t/a)	2.782
		Price of By-Product - rape straw (Euro/t)	30.5
		Allocation to Main Output - biodiesel (%)	54.52896274
	Transport	Raw Rapeseed Requirement (t ros/t bd)	2.839
		Allocation to Main Output - biodiesel (%)	63.31747556
	Drying	Dried Rapeseed Requirement (t dos/t bd)	2.664
		Allocation to Main Output - biodiesel (%)	63.31747556
	Storage	Dried rapeseed requirement (t dos/t bd)	2.664
		Allocation to Main Output - biodiesel (%)	63.31747556
	Extraction	Crude Rapeseed Oil Requirement (t cro/t bd)	1.079
		Amount of Main Output - crude rapeseed oil (t/a)	1.079
		Price of Main Output - crude rapeseed oil (Euro/t)	394.06
		Amount of By-Product - crude rapeseed oil (t/a)	1.575
		Price of By-Product - crude rapeseed oil (Euro/t)	102.48
		Allocation to Main Output - biodiesel (%)	63.31747556
	Refining	Refined Rapeseed Oil Requirement (t rro/t bd)	1.052
		Allocation to Main Output - biodiesel (%)	87.35332464
	Esterification	Amount of Main Product - biodiesel (t/a)	1
		Price of Main Product -biodiesel (Euro/t)	326.96
		Amount of By-Product - crude glycerine (Euro/t)	0.1
		Price of By-Product - crude glycerine (Euro/t)	473.36
		Allocation to Main Output - biodiesel (%)	87.35332464
	Distribution	Amount of Main Product - biodiesel (t/a)	1

Figure 6.1 Basic Data for Biodiesel Example.

Ideally, data should also be accumulated (from reputable sources - see Section 6.2) for each of the items on the inventory of system processes, prior to input into the BIOMITRE Tool. For each row, 5 pieces of data are required; primary energy, CO₂, CH₄, N₂O, and total GHG.

6.2 Obtaining and Checking Data

Since the BIOMITRE Tool is designed so that users can input their own data in order to generate project-, time-, and place-specific results, close attention must be paid to the nature and source of these data. Much may relate to the specific design parameters of the project being studied. However, there may be a need for the user to input other data which are related but not directly available within the project design. In such cases, studies and data available elsewhere will need to be selected and used.

Ideally, studies which are to be used as sources of data should be transparent and should clearly explain the systems considered and the processes included in the analysis. Most specifically, all major assumptions and key parameters should be stated. A study would be regarded as being completely transparent if the information which it contains could be adopted with confidence and modified, if necessary, to calculate new results which reflect representative circumstances in the EU or any member state. Of specific concern in the matter of transparency are matters relating to allocation products and procedures for partitioning energy inputs and GHG outputs between different products. Numerous biomass energy technologies have diverse main products, co-products, by-products and waste products. Existing studies adopt a range of allocation procedures which may or may not be appropriate.

Another common weakness within existing studies is in consistency of data used and calculations. It is essential that potentially large inputs are calculated using the same systems analysis principles and rigorous approach to feedstocks and allocation issues as to the main process chain itself. Most studies recognise that the primary energy consumption and GHG emissions of manufacturing major inputs can play a prominent role in the calculation of the energy and carbon requirements of the biomass energy product but, unfortunately, full details of the derivation of these elements are only provided in a few instances.

As a consequence of this, it can be seen that completely transparent, complete studies are very important. Obviously, degrees of transparency exist and many studies which have only partial transparency may do so for various good reasons, but their use is limited here. Clearly, this is irrespective of the fact that the study in question may be full, accurate and relevant for the purposes to which it was intended. Also, even for relatively transparent studies, their relevance here may be reduced because assumed growing conditions do not reflect circumstances in the EU. For further information on data and potential reference studies, refer to Appendices B and C.

It is therefore of critical importance for the purposes of transparency, to fill in the literature references in each data entry box when inputting data into the BIOMITRE Tool. Refer to the yellow coloured cells at the bottom of data boxes. The references are then stored in a separate sheet called "LIT.REF" (see also the BIOMITRE User Manual, Appendix A).

6.3 Energy and GHG Data

As discussed in Section 4.3, it is a good idea to assemble key data before inputting using the BIOMITRE Tool is commenced. The user should follow the advice laid out

in ISO14040 (see also Section 3.4.2 and 6.2) to identify and evaluate appropriate data sources.

It is envisaged that most users will rely upon existing published data sources in compiling most of the energy and GHG data. However, it is possible that the Tool may be used to evaluate a project for which specific physical data is available, so that most use can be made of the Level 3 data input option. Hence, there are two main methods of calculating total energy inputs and associated GHG emission outputs - these are generally referred to as process analysis and statistical analysis. The following paragraphs summarise these two options, and are adapted from a previous study (Elsayed and Mortimer, 2001).

Process analysis involves determining energy and GHG parameters principally using physical data for a specific project. This requires considerable information on the process under examination and, ideally, all the processes in the supply chain from the original raw materials which provide all the products and services used in the process. This can be a very demanding requirement, since process analysis must be based on either exhaustive investigation of the entire supply chain and all its links and/or a very extensive database of energy and carbon requirements for all the inputs to the process under consideration. Apart from the substantial amounts of time and effort which may be needed in the collection and analysis of all necessary data, problems can also be encountered with the confidentiality or proprietary nature of the information required. The results obtained are usually very specific to a particular product or service derived from a given process at a certain time and location. This means that such results are often used with a relatively high degree of confidence since they are regarded as comparatively accurate and reliable. However, one subsequent drawback is that considerable work is usually required to obtain results which may reflect the range of sources and processes used to obtain typical products and services generally available on the economic market.

The alternative method of **statistical analysis** relies on national financial statistics which summarise all the processes and all the subsequent products and services which comprise the economy of a single country, part of a country, or collections of countries. Such statistics are normally represented by means of so-called input-output tables which can be manipulated by established mathematical procedures to derive energy and carbon intensities of groups of products and services. Provided that the input-output tables are suitably prepared and information is available on the fuel and electricity purchases of individual groups of industries, then it is possible to derive results relatively quickly and easily. Despite this particular attraction, even with highly detailed, large and disaggregated input-output tables, subsequent results consist of statistical averages for potentially-broad or general ranges of products and services. Hence, they are often regarded as relatively approximate results which are used when specific results from process analysis are not available. However, by using a variety of other statistical sources, it is possible to estimate the ranges of likely energy and carbon intensities which these results reflect. This provides indications of their comparative accuracy and reliability.

Another feature of the results of statistical analysis which may sometimes be a cause for concern is that, unlike process analysis which produces energy and GHG requirements measured per unit physical output (for example, MJ/kg or kg CO₂-eq./kg), this method derives energy and carbon intensities measured per financial output (for example, MJ/Euro). In addition to problems of unfamiliarity which this may create, it is necessary to use energy and GHG intensities with particular caution. The reason for this is that the financial value incorporated in an energy or GHG intensity must be equivalent to the financial value of the product or service which is being

evaluated in an energy or GHG analysis. There can be substantial differences in financial values, in terms of factory-gate, wholesale or retail prices or costs. Hence, it is necessary to ensure that complementary data are used together. Because of this perceived difficulty, it is often preferred that energy and carbon intensities obtained from statistical analysis are converted to energy and GHG requirements. Again, special care is needed to achieve this properly.

Frequently, it is necessary to combine the results of process and statistical analysis in the evaluation of energy and carbon budgets. This is mainly due to incompletely comprehensive databases. As a consequence of basic considerations which affect their derivation, results from process analysis are often used for basic products and services, whilst results from statistical analysis have to be used for more complex products and services.

6.4 Dealing with Multiple outputs

The BIOMITRE Tool is able to deal with multiple outputs from a Biomass energy technology, and provides a means for calculating total energy, GHG and cost-effectiveness for the project on an energy basis. For example, if the project will produce both heat and power, then the starting point to reflect this in the Tool is to select “combined conversion unit” when data fields in the conversion sheet are to be completed (see BIOMITRE User Manual, Appendix A).

6.5 Timing Issues

The current version of the BIOMITRE software tool relies on a simplified approach to handling energy inputs and outputs that may occur at different times. This involves annualising system inputs and outputs over the life cycle of a biomass energy project. Hence all relevant data must be prepared for input into the BIOMITRE Tool on the basis of emissions per year. Therefore, for example, indirect primary energy inputs (and the resultant GHG emissions) in construction of plant materials need to be annualised over the expected lifetime of the plant, in order to provide an annual equivalent figure for input into the model.

Direct emissions from annual crops are normally expressed in energy/emissions per year, so these figures can be used directly in the Tool. However, where crop cycles extend beyond annual patterns, for example, where crop rotation is used to fix Nitrogen in organic systems, or in forestry or perennial systems, where growing and cropping cycles can be relatively complex, data must be annualised carefully before entering data into the Tool. Also, where vegetation or soil carbon stock changes are expected to occur, again, these must be annualised over the lifetime of the project. This is discussed further in Section 6.6.4.

The annualising of cost data must be carried out with great care, particularly for bioenergy projects that involve a complex pattern of costs over many years. Most importantly, all costs must be discounted to the base year of the project before being combined and annualised (see Section 6.7).

6.6 Estimating Vegetation Carbon Stock Changes

In most cases, the greenhouse gas balance of a bioenergy system will be determined primarily by the amount of non-renewable energy (in various forms) consumed as part of the biomass production, logistics and conversion stages and the efficiency of biomass production and utilisation. However, there can be a secondary contribution to the greenhouse gas balance due to changes in vegetation-based carbon stocks associated with the inception of a bioenergy project. For some projects, these changes can be significant and in all cases it is important to demonstrate that potential changes have been accounted for. For example, suppose a bioenergy project involves establishing new forests on an area of barren land for sustainable production and woodfuel. The growing forests will sequester carbon from the atmosphere and, even though trees are cut down for fuel, on balance, the carbon stocks on the area of land should increase. The process of carbon sequestration by crops and trees is often misunderstood and a description of the fundamentals is provided in Appendix D. As discussed, in general, a particular combination of site, vegetation type and management regime results in a characteristic, long-term average carbon stock becoming established on an area of land. The two main contributions to the total carbon stock are:

- Living biomass (of the vegetation)
- Soil (on which the vegetation is growing).
-

Two other carbon stocks that can also be involved are:

- Dead biomass
- Harvested biomass products.

As explained in Appendix D, these latter carbon stocks are generally small and often can be ignored. Changing the vegetation on an area of land is likely to lead to a change in the carbon stock; equally, changing the way in which existing vegetation is managed will often cause changes in carbon stocks.

Figure 6.2 is a simplistic representation of how carbon stocks in living biomass and soil are likely to vary with vegetation and management. Thus, for example, changing the vegetation on an area of land from annually-cropped plants to trees and shifting to a forestry system should result in an increase in carbon stocks; similarly clearing an area of undisturbed land by clearing perennial plants, replacing with trees and managing as a short rotation cropping system is likely to result in a small change in carbon stocks that is difficult to determine. In preparing input data for the BIOMITRE software tool, the user needs to establish the magnitude of any such stock changes associated with the introduction of the biomass energy project. It is suggested that this is most easily done by determining the characteristic carbon stocks of the land system before and after the inception of the biomass energy project, and then working out changes as the differences between “before” and “after” carbon stocks. Table 6.1 can be used as a form for preparing input data on carbon stock changes.

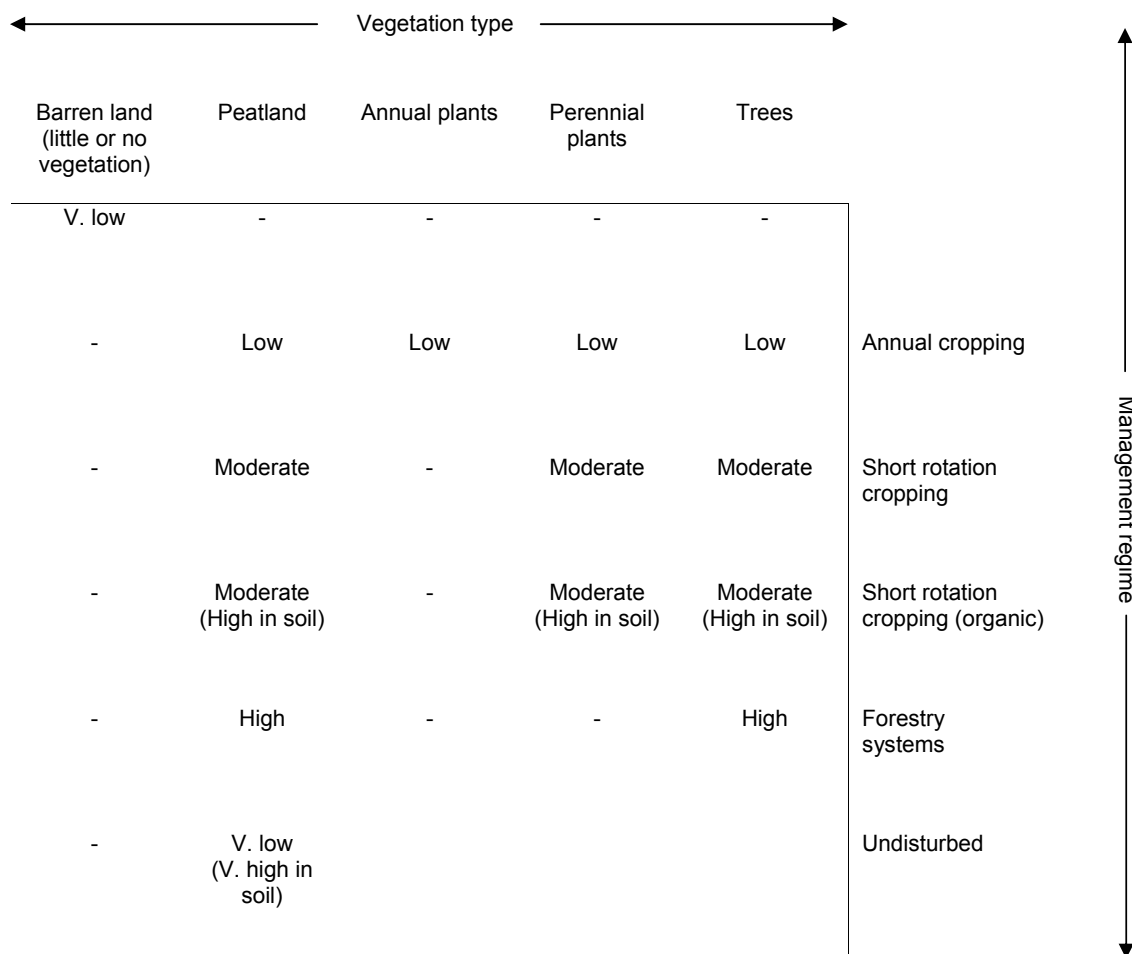


Figure 6.2 Typical relative levels of carbon stocks associated with types of vegetation and management regime

(1) Component	(2) Carbon stocks (Tc ha ⁻¹)		(3) Carbon stock change (tC ha ⁻¹)	(4) Land area affected (ha) (see note 1)	(5) Total carbon stock change (tC) (see note 2)	(6) Carbon dioxide equivalent (tCO ₂ -eq) (see note 3)
	Before project	After project				
Living biomass						
(Dead biomass)						
Soil						
(Harvested biomass)						
Total						

Table 6.1 Preparing input data on vegetation carbon stock changes

Notes:

1. Column (3) – column (2)
2. Column (5) x column (6)
3. Column (6) x 44/12

The challenge for the user is to determine what numbers to enter in columns (2) and (3) of Table 6.1. There are three options which may be seen as broadly consistent with the three levels of data that may be specified for energy inputs:

- Characteristic results from research literature
- Results for similar projects
- Project-specific data or model estimates.

Whatever source of data is used, as with energy inputs and outputs, it is important to make an assessment of the extent to which vegetation carbon stock changes are strictly attributable to the biomass energy project, through reference to an appropriate baseline projection. The concept of the baseline is fully discussed in Appendix E.

6.6.1 Characteristic results

The crudest approach to quantifying vegetation carbon stocks involves relying on 'characteristic results'. As suggested in Figure 6.2, it is possible to identify "characteristic", "average" or "typical" levels of carbon stocks that are likely to be associated for particular combinations of site types, vegetation types and management regimes. Some attempts have been made to quantify characteristic carbon stocks for relevant site-vegetation-management systems in different countries in the European Union. The user should check whether a suitable national database exists for the locality, country or region of interest; alternatively a search of scientific literature may reveal relevant results that can form the basis of assumptions about characteristic carbon stocks. However, such databases and research results will sometimes be difficult to track down and in any case are unlikely to be comprehensive. An important but basic source of data on characteristic carbon stocks can be found in chapter 3 in the Good Practice Guidelines report of the Intergovernmental Panel on Climate Change (IPCC, 2003). This presents tables of characteristic carbon stocks (or 'default values') in living biomass and soil.

Alternatively, it might be possible to draw on summary results from vegetation carbon accounting models that deal with systems relevant to the biomass energy project. These are most likely to be of interest when considering forestry systems for which a number of forest carbon accounting models have been developed in the European Union. The main examples are listed in Table 6.1 along with details of how to gain access to each model. If a carbon accounting model is used, great care must be taken to ensure that the model is parameterised appropriately for the systems being considered and that correct and documented assumptions are made when preparing input data. The summarising of model simulations to produce characteristic results must also be done with caution and it is recommended that advice is sought from experts who are familiar with the outputs of such models.

Data and results from such sources clearly rely on many underlying assumptions and generalisations; they will only represent true carbon stocks for a project 'on average' and calculations of carbon stock changes based on such data should be regarded as indicative. It is recommended that potential carbon stock changes due to dead and harvested biomass are not accounted for when adopting this approach.

6.6.2 Results from similar projects

There may be situations in which an evaluation has already been carried out for a project that is similar or related to the biomass energy project under consideration.

This 'preceding' project may itself be the subject of a feasibility study or may have progressed to implementation. If the preceding project involves similar changes in vegetation and management regime across similar site types then it may be possible to adapt data or assumptions about carbon stocks and stock changes for use as input data in the evaluation of the current project. If such an approach is adopted then it is important that:

- The similarity of the preceding project to the current project (in terms of site vegetation/management changes) is demonstrable;
- The data, calculations and results used in the preceding study have been the subject of a sufficient validation or review exercise;
- Any assumptions and calculations made in adapting results to the current study are fully documented.

Provided that these conditions are met, results from similar or related projects should be more representative of actual changes in vegetation carbon stocks, when compared to relying on characteristic results.

6.6.3 Project-specific results

Ideally, data or results on vegetation carbon stocks and stock changes should relate directly to the land areas encompassed by the project. The most obvious way of obtaining data on carbon stocks prior to implementation of the project is to carry out a statistically robust inventory of carbon stocks in the existing vegetation, soil and, if appropriate, dead biomass. Ecologists, agricultural scientists and foresters have developed suitable survey and measurement techniques and it is recommended that reference is made to appropriate manuals of procedure that are the accepted standards for the countries of interest. As explained in Appendix D, carbon stocks in vegetation biomass (and to a lesser extent soil) can be expected to fluctuate around a longer term trend or equilibrium value, therefore care must be taken when interpreting trend or the snapshot provided by a one-off inventory. Vegetation carbon accounting models may be of use when interpreting the results of inventories and, used in conjunction with reliable site specific parameters and input data, can be used to forecast the development of carbon stocks over time and thereby estimate long-term carbon stock changes. Once a biomass energy project has been implemented, periodic inventories (say every five or ten years, or at commercially significant stages of project development) can be used to directly monitor carbon stocks and stock changes.

Clearly, obtaining project-specific results using methods such as those described above should provide estimates of vegetation carbon stock changes with high accuracy and, as a project is implemented, the periodic monitoring approach can be used for verification. However, the financial and technical investment needed to provide project-specific assessments can be significant. Where costs are high and the carbon stock changes likely to be small or difficult to register, there is a case for adopting one of the simpler and cheaper approaches considered above. In the extreme case, it may be acceptable to review existing data and scientific understanding and establish whether there are sufficient grounds to be confident that the biomass energy project should have a negligible or positive impact on vegetation carbon stocks. A commercial decision may then be taken not to account for vegetation carbon stock changes. In such cases, the relevant input data fields in the BIOMITRE software tool should be set to zero.

6.6.4 Preparing stock change results for use in the BIOMITRE Tool

As explained in Appendix D, the principal impact of vegetation carbon stock changes is on carbon dioxide, but in some instances other greenhouse gases may be involved, sometimes through complex processes. In many situations, a first order estimate can be obtained by assuming all impacts are on the carbon dioxide balance. The methodologies adopted in the BIOMITRE software tool for allocating greenhouse gas savings/emissions from vegetation carbon stock changes to multiple products of a system is the same as described in Section 6.4. Also, as explained in Section 6.5, the current version of the BIOMITRE software tool relies on a simplified approach to handling energy inputs and outputs that may occur at different times. This involves annualising system inputs and outputs over the life cycle of a biomass energy project.

The vegetation carbon stock changes in tonnes CO₂ equivalent, as recorded in column (6) of Table 6.1 also need to be annualised so as to be expressed in tonnes CO₂ equivalent per year. A simple approach is recommended for making the necessary calculations and Table 6.2 can be used as a guide to deriving and recording the results in a transparent manner. The first step in the calculations involves assigning as characteristic “transition period” to each total carbon stock change as obtained from Table 6.1. This is the period in years over which the relevant carbon stock change is assumed to take place. Dividing the value for total carbon stock change by the transition period gives an estimate of the annualised stock change.

(1) Component	(2) Total carbon stock change (tCO ₂ -eq) (see note 1)	(3) Transition period (years)	(4) Annualised stock change (tCO ₂ -eq y ⁻¹) (see note 2)	(5) Project period (years)	(6) Adjustment factor (see note 3)	(7) Adjusted annualised stock change (tCO ₂ -eq y ⁻¹) (see note 4)
Living biomass						
(Dead biomass)						
Soil						
(Harvested biomass)						
Total						

Table 6.2 Annualising input data on vegetation carbon stock changes

Notes:

1. From Table 6.1, column (6)
2. Column (2) / column (3)
3. Column (3) / maximum (column (3), column (5))
4. Column (4) x column (6)

Wherever possible, the values assigned to transition periods should be obtained from project-specific data or results, or from verified values in the scientific literature or already used in other similar projects. However, notional values are given in Table 6.3 for use where no supporting data or precedents are available. Different values for the transition period are suggested, depending on the type of carbon stock transition being considered.

In some cases this approach may lead to an overestimation of estimates of annualised carbon stock change. For example, suppose that a biomass energy project involves establishing annual crops on previously barren ground, with the result that the carbon stock in living biomass on the land increases by 10 tCO₂-eq y⁻¹. If the transition period is estimated to be 1 year then the annualised carbon stock

change is calculated as $10/1 = 10 \text{ tCO}_2\text{-eq y}^{-1}$. However, suppose that the project lifetime of the biomass energy project (i.e. the period for which a commitment is made to maintain the project) is 15 years. The annualised estimate derived as shown above would give a misleading impression of an annual carbon stock change of $10 \text{ tCO}_2\text{-eq y}^{-1}$ for each of the 15 years of the project, whereas in reality such a change would take place over just one year, with no further change in subsequent years. Strictly, an adjustment should be made to the annualised carbon stock change to account for this. Columns (5)–(7) of Table 6.2 are included for this purpose.

Component	Transition period (years)
Living biomass (as established after implementation of project)	
Sparse/no vegetation	1
Annual crop	1
Perennial crop	2
Rotational forestry system	= Rotation
Continuous forestry system	70
Undisturbed vegetation	100
Soil (increase in carbon stocks)	100
(decrease in carbon stocks)	
Dead biomass (increase in carbon stocks)	50
Biomass (decrease in carbon stocks)	5
Harvested biomass	70

Table 6.3 Suggested default values for carbon stock change transition periods

6.7 Cost-effectiveness and Cost Data

Information on costs associated with an energy project are required to enable estimates of project cost-effectiveness to be made. In the context of the BIOMITRE software tool, the main costs of interest are those associated specifically with achieving reductions in fossil energy consumption or abatement of greenhouse gas emissions. This implies that the relevant costs are marginal, i.e. associated only with those activities and processes involved in delivering these services. In some contexts, particularly where a new energy project is proposed with the explicit intention of displacing a new (and more energy-intensive) one, it may be appropriate for these costs to be estimated as the simple difference between the total cost of the new project and the cost of continuing to supply energy with the existing system. However, in many cases, identifying the costs attributable to delivering reductions in energy consumption and greenhouse gas emissions will be a matter for careful interpretation and argument. Of course, a highly pessimistic upper bound for costs can always be established by attributing the full cost of the project; in any case this is a useful calculation for projects with the primary aim of reducing greenhouse gas emissions, and a valid approach. However, if there is a requirement to generate results with alternative assumptions about costs, then separate calculations must be carried out using the BIOMITRE software tool based on complete alternative input data sets as required.

6.7.1 Deciding what types of cost to consider

It is possible to identify different types of cost and these can be categorised as (Norris, 2001):

- Direct;
- Indirect;
- Contingent;
- Intangible;
- External.

Direct costs include costs of capital investments, labour, raw material and waste disposal, operational and maintenance costs. Indirect costs include costs not allocated to product or processes and may include both recurring and non-recurring costs, as well as both capital and operational and maintenance costs. Contingent costs include costs of fines and penalties, forced clean-up, liabilities, etc. Intangible costs are costs that are difficult to measure such as consumer acceptance and loyalty, corporate image, worker moral, etc. External cost is borne by others (often the society) than those creating the costs. A typical external cost is the cost of climate change.

It is recommended that only direct costs excluding energy taxes and environmental fees are considered in the calculation of the cost difference between fossil and bioenergy systems. Climate change costs must be excluded to avoid double counting as the greenhouse gas mitigation cost is being estimated. Hence, energy taxes and environmental fees reflecting climate change costs must be excluded. Furthermore, as the bioenergy alternative should fulfil the same function as the fossil system, the external cost difference between the systems should mostly be linked to greenhouse gas emissions and not to other types of external costs.

6.7.2 Allocating costs to multiple outputs

As already noted, in situations where an energy system is providing multiple outputs or services, allocating costs to individual outputs can be problematic. The approach to allocation of costs is different to that adopted in accounting for energy inputs and associated greenhouse gas emissions, in that economic conventions are usually adopted. Ideally, only those costs that are incurred directly as a result of delivering reductions in greenhouse gas emissions should be counted. However, often it will be impossible to attribute distinct costs to distinct outputs and some form of apportioning of costs may be necessary. One option might involve using the BIOMITRE software tool to produce two sets of results (or two 'runs', see the BIOMITRE User manual, Appendix A), one each with optimistic and pessimistic assumptions about the attributable costs of a project. These results might be used to determine the range for the total costs of the greenhouse gas abatement provided by the project.

6.7.3 Accounting for timing of costs

Standard discounting procedures should be applied to costs that are incurred over the life cycle of the project. These results are required in any case to establish the net discounted revenue and/or internal rate of return of a proposed project. However, the choice of discount rate is likely to be very specific to the locality in which the project is being developed and the context in which the evaluation is being made.

6.7.4 Sources of cost data

Compared to data on energy, emissions and vegetation carbon (Sections 6.2, 6.3 and 6.6) comprehensive and robust sources of cost data are even harder to find. However, it is more likely that reasonable estimates of actual costs will be available when new energy projects are being evaluated for feasibility and economic viability. As with other input data requirements for the BIOMITRE software tool, three types of data are supported in terms of the accuracy and detail with which they are represented:

- Characteristic aggregate costs;
- Characteristic detailed costs;
- Project-specific costs.

6.7.5 Characteristic aggregate results

The crudest way of representing costs involves providing data on total costs for the entire project or significant project 'building blocks'. While this approach has the appeal of simplicity, it is likely that it will prove difficult to identify reliable sources of existing data that are expressed in appropriate units and are suitable for applying to the project being considered. It will be necessary to carry out a thorough review of widespread and fragmented sources of data that may potentially be relevant for the locality and type of project under evaluation. It is not possible to recommend standard sources because of the geographical and technical specificity of such data. However, where available, broad brush data of this kind may be a sufficient level to aim for in representing reference system costs.

6.7.6 Characteristic detailed costs

For some types of projects in the agricultural and forestry sector, it will be possible to derive detailed cost data from published tables of characteristic standard costs for particular operations. For example, in the United Kingdom, books providing tables of standard costs are published periodically. These types of data constitute a robust basis for project evaluation, particularly in the early stages of project development. Similar data for energy conversion and delivery processes may be harder to find and it may be necessary to resort to representing these in a more broad-brush manner.

6.7.7 Project-specific costs

Ideally, detailed input data should be obtained on the costs associated with proposed energy system. In principle, this requires an extremely comprehensive and detailed analysis of the costs involved in implementation of the energy system. However, in practice, good estimates will be obtained or estimated routinely as part of the economic evaluation of a project and development of a business case. When demonstrating the economic attractiveness of a project, it is essential to base the calculations on reasonable and defensible cost estimates that have a transparent basis; this is equally true when evaluating the cost-effectiveness of delivered reductions in energy consumption and greenhouse gas emissions. In situations where similar projects have already been implemented, these should be reviewed to identify the extent to which costs of operations and processes are applicable to the project under consideration.

6.8 Reference Systems and Allocation

The general introduction and discussion of reference systems and allocation are contained within sections 3.4.2.2 and 3.4.2.3 respectively. Provided the guidelines in these sections and in ISO14040 are followed, data preparation for reference systems should be relatively straightforward. The current version of the BIOMITRE Tool does not differentiate between levels of input data for reference systems, and the level of detail required is generally less than that for the main processes of the project being studied.

When preparing allocation data, as with reference data, it is important to follow the general guidelines and advice in the relevant section above and in ISO14040. Careful attention must be paid to the decision as to which allocation procedure to use, and note that not allocating is the same as allocating all energy, GHG and costs to the main product. Where by-products are produced this may lead to unacceptably inaccurate results.

Once the appropriate decision is made, then relevant data on either mass, price, energy content or substitute products must be compiled. Where allocation is to be achieved by partitioning on the basis of mass, price or energy, the only data requirements for the tool are the final data - that being the total mass/price/energy relative to that of the main product at that point in the process chain. The Tool will then automatically calculate on the basis of the % quantity of the main product and by-product at that point in the process chain.

Where substitution is the preferred method of allocation, the total energy, emissions and costs of the substitution product which will be replaced by the by-product is required, on a like-for-like basis. There may of course be extensive calculation work required in order to arrive at these headline data, but this must be undertaken outside the Tool in its current version. Once the headline substitution data is entered, the Tool will then automatically subtract from the running total energy use, GHG and cost the values entered for the substitution product at that point in the process chain.

7. Summary Results

There are many ways in which the detailed results for energy and greenhouse gas balances of a project may be summarised into simpler statistics. The main examples are described below. The calculation of these statistics involves the calculation of total inputs and outputs in terms of energy, greenhouse gases and costs, and these procedures are discussed briefly. The main options for summarising results in the BIOMITRE software tool are also described.

7.1 Total inputs and outputs

7.1.1 Energy

Summary statistics on the energy balance of a project are calculated based on:

- The sum of all energy inputs
- The sum of all (useful) energy outputs.

These quantities must be calculated over the full life cycle of the project. Where energy is produced by a system in different forms (e.g. electricity and heat) or for different end uses, these outputs need to be expressed in common and compatible units before being combined (see Section 6.4). Care must also be taken where energy inputs are shared by different energy systems (e.g. when co-firing with biomass and coal) to ensure that the correct proportions of energy inputs are attributed to the relevant processes. If required, in addition to calculating sums for a complete life cycle, sums can be calculated for periods within a project life cycle and used as the basis for calculating statistics to show variations in system performance over time.

7.1.2 Greenhouse gases

Summary statistics on the greenhouse gas balance of a project should be calculated based on the sums of emissions for each greenhouse gas over the full life cycle of the project. The points made in the discussion under Section 7.1.1 also apply here. In addition suitable equivalence factors can be used to express emissions for different greenhouse gases in common units so that quantities for the different gases can be combined. The standard unit is a gram, kilogram or tonne of CO₂-equivalent and standard conversion factors for converting methane and nitrous oxide emissions into CO₂-equivalent units are required.

7.1.3 Costs

The cost effectiveness of fossil fuel substitution from a climate change perspective could be expressed as a greenhouse gas mitigation cost. That cost could be defined as the cost differences between the fossil and bioenergy systems divided by the greenhouse gas reduction over the full life cycle of the project. The expected cost differences might be expressed as average annual cost reduction, or discounted to year zero. The greenhouse gas reduction will then be expressed as average annual emission reduction and total reduction, respectively. The use of annual units implies

that all non-annual costs should be annualised. An appropriate discounting procedure should be applied to costs incurred at different times prior to calculation of sums. Again, the points made in Section 7.1.1 apply. Care must also be taken to ensure that only those costs attributable to the project are included (see Section 6.7).

7.2 Energy and greenhouse gas balances

Having calculated the total energy inputs and outputs and the associated greenhouse gas emissions, it is then possible to compute a number of statistics which summarise the energy and greenhouse gas balances of a project, as follows:

- Net energy ratio
- Net energy requirement
- Net energy per hectare
- Net greenhouse gas emissions factor
- Unit energy credit
- Total energy credit
- Energy credit per hectare
- Unit greenhouse gas credit
- Total greenhouse gas credit
- Greenhouse gas credit per hectare.

7.2.1 Net energy ratio

This is the output:input ratio in energy terms for the energy producing system:

$$\text{Net energy ratio} = \frac{\text{Total useful energy output}}{\text{Total primary energy input}}$$

As can be seen from this definition, the net energy ratio represents the number of joules of energy produced by the system per joule of energy expended. It must be stressed that the total primary energy input forming the denominator of the above equation should include all inputs of fossil energy required to produce, convert, deliver and consume the useful output energy. This includes fossil fuel expended directly in generating useful output, for example, for an oil fired heating system it includes the oil burned directly in producing the useful heat. However it should *not* include any allowance for inputs of solar energy implicit in the growing of biomass as part of the bioenergy project because this is taken to be a renewable energy source. Equally, the stored solar energy expended in generating the useful output of a system (e.g. through burning of biomass produced by a bioenergy system) is not included in the denominator. As a consequence of these conventions, any fossil fuel based energy system will have a net energy ratio of less than 1, while a renewable energy system should always have a net energy ratio greater than 1. Indeed, the net energy ratio of an energy system *must* be significantly greater than 1 for it to be renewable.

Note that the calculation of the net energy ratio is based on absolute data for the energy system being considered, i.e. it does not involve calculations relative to a reference energy system.

7.2.2 Net energy requirement

This is the input:output ratio for the energy producing system and is simply related to the net energy ratio:

$$\begin{aligned} \text{Net energy requirement} &= \frac{\text{Total primary energy input}}{\text{Total useful energy output}} \\ &= \frac{1}{\text{Net energy ratio}} \end{aligned}$$

7.2.3 Net energy per hectare

For a bioenergy system, this may be defined as:

$$\frac{\text{Total useful energy produced} - \text{Total primary energy input}}{\text{Land area required by project}}$$

The statistic can be calculated over the life cycle of the project, in which case, it has units of GJ ha⁻¹. If annualised, the units are GJ ha⁻¹ y⁻¹. Clearly, bioenergy projects need to deliver a net energy per hectare significantly greater than zero to be viable. As with the energy ratio and energy requirement, this is an absolute measure of system performance and a reference system is not used in calculating the statistic.

7.2.4 Net greenhouse gas emissions factor

This is the ratio of the total net greenhouse gas emissions from an energy system to the total quantity of useful energy produced:

$$\text{Net greenhouse gas emissions factor} = \frac{\text{Net greenhouse gas emissions}}{\text{Total useful energy produced}}$$

The units are usually grams CO₂-equivalent per megajoule (gCO₂-eq MJ⁻¹) or, alternatively, gCO₂-eq kWh⁻¹. The total net greenhouse gas emissions are calculated based on the total quantity of fossil fuels used as inputs to the production process and as part of direct combustion in delivering the useful energy. The statistic may be calculated either accounting for or not accounting for net changes in vegetation carbon stocks. If allowance is made in calculations for such changes this needs to be done relative to a reference land use; otherwise this statistic is an absolute measure of system performance and a reference system is not involved.

7.2.5 Unit energy credit

This is the quantity of energy consumption avoided by developing an energy project as a replacement for an existing (more energy intensive) system, expressed per unit of useful energy delivered:

Unit energy credit	=	Net energy requirement for reference system	-	Net energy requirement for project
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The unit energy credit is strictly dimensionless, but can be regarded as having units of GJ GJ⁻¹ or kWh kWh⁻¹. Clearly, a viable renewable energy project needs to have a unit energy credit significantly above zero.

7.2.6 Total energy credit

This is the quantity of energy consumption avoided by developing an energy project as a replacement for an existing (more energy intensive) system, expressed for the total life cycle of the project:

Total energy credit	=	Unit energy credit	x	Total useful energy produced over life cycle of project
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7.2.7 Energy credit per hectare

This is the total energy credit expressed as a ratio to the productive land area required for a bioenergy project:

$$\text{Energy credit per hectare} = \frac{\text{Total energy credit}}{\text{Productive land area of project}}$$

7.2.8 Greenhouse gas credits

Three types of greenhouse gas emissions credit can be defined:

- Unit greenhouse gas credit
- Total greenhouse gas credit
- Greenhouse gas credit per hectare.

These are analogous to the energy credit statistics discussed above. The unit greenhouse gas credit can be calculated as:

Unit greenhouse gas credit	=	Greenhouse gas emissions factor for reference system	-	Greenhouse gas emissions factor for project
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Usually it has units of kgCO₂-eq GJ⁻¹, gCO₂ MJ⁻¹ or gCO₂ kWh⁻¹. A good renewable energy project should have a unit greenhouse gas credit significantly above zero. The total and per-hectare greenhouse gas credits are calculated in a similar manner to the total and per-hectare energy credits.

7.3 Cost effectiveness ratios

Cost effectiveness ratios can be used to evaluate the cost (or by some interpretations worth) of the energy consumption avoided and greenhouse gas emissions abatement delivered by an energy project. These ratios can also be used to rank different projects or different management options within a project. For all practical purposes these ratios need to be calculated relative to a reference energy system which the proposed project aims to replace.

7.3.1 Cost per unit of energy delivered

The BIOMITRE Tool provides summary cost data results in the form of costs (in €) per unit of energy (GJ) delivered as the final energy service (either in the fuel, power, or heat, or combination thereof). Totals are provided for the reference system and for the biomass system, and total avoided costs are also provided (i.e. costs for the biomass system subtracted from those for the reference system). The statistic is usually expressed in units of € GJ⁻¹, € MJ⁻¹ or € kWh⁻¹.

7.3.2 Cost per unit of greenhouse gas abated

This is the cost associated with avoiding a unit of greenhouse gas emissions relative to an existing (more energy intensive) system. The statistic is usually expressed in units of € tCO₂-eq⁻¹. This ratio can be calculated based on total costs and greenhouse gas emissions abated for the intended life cycle of the proposed project:

$$\text{Cost per unit greenhouse gas abatement} = \frac{\text{Total cost attributable to greenhouse gas abatement}}{\text{Total greenhouse gas credit}}$$

Although this statistic is not automatically generated within the BIOMITRE Software Tool, a similar measure of cost per unit of greenhouse gas abated can be derived by expressing the cost premium of biomass energy (i.e. take the value for avoided costs per MJ and remove the negative sign) as a ratio with respect to the greenhouse gas emission avoided per MJ.

7.4 Appropriate use of summary statistics

Energy ratios/requirements and greenhouse gas emissions factors (Sections 7.2.1, 7.2.2 and 7.2.4) have been used extensively to support the discussion of the direct and indirect substitution roles of wood products, but these statistics are not without limitations (Schlamadinger, *et al.*, 1997).

It may be argued that energy ratios and emissions factors are extremely sensitive measures. For example, one type of bioenergy system may require an input of 4 GJ of fossil energy to produce 100 GJ for a unit area of land, while another type of bioenergy system may require 2 GJ of fossil energy to produce the same output. These two systems produce a net energy output of 96 GJ and 98 GJ respectively per unit of land area, and should probably be regarded as very similar in performance. However, the energy ratios for the two systems are 100/4 = 25 and 100/2 = 50, in other words, the energy ratio for one system is double the value for the other. However, it cannot be denied that one system *is* producing twice as much energy per unit of input energy as the other.

The interpretation of energy ratios and emissions factors will depend to a great extent on the context of the particular systems being evaluated or compared. For example, if systems for simple wood fuel production are being analysed, a threshold minimum acceptable energy ratio value of about 10 might be used as a test of system viability, and a key criterion in sifting and selection. The distinction between two different systems with energy ratios well in excess of the threshold value (for example 25 and 50) may be less important in this context.

The sensitivity of energy ratios and emissions factors has also led to some concern about the potential for large errors in estimates if energy inputs or outputs are not assessed accurately. It has even led to the suggestion that energy ratios can be manipulated to support preferred outcomes, by judicious inclusion or omissions of energy inputs or outputs. These criticisms are, however, strictly irrelevant to an assessment of energy ratios and emissions factors as summary statistics, rather, they confirm and emphasise the critical importance of accurate system definition, appropriate accounting for associated energy flows, and the need for all methods of calculation to be transparent to the user.

Arguably, a more serious criticism of energy ratios and emissions factors is that they break down as useful and meaningful statistics in extreme cases. For example, a system that requires just 1 joule of fossil energy input to produce 1000 joules of useful bioenergy from 1 hectare of land has the very impressive energy ratio of 1000, but the net bioenergy produced by one hectare of land (a mere 999 joules) is far too small to be worth considering as viable. To avoid inappropriate conclusions being drawn from absurd situations such as this, net energy output per hectare (Section 7.2.3) is used as a summary statistic in situations where land area available for bioenergy projects is more of a constraint than availability of fossil energy. Unfortunately, it is just as easy to demonstrate that this statistic will also break down in certain extreme cases.

Finally, energy ratio summary statistics may hide the fact that a bioenergy generation scheme may depend on a very large internal 'energy subsidy'. For example, consider a hypothetical bioenergy production system in which very small quantities of fossil fuel are consumed to produce 1 tonne of wood, but a further 3 tonnes of wood are also consumed internally within the production process. Only 1 out of 4 tonnes of harvested wood are available for use as energy or materials. By any standard, this process would be regarded as inefficient, but this would not be apparent from the energy ratio, because the 'renewable' wood fuel consumed in the process would not be included in the denominator when calculating the statistic. In such cases, statistics such as the net energy per hectare should give a better indication of dependence on such 'biomass subsidies'.

Inefficiencies within a system come to light when results for energy and greenhouse gas balances are incorporated into policy-level models and the system is compared to other alternative options, and of course inefficiency becomes immediately apparent when the detailed energy balance sheet is scrutinised. Schlamadinger *et al.* (1997) have proposed a rigorous methodology for the evaluation of specific bioenergy production schemes. The authors list eleven principles relating to methodology for the calculation of energy and greenhouse gas balances of bioenergy systems, essentially building on the principles of industrial energy analysis. They place particular emphasis on evaluating the environmental performance of a proposed bioenergy (or bio-fibre) scheme from a marginal standpoint, in direct relation to an alternative 'reference' system. This reference system could be the 'null' system, in other words the alternative of no energy generation, but for most real situations, an attempt should be made to define a roughly equivalent fossil-based energy system as the reference system. Comparison with a meaningful reference system is an important way to highlight extreme cases or anomalous or misleading summary results. The energy and greenhouse gas credit statistics described above can be used to summarise the performance of a new energy project in relation to an existing (reference) system.

In conclusion, summary statistics should not be used in isolation to interpret the environmental performance of a particular bioenergy or bio-fibre production system. Instead, several statistics should be used in combination. Moreover, these results must be considered in the context of the full description of the energy and emissions budgets for the system. However, despite the issues raised above, for most purposes, the statistics presented above are sufficient as measures of system performance because extreme cases such as those illustrated here are unlikely to be considered as practical bioenergy and bio-fibre production systems. Evidence for the robustness of the statistics is found in the observation that estimates reported in the scientific literature for particular technologies exhibit reasonable consistency.

Ideally, the details of energy and greenhouse gas balance research results need to be incorporated as underpinning data into a more comprehensive evaluation of any given project results. In this way, a range of projects can be embedded into large-scale scenario simulation models to enable evaluation of regional policy options.

7.5 Statistics presented by the BIOMITRE Tool

The Biomitre tool can provide total or detailed primary energy inputs, greenhouse gas emissions and costs for a wide range of biofuels. For the biomass production and reference land use modules the tool calculates primary energy inputs and greenhouse gases emissions. These are displayed in the "Results Table" at the top of each module as follows:

- Primary Energy: MJ/ hectare/ year
- Emissions: kg of CO₂ equivalent/ hectare/ year
- Costs: €/ hectare/ year.

For the logistics (transport, drying or other primary conversion step) module the tool calculates primary energy inputs and greenhouse gases emissions. These are displayed in the "Results Table" at the top of each module as follows:

- Primary Energy: MJ/ ton of biomass delivered/ year
- Emissions: kg of CO₂ equivalent/ ton of biomass delivered/ year
- Costs: €/ tonne of biomass delivered/ year.

For main conversion and end-use modules the outputs are displayed as follows:

- Primary Energy: MJ/ GJ delivered/ year
- Emissions: kg of CO₂ equivalent/ GJ delivered/ year
- Costs: €/ GJ delivered/ year.

In the case of transport fuels the end-use module can be also displayed as follows:

- Primary Energy: MJ/ kilometre/ year
- Emissions: kg of CO₂ equivalent/ kilometre/ year
- Costs: €/ kilometre/ year.

A summary of all the modules and all the project's details are presented in the "Results" module. The calculations can be carried out and saved for up to three runs. The main outputs are displayed in a table which summarises the results from all the modules and their totals (total biomass system, total reference system) as summarised in Table 7.1.

Model output descriptor	Definition of statistic and reference
Primary Energy: MJ/ GJ delivered	Net energy requirement (Section 7.2.2)
Emissions: kg of CO ₂ equivalent/ GJ delivered	Net greenhouse gas emissions factor (Section 7.2.4)
Costs: €/ GJ delivered	Internal costs (Section 7.3.1)
Avoided energy: MJ/ GJ delivered	Unit energy credit (Section 7.2.5)
Avoided Emissions: kg of CO ₂ eq	Unit greenhouse gas credit (Section 7.2.8)
Avoided Costs: €/ GJ delivered	Unit cost credit/debit (Section 7.3.1)
Net Cost Effectiveness	€/ MJ primary energy input €/ kilograms CO ₂ equivalent

Table 7.1 Overview of summary statistics produced by BIOMITRE software tool

The above results are also plotted in graphs for three runs and for three different functional units:

- 1 GJ final output per year
- Plant scale, project lifetime
- Available area, project lifetime.

For further details on the procedures for inputting data and deriving results, the reader is referred to the BIOMITRE User manual (Appendix A).

7.6 Sensitivity Analysis

The current version of the BIOMITRE Tool does not contain a formalised means of undertaking sensitivity analysis. However, since there are likely to be uncertainties in some data, the user must be able to use the Tool to assess the impacts of changes within a range of a particular data value where uncertainty exists. The means of achieving this is to simply use multiple runs of the Tool. Since multiple runs can be saved within the same spreadsheet, the effects of varying a parameter or parameters can be calculated and assessed by the user. Where key, influential data is uncertain, the effect of expected ranges should be reported whenever BIOMITRE Tool results are being presented.

7.7 Optimising the GHG Benefits of Biomass Energy Projects

Currently the BIOMITRE Tool looks only at the GHG balance and cost effectiveness of a given biomass energy technology. There is no simple facility for identifying the optimal GHG and cost effectiveness benefits depending on limited resources, such as biomass, land, or Euros. Assumptions may be made and the model can be run several times under different assumptions (as for sensitivity analysis in Section 7.3, but this time varying parameters which may be considered to affect optimality). However, such assumptions may not be correct. For example, it could be assumed that the best way to optimise a system is if it uses its own output to operate the process, because then the input/output ratio of energy can be reduced to close to zero. However, this overlooks the fact that using the output of the system to operate it will reduce GHG mitigation elsewhere, because less "product" is being sold to the outside world. The following text discusses where the characteristic output numbers

of the BIOMITRE Tool are appropriate to be used for optimisation of biomass energy systems, and where other methods may also be used.

It is suggested that the limiting resource that will define the extent to which forest and land management and biomass fuels can be used to limit net GHG emissions, is the most important parameter when the method for maximizing the GHG emission reductions of biomass energy systems is selected. The question is, how much GHG reduction can be achieved per unit of the limiting resource?

Where the biomass resource or the markets for biomass energy are limited, GHG emissions per kWh of biomass energy (produced or sold) can be used as an optimisation variable. This procedure is very similar to using "input-output ratios" and "cumulative energy invested per energy produced" (although these two are based on energy rather than GHG emissions). GHG emissions per kWh of produced biomass energy could be minimized artificially, however, if a biomass energy fuel chain used its own end-products for operating the fuel chain. This could result in no CO₂ emissions, but it would also result in less end-product available to outside markets and thus, less fossil fuel substitution in the outside market. To allow for this, it is suggested that the GHG emission **reductions** per kg of biomass or per kWh of produced biomass energy are highlighted **in comparison to a fossil reference energy system**.

Where land resources are assumed to be the limiting factor (for example, in producing dedicated energy crops), another method seems appropriate, namely maximisation of GHG emission reductions **per ha of land**. The fact that the methods suggested above might be misleading here can be shown with an example: When more fertilizer is applied in biomass production, the GHG emissions reduction per kWh biomass energy (in comparison with a fossil reference system) will be **smaller**, as long as the relative increase of fossil fuel input (fertilizer) is greater than the relative increase of biomass yield. Assume a base case with 5 GJ fertilizer input and 100 GJ of yield. Increasing the fertilizer to 10 GJ might increase the yield to 150 GJ. The emissions from producing fertilizer, if calculated per unit of biomass output, will be increased, and thus the GHG emissions reduction per kWh biomass energy will be smaller. But, on the other hand, the net energy yield or the GHG emission reductions per ha of land are **increased**, because more fertilizer inputs lead to higher biomass yields, the increase in energy output often exceeding the increase in energy input through fertilizers several times. In the example above, the energy output increases by 50 GJ whereas the energy input through fertilizers increases by only 5 GJ, so that the net energy yield per ha of land increases from 95 to 140 GJ, i.e. by 45 GJ. Similarly, a system with very low yield per hectare, but no or very low fossil fuel input might be preferable when the GHG emission reductions per kg biomass or kWh biomass energy are of interest, but might not be as attractive from an "efficient" land use point of view.

Hence, depending on the circumstances, different optimisation procedures might be recommended. Influencing factors on the decision over what to optimise include:

- Is the optimisation from a macro or micro-economic perspective?
- What is the limited resource?
- What time frame is taken into account?
- Which GHGs should be considered?
- Is carbon sequestration included?
- What is the system boundary and the optimisation objective? National? LCA-type, etc?

7.8 Reporting

In common with the majority of software tools, the BIOMITRE Tool is capable of providing informative and sophisticated interpretations, but the results it produces are only as accurate as the data (and the way the data are inputted and used) allow. It is therefore essential that the user is confident with both the underlying theory and practice of LCA, and the quality and appropriateness of the data they have used. Inevitably, there are uncertainties about data. The potential influence of these uncertainties upon the results should be reported. Hence, when results from the Tool are presented, a statement should accompany them, relating to the user's experience, and their confidence in the dataset used.

8. Examples and Future Developments

Case Studies have been developed in order to illustrate the BIOMITRE Tool application to a range of biomass technology projects. Descriptions, explanations and illustrations of these are presented in the BIOMITRE User Manual (see Appendix A). In addition, further case studies have been developed by participants in International Energy Agency (IEA) Task 38, which co-funded the BIOMITRE Project. Although these have not yet utilised the BIOMITRE Tool, there was a mutually beneficial relationship between the development of these case studies and the BIOMITRE Tool. Further information on the Task 38 case studies is provided in Appendix F, and for future developments on these the reader is referred to the Task 38 website at: www.joanneum.at/iea-bioenergy-task38.

Dissemination of the BIOMITRE Tool is encouraged, and its use is free provided it is not being supplied to a 3rd party for commercial gain, although any modifications or applications should be notified to the BIOMITRE website; www.joanneum.at/biomitre. One early dissemination paper which may also provide the reader with further information on the construction and development of the BIOMITRE Tool is included in Appendix G.

Regarding developments, it should be stressed that, while the BIOMITRE Tool is considered to be a major step forward in the standardisation of biomass energy technology energy, GHG and cost-effectiveness assessment, further developments in this rapidly developing field are inevitable. In order to keep abreast of these, a website is maintained, from which the BIOMITRE Tool can be downloaded free of charge, and through which you can keep updated regarding developments in the field: www.joanneum.at/biomitre.

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APPENDIX A. BIOMITRE Tool User Manual
(see pdf file: 'APPENDIX A')

APPENDIX B. BIOMITRE Review of Methodologies
(see pdf file: 'APPENDIX B')

APPENDIX C. BIOMITRE Collation of Existing Data
(see pdf file: 'APPENDIX C')

**Appendix D. Fundamentals of Vegetation Carbon
Dynamics (see pdf file: 'APPENDIX D')**

**APPENDIX E. Project-based Greenhouse Gas
Accounting Paper (see pdf file: 'APPENDIX E')**

APPENDIX F. IEA Bioenergy Task 38 Case Studies
(see pdf file: 'APPENDIX F')

**APPENDIX G. BIOMITRE Paper Presented in Rome,
June 2004
(see pdf file: 'APPENDIX G')**