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IEA Bioenergieprogramm 2010-2012
Task 38: Treibhausgasbilanzen von Biomasse- und Bioenergiesystemen

S. Woess-Gallasch

Berichte aus Energie- und Umweltforschung

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IEA Bioenergieprogramm 2010-2012
Task 38: Treibhausgasbilanzen von Biomasse- und Bioenergiesystemen

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JOANNEUM RESEARCH Forschungsgesellschaft

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Ein Projektbericht im Rahmen der Programmlinie

IEA FORSCHUNGS KOOPERATION

Impulsprogramm Nachhaltig Wirtschaften

Im Auftrag des Bundesministeriums für Verkehr, Innovation und Technologie

Vorbemerkung

Der vorliegende Bericht dokumentiert die Ergebnisse eines Projekts aus dem Programm FORSCHUNGSKOOPERATION INTERNATIONALE ENERGIEAGENTUR. Es wurde vom Bundesministerium für Verkehr, Innovation und Technologie initiiert, um Österreichische Forschungsbeiträge zu den Projekten der Internationalen Energieagentur (IEA) zu finanzieren.

Seit dem Beitritt Österreichs zur IEA im Jahre 1975 beteiligt sich Österreich aktiv mit Forschungsbeiträgen zu verschiedenen Themen in den Bereichen erneuerbare Energieträger, Endverbrauchstechnologien und fossile Energieträger. Für die Österreichische Energieforschung ergeben sich durch die Beteiligung an den Forschungsaktivitäten der IEA viele Vorteile: Viele Entwicklungen können durch internationale Kooperationen effizienter bearbeitet werden, neue Arbeitsbereiche können mit internationaler Unterstützung aufgebaut sowie internationale Entwicklungen rascher und besser wahrgenommen werden.

Dank des überdurchschnittlichen Engagements der beteiligten Forschungseinrichtungen ist Österreich erfolgreich in der IEA verankert. Durch viele IEA Projekte entstanden bereits wertvolle Inputs für europäische und nationale Energieinnovationen und auch in der Marktumsetzung konnten bereits richtungsweisende Ergebnisse erzielt werden.

Ein wichtiges Anliegen des Programms ist es, die Projektergebnisse einer interessierten Fachöffentlichkeit zugänglich zu machen, was durch die Publikationsreiche und die entsprechende Homepage **www.nachhaltigwirtschaften.at** gewährleistet wird.

Dipl. Ing. Michael Paula
Leiter der Abt. Energie- und Umwelttechnologien
Bundesministerium für Verkehr, Innovation und Technologie

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Kurzfassungen

Kurzfassung deutsch

Ausgangssituation und Motivation:

IEA Bioenergy Task 38 „Greenhouse Gas Balances of Biomass and Bioenergy Systems„ ist seit 2001 aktiv (zuvor von 1995 – 2001 Task XV bzw. Task 25). Sie ist ein Netzwerkprojekt, das 2010 - 2012 die Zusammenarbeit von Forschern aus folgenden zehn teilnehmenden Ländern ermöglichte: AUS, AUT, BEL, BRA, FIN, GER, NL, NOR, SWE, USA. Österreich hat in diesem Triennium wieder auf Wunsch aller Beteiligten die Funktion des „Operating Agent“ und des „Task Leader“ übernommen. Im Rahmen des dieses Projektes werden die Aufgaben des „National Team Leaders“ (NTLs) wahrgenommen.

Inhalte und Zielsetzungen:

Ziel dieses Projektes ist es, in der IEA Bioenergy Task 38 als österreichischer Vertreter teilzunehmen, österreichische Beiträge einzubringen, über die Aktivitäten der Task 38 in Österreich zu informieren und die Interessierten zu vernetzen. Dieser Bericht dokumentiert die hierzu durchgeführten Arbeiten.

Die Task 38 entwickelt nicht wie die meisten anderen Tasks konkrete Technologien, sondern befasst sich mit der Methodik zur Berechnung der Treibhausgas(THG)-Bilanzen von Biomasse- und Bioenergiesystemen und deren konkrete Anwendung. Hauptziel ist es, durch Weiterentwicklung und Anwendung der von der Task entwickelten „Standard-Methode“ alle Prozesse von ausgewählten Biomasse- und Bioenergiesystemen zu untersuchen und THG-Bilanzen, im Vergleich zu fossilen Energieträgern und zu konventionellen Werkstoffen zu erstellen. Auf Basis einer Lebenszyklusanalyse und, wenn nötig, einer Berechnung von Kohlenstoffspeicherungsänderungen, werden die THG-Emissionen ermittelt. Maßnahmen im Bereich der Landnutzung und Folgen derer direkten und indirekten Änderung auf die THG-Bilanz und ihrem zeitlichen Verlauf sind ein Schwerpunkt in der Task. Die für 2010 – 2012 geplanten Inhalte der Task umfassten (Auswahl):

- Adaptierung der Standard-Methode durch Integration neuer Anforderungen:
    - THG-Emissionen aus direkter (dLUC) und indirekter Landnutzungsänderung (iLUC):
    - Behandlung des Zeitaspektes von THG-Emissionen aus forstlicher Bioenergienutzung;
    - Evaluierung der von der Task 38 zu betrachtenden Umweltaspekte und eventuelle Integration in die Standard-Methode: Albedo-Effekte, Bereich Wasser in der Landnutzung;
    - Entwicklung und Dokumentation der adaptieren Standard-Methode: Anleitung wie auf Projektebene THG Bilanzen von Biomasse- und Bioenergiesystemen zu berechnen sind;
- Durchführung von neuen Fallstudien („Case Studies“);
- Organisation von und Mitwirkung in Workshops und Meetings zu Themen der Task.

Für die Beteiligung Österreichs in den Jahren 2010-212 wurden folgende drei Arbeitspakete definiert:

- **AP Nr. 1 Österreichische Forschungsaktivitäten:** österreichischen „Case Studies“; THG-Emissionen aus direkter und indirekter Landnutzungsänderung; Zeitaspekt bei der THG-Bilanzierung von forstlichen Bioenergiepfaden, Albedo-Effekt;
- **AP Nr. 2 Nationale Vernetzungs- und Verbreitungsaufgaben:** Verbreitung und Informationsaustausch über Task 38 Aktivitäten, Organisation nationaler Treffen (Task 38 Round Tables), Teilnahme an nationalen Veranstaltungen, Aussendungen, Informationsaussendungen etc.;
- **AP Nr. 3 Teilnahme an Task Workshops, Business Meetings und Expertentreffen:** Einbringen der österreichischen Expertise in die Task Veranstaltungen.

Methodische Vorgehensweise

Alle Task Arbeiten werden in enger Kooperation mit den Task Partnern, den NTLs, durchgeführt, wobei die österreichischen Vertreter in ihrer Funktion als „Task Leader“ und „Assistant of the Task Management“ auch leitende Funktionen übernehmen. Nationale Aktivitäten umfassen:

- Informationsaustausch: Einbringen der für die Task relevanten Forschungsagenda aus Österreich in die Task sowie Verbreitung von Task 38 Ergebnissen und Informationen in Österreich.
- Netzwerkaufbau: weiterer Ausbau des bereits bestehenden nationalen Netzwerkes zum Thema Treibhausgasbilanzierung von Biomasse- und Bioenergiesystemen

Ergebnisse

Folgende Arbeiten repräsentieren die Hauptergebnisse dieses Trienniums (Auswahl, Highlights):

- „Case Studies“: Abschluss zweier österreichischer „Case Studies“ zu einer Biogasanlage (Anhang 1), und einem Bioraffinerie-Konzeptes zur Erzeugung von Bioethanol (Anhang 2).
- THG-Bilanzierung aus durch Bioenergie verursachtem dLUC und iLUC: Die Kenntnisse der Task 38 wurden in die IEA Bioenergy ExCo Broschüre eingebracht. Eine „Special Section“ mit dem Titel

„"Land Use Impacts of Bioenergy. Selected Papers from the IEA Bioenergy Task 38 Meetings in Helsinki, 2009 and Brussels, 2010" wurde veröffentlicht.

- Zeitlicher Aspekt der THG Bilanzierung forstlicher Bioenergiesysteme: Bei der 19. EU Biomassekonferenz wurde ein Papier (Anhang 4) eingebracht. Für ExCo69 und 70 wurden „draft statements" ausgearbeitet. Es wurden drei nationale „Round Tables" in Wien organisiert und die Ergebnisse in einem Protokoll dokumentiert (Anhang 3).
- Albedo-Effekt: Eine Publikation wurde 2010 fertig gestellt. Im Rahmen eines EU Projektes wurden die Forschungsaktivitäten fortgesetzt, Die Evaluierung in der Task ergab, dass der Albedo-Effekt in die Standard-Methode zu integrieren ist.
- Abschluss der IEA Bioenergy ExCo Broschüre mit dem Titel „Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy" (Anhang 5);
- Mitarbeit am Task 38 Programm für das neue Triennium 2013-2015 mit dem Titel "Climate Change Effects of Biomass and Bioenergy Systems".

Kurzfassung englisch

Background and motivation:

IEA Bioenergy Task 38 - "Greenhouse Gas Balances of Biomass and Bioenergy Systems" - has been active since 2001 (from 1995 – 2000 it was called "Task XV" and TASK 25). The Task is a network activity which encourages the cooperation of researchers in participating countries. In 2012 the participating countries were AUS, AUT, BEL, BRA, FIN, GER, NL, NOR, SWE, USA. Until end of 2012. The Task management is led by Austria. Funding of this project covers the function and duties of the National Team Leader (NTL).

Contents and aim:

As Austrian representative in Task 38, the duties are to bring Austrian expertise into the Task, to inform Austrian institutions and researchers on Task 38 activities and to initiate research exchanges. This report summarizes mainly the activities carried out by the Austrian NTL during this period.

Unlike most other Tasks in IEA Bioenergy, Task 38 does not analyze new technologies, but deals with the methodology of **G**reen**H**ouse **G**as (GHG) balances of biomass and bioenergy systems. This is achieved by applying the standard methodology developed by the Task, based on Life Cycle Assessment. This methodology includes the time-dependent GHG implications of bioenergy systems such as carbon stock changes from land management change and material substitution. Impacts of bioenergy are estimated by comparing the GHG emissions from the bioenergy system with a system which provides the same services using fossil energy and conventional materials.

The topics and activities of the Task in the triennium 2010 -2012 included (selection):

- Revising the Task 38 Standard Methodology by integrating and documenting new aspects:
  - Address emissions from direct (dLUC) and indirect (iLUC) land use change
  - Assess the time-dependent value of GHG emissions and removals
  - Assess non-GHG impacts such as albedo effects and water usage;
  - Documentation of the adapted Task 38 Standard Methodology.
- Conducting new case studies that are of interest to participating countries;
- Organising and participating in Task 38 events with input on Task 38 topics.

Three work packages were defined for the participation of Austria from 2010 to 2012:

- **WP no. 1, Austrian research activities:** Continuing activities on Austrian „Case Studies"; adaptation of the Task 38 Standard Methodology concerning GHG emissions from direct and indirect land use change; time-dependency of GHG emissions from forest biomass, albedo effect;
- **WP no. 2, National networking and diffusion of information:** Diffusion and information exchange of Task 38 activities in Austria, incorporating Austrian stakeholders, organisation of national meetings (Task 38 Round Tables), participation in Austrian events;
- **WP no. 3, Participation in Task 38 workshops, business meetings und expert meetings:** incorporation of Austrian expertise by participating in the international Task 38 events.

Methodological procedure

All activities on an international level are performed in close cooperation with the partners of Task 38, the NTLs. The Austrian participants in Task 38 in their function as “Task Leader” and “Assistant of the Task Management” fulfill also a leading position. The activities on national level are:

- Information exchange: To insert relevant information from Austria into the Task and to disseminate Task 38 results and information in Austria;
- Networking: to further expand the existing international network on the topic of GHG balances for Biomass and Bioenergy systems.

Results

The following topics represent the main results in the triennium 2010 – 2012 (selection, highlights):

- Austrian case studies: Finalization of two Austrian case studies, one on GHG benefits of a biogas plant, (appendix 1), and the other one on a bioethanol oriented biorefinery concept (appendix 2);
- Observation of the international research activities in the field of dLUC and iLUC: the knowledge of the Task 38 on this topic was included in a IEA Bioenergy ExCo document. A “Special Section” entitled “Land Use Impacts of Bioenergy. Selected papers from the IEA Bioenergy Task 38 Meetings in Helsinki, 2009 and Brussels, 2010” was published.
- Activities in the field of the timing of GHG balances for forest based bioenergy systems: A contribution to the proceedings (appendix 4) on this topic was prepared for the 19th EU biomass conference. For ExCo69 and ExCo70 a draft for a position paper was prepared. Three national round tables on this topic were organized in Vienna and the final results documented in a protocol (appendix 3).
- Albedo effects: A publication was finalized in 2010 and the results were implemented in Task 38. In the context of an EU project the research activities are continuing. As a consequence the title of Task 38 will be changed for the triennium 2013-2015 to “Climate Change Effects of Biomass and Bioenergy Systems“.
- Finalization of the IEA Bioenergy ExCo document with the title „Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy” (appendix 5).
- Planning activities for the new triennium 2013-2015.

1 Einleitung

Das Aufgabengebiet der Task 38 beinhaltet die Entwicklung einer Methodik zur Berechnung von Treibhausgas-(THG-) Bilanzen von Biomasse- und Bioenergiesystemen und deren konkrete Anwendung. Neue Erkenntnisse und Fragestellungen machen es notwendig, diese Standard-Methode laufend zu adaptieren. Abbildung 1 stellt die von Task 38 entwickelte Standard-Methode auf Basis einer Lebenszyklusanalyse (Life Cycle Assessment – LCA) schematisch dar. Die Task ist seit 1995 aktiv, im Zeitraum von 1995 - 1997 unter dem Titel „Task XV“ und von 1098 bis 2000 unter dem Titel „Task 25“.

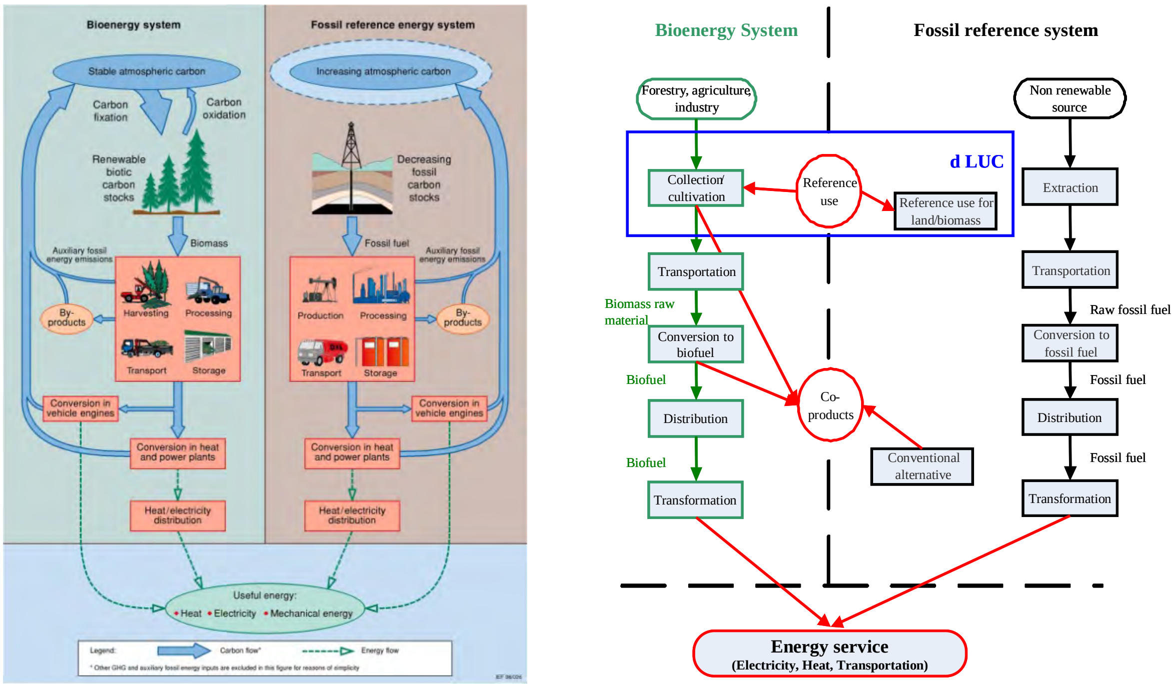

Abbildung 1: Task 38 Standard-Methode zur Berechnung von THG-Emissionsbilanzen und LCA-Flussdiagramm

Auf Basis einer LCA und, wenn notwendig, zusätzlich auf Basis einer Berechnung von Kohlenstoffspeicherungsänderungen, werden die THG-Emissionen aus der Biomasserohstoffgewinnung, aus der Errichtung, dem Betrieb und der Entsorgung von Biomasse- und Bioenergiesystemen über den ganzen Lebenszyklus ermittelt. Durch geeignete Wahl der Systemgrenzen wird nicht nur der Ersatz fossiler Brennstoffe durch Bioenergieträger, sondern auch Sekundäreffekte, wie z.B. die Hilfsenergieaufwendungen („upstream energy inputs“) zur Herstellung und Umwandlung von Biobrennstoffen sowie die Auswirkungen der Biomassenutzung auf die Kohlenstoffspeicherung in Land- und Forstwirtschaft („carbon stock dynamics“) analysiert. Bioenergie wird sehr oft als Koppelprodukt mit Holzprodukten erzeugt („by-products“), die ebenso kohlenstoffrelevant sind, und dann in die Analysen mit einzubeziehen sind.

Durch Anwendung der Standard-Methode auf konkrete Biomasse- und Bioenergiesysteme werden deren THG-Minderungspotentiale im Vergleich zu konventionellen Produktions- und fossilen Energiesystemen aufgezeigt. Die Task führt diesbezüglich seit 2001 sogenannte

„Case Studies“ an ausgewählten, konkreten Bioenergie- und Biomassesystemen durch. Sie dienen einerseits dazu, diese hinsichtlich der THG-Emissionen zu bilanzieren und deren Minderungspotentiale aufzuzeigen, und andererseits als Instrument um neue methodische Erkenntnisse der Task 38 zu testen und erstmals anzuwenden.

Entscheidungsträger in der Klima- und Energiepolitik auf internationaler und nationaler Ebene sollen durch die Task bei der Umsetzung von Programmen zur Eindämmung und Reduzierung der THG-Emissionen Unterstützung finden. Die Task ist ein Netzwerkprojekt, das die Zusammenarbeit von Forschern in den teilnehmenden Ländern ermöglicht. Ein weiterer wichtiger Schwerpunkt der Task ist die Organisation von und das Mitwirken in internationalen und nationalen Workshops und Meetings zu den Themen der Task, sowie die Veröffentlichung der wichtigsten Ergebnisse.

Die Task 38 analysiert also nicht wie die meisten anderen Tasks konkrete Technologien, sondern befasst sich mit der Methodik zur Berechnung von THG-Bilanzen von verschiedenen Biomasse- und Bioenergiesystemen.

Im Triennium 2010 – 2012 wurden vorranging folgende drei Themenbereiche mit Bezug auf die Adaptierung der Task 38 Standard-Methode behandelt:

- THG-Emissionen aus der direkten (dLUC) und indirekten Landnutzungsänderung (iLUC);
- Betrachtung des Zeitaspektes („timing“) von THG-Emissionen aus der forstlichen Bioenergienutzung und wie sie dokumentiert werden können;
- Evaluierung der Erweiterung der von der Task 38 zu betrachtenden Umweltaspekte und Integration in die Task 38 Standard-Methode: Es wurde beschlossen den Albedo-Effekt offiziell in die Task 38 Standard-Methode zu integrieren.

Der Bericht gibt Informationen zum Projektinhalt (Kapitel 2), stellt die wichtigsten Ergebnisse dieses Trienniums mit spezieller Berücksichtigung der österreichischen Beiträge dar (Kapitel 3), informiert über die Einbindung und Vernetzung der österreichischen Zielgruppe, über Relevanz und Nutzen der IEA-Beteiligung in Österreich (Kapitel 4), geht auf Schlussfolgerungen (Kapitel 5) und Empfehlungen (Kapitel 6) ein. Die wichtigsten Publikationen und dokumentierten Ergebnisse werden in Kapitel 7 aufgelistet. Eine Auswahl einiger Dokumente befindet sich im Anhang.

2 Hintergrundinformation zum Projektinhalt

Im Triennium 2010 - 2012 nahmen insgesamt 10 Staaten an der Task 38 „Greenhouse Gas Balances of Biomass and Bioenergy Systems“ teil. Dies Task wurde von Österreich geleitet, und übernahm damit die Funktion des „Operating Agents“ (Josef Spitzer) und des „Task Leaders“ (Neil Bird). Die nachfolgende Zusammenstellung gibt eine Übersicht über die Task 38 Beteiligung:

Teilnehmende Länder (10):	Australien, Belgien, Brasilien, Deutschland, Finnland, Niederlande, Norwegen, Österreich, Schweden, USA.
Task-Leiter:	Neil Bird, JOANNEUM RESEARCH Forschungs-gesellschaft mbH, Österreich, CO Task Leader ist Annette Cowie, Australien.
Österreichischer Teilnehmer:	Susanne Woess-Gallasch, JOANNEUM RESEARCH Forschungsgesellschaft mbH,

Task-Homepage: http://www.ieabioenergy-task38.org

Tabelle 1: Die Task 38 Mitglieder

AUSTRALIA **Annette Cowie** (CO-Task Leader) National Centre for Rural Greenhouse Gas Research New England Armidale NSW 2351 Australia Phone: +61 2 6773 3924 Fax: +61 2 6773 3238 e-mail: annette.cowie@une.edu.au	BELGIUM: **Florence Van Stappen** Walloon Agricultural Research Centre (CRA-W) Chaussee de Namur 146 B-5030 Gembloux, Belgium Phone: +32 81 627 185, Fax: +32 81 615 847 e-mail: vanstappen@cra.wallonie.be
AUSTRIA: **Neil Bird** (Task Leader) JOANNEUM RESEARCH Forschungsgesellschaft mbH Elisabethstrasse 5, A-8010 Graz, Austria Phone: +43 316 876 1423 Fax: +43 316 876 91423 e-mail: neil.bird@joanneum.at **Susanne Woess-Gallasch** (National Team Leader) JOANNEUM RESEARCH Forschungsgesellschaft mbH Phone: +43 316 876 1330 Fax: +43 316 876 91330 e-mail: susanne.woess@joanneum.at	BRAZIL: **Manoel Regis Lima Verde Leal** Brazilian Bioethanol Science and Technology Laboratory Giuseppe Maximo Scolfaro Street 10.000 Campinas Sao Paulo - Brazil Phone: +55 19 3518 3124, Fax: +55 19 3518 3104 e-mail:regis.leal@bioetanol.org.br **Newton Paciornik** Ministry of Science and Technology Praia do Flamengo 200, 7º Rio de Janeiro - Brazil Phone: +55-21-25550308, Fax: +55-21-25550306 e-mail: npaciornik@mct.gov.br
FINLAND: **Sampo Soimakallio** VTT Technical Research Centre of Finland Tekniikantie 2, P.O. BOX 1000, FIN-02044 VTT, Finland Phone + 358 20 722 6767, Fax +358 20 722 7604 e-mail: sampo.soimakallio@vtt.fi **Kim Pingoud** VTT Technical Research Centre of Finland Tekniikantie 2, P.O. BOX 1000, FIN-02044 VTT, Finland Phone +358-20-722 5074, Fax +358 20 722 7604 e-mail: kim.pingoud@vtt.fi	GERMANY **Sebastian Rueter** Federal Research Centre for Rural Areas, Forestry and Fisheries, Inst. for Wood Technology and Wood Biology Leuschnerstr. 91, P.O. Box 80 02 09, D-21031 Hamburg, Germany Phone +49 40 73962-619 Fax: +49-40-73962-699 email: sebastian.rueter@vti.bund.de
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Alle Task 38 Arbeiten auf internationaler Ebene werden in enger Kooperation mit den Task Partnern, den so-genannten “National Team Leaders” (NTLs) durchgeführt, wobei die österreichischen Vertreter in ihrer Funktion als „Task Leader“ und „Assistant of the Task Management“ dabei auch leitende Funktionen übernommen haben. Die Aktivitäten auf nationaler Ebene umfassten:

- Österreichische Forschungsarbeiten zu Task Themen (nur z.T. durch Projekt gefördert).
- Informationsaustausch: Einbringen von Task 38 relevanten Informationen aus Österreich in die Task sowie Wissensverbreitung von Task 38 Ergebnissen und Informationen in Österreich in den von der Task organisierten Veranstaltungen.
- Netzwerkaufbau: weiterer Ausbau des bereits bestehenden internationalen Netzwerkes zum Thema THG-Bilanzierung von Biomasse- und Bioenergiesystemen.

2.1 Ziele der Task 38 und der österreichischen Beteiligung

Hauptziel der Task 38 ist es, durch Weiterentwicklung und Anwendung der bereits bestehenden Standard-Methode, alle Prozesse von ausgewählten Biomasse- und Bioenergiesystemen zu analysieren und THG-Bilanzen zu erstellen. Im Vergleich zu fossilen Energieträgern und zu konventionellen Werkstoffen, z.B. im Hausbau (Beton, Glas, Stahl etc.) werden THG-Minderungspotenziale aufgezeigt, denen eine verstärkte Nutzung von verfügbaren Biomasseressourcen zugrunde liegt. Maßnahmen im Bereich der Landnutzung (Waldschutz, Aufforstung) und deren Optionen zur Senkung der THG-Emissionen sind ein weiterer Schwerpunkt in der Task. Die Bioenergienutzung ist in vielen Fällen untrennbar mit der Landnutzung und damit mit dem Thema der Kohlenstoffsenken und Kohlenstoffquellen verbunden.

Die Fragestellungen der THG-Emissionen aus der direkten und indirekten Landnutzungsänderungen stellten im Triennium 2010 -2012 ein wichtiges Aufgabengebiet der Task dar. Die auf internationaler und nationaler Ebene kontroversiell diskutierte Fragestellung des zeitlichen Aspektes der THG-Emissionen bei der energetischen Nutzung forstlicher Biomasse, war ein Schwerpunkt in der Task. Beide Themenbereiche sind wissenschaftlich noch nicht vollständig erfasst und stehen weiterhin auf der Agenda, so dass Task 38 auch im Triennium 2013 – 2015 hier weiterhin aktiv sein wird.

Die Task evaluierte in diesem Triennium ob in Zukunft offiziell zusätzliche Umweltaspekte betrachtet und in die Task 38 Standard-Methode integriert werden sollen: Zur Diskussion standen der Albedo-Effekt und der Wasserkonsum und Gewässerbelastungen durch energetische Biomassenutzung. Es wurde von den NTLs beschlossen, den Albedo-Effekt offiziell in die Task 38 Standard-Methode aufzunehmen. Die Task plant hingegen nicht mehr sich in Zukunft mit dem Umweltaspekt Wasser zu befassen, da dieses Thema bereits von Task 43 abgedeckt wird.

Entscheidungsträger in der Klima- und Energiepolitik auf internationaler und nationaler Ebene sollen durch die Task bei der Umsetzung von Programmen zur Eindämmung und Reduzierung der THG-Emissionen Unterstützung finden. Die Task ist ein Netzwerkprojekt, das die Zusammenarbeit von Forschern in den teilnehmenden Ländern ermöglicht.

Die zentralen Ziele der Task 38 sind im Proposal für 2010-2012 definiert und umfassen (Original in Englisch und Übersetzung in Deutsch in Klammer):

- Promote the sustainable use of biomass and bioenergy through increased understanding of the GHG and other impacts (Förderung der nachhaltigen Nutzung von

Biomasse und Bioenergie durch ein verstärktes Verständnis der damit verbundenen THG Emissionen und anderer Einflüsse);

- Improve and modify the “standard methodology” for the calculation of GHG balances based on life-cycle analysis by incorporating new issues, technologies and topics as they appear (Verbesserung und Modifizierung der Task 38 Standard Methode zur Berechnung von THG Bilanzen, auf einer LCA beruhend, indem neue Fragestellungen, Technologien und Themen inkludiert werden);
- Work in cooperation with other IEA Bioenergy Tasks to assess GHG balances of new technologies; (kooperative Zusammenarbeit mit anderen IEA Bioenergy Tasks, um die THG Bilanzierung neuer Technologien zu ermitteln);
- Assess and report on best practices in participating countries for reducing GHG emissions using biomass and bioenergy; (Bewertung und Bericht über die besten konkreten Maßnahmen in den teilnehmenden Ländern zur Reduzierung der THG-Emissionen durch die Nutzung von Biomasse und Bioenergie).
- Aid decision makers in selecting mitigation strategies that optimise GHG benefits by disseminating the results of the above-mentioned activities. (Hilfestellung für Entscheidungsträger bei der Auswahl von Strategien, die THG-Minderungs-potenziale optimieren, indem entsprechende Ergebnisse verbreitet werden).

Auf österreichischer Ebene wurden für das Triennium 2010 – 2012 folgende Projektinhalte in Form von Arbeitspaketen definiert (Projekt Nr. 828106 und 824974):

- **AP Nr. 1, Österreichische Forschungsaktivitäten:** Mitarbeit bei der Adaptierung der Task 38 Standard-Methode zur THG- Bilanzierung hinsichtlich THG-Emissionen aus direkter und indirekter Landnutzungsänderung; methodische Erfassung der Zeitdimension der THG-Emissionen von forstlichen Bioenergiesystemen, weiterführende Forschungsaktivitäten zum Albedo-Effekt (Modell), Analyse von Biomasseketten, die kaskadische Nutzung und Recycling inkludieren (erfolgte anhand einer Case Study), Arbeiten an den österreichischen „Case Studies“, Konzept für eine neue österreichische „Case Study;
- **AP Nr. 2, Nationale Vernetzungs - und Verbreitungsaufgaben:** Verbreitung und Informationsaustausch über Task 38 Aktivitäten in Österreich (durch Teilnahme an österreichischen Veranstaltungen, Aussendungen, Informationsaussendungen), Organisation nationaler Treffen, Aufnehmen von Anregungen österreichischer Akteure und Einbringung in die Task;
- **AP Nr. 3, Teilnahme an Task 38 Workshops, Business Meetings und Expertentreffen:** Einbringen der österreichischen Expertise in Task 38 Workshops und Konferenzen sowie in die Task 38 Business Meetings und Expertentreffen.

3 Ergebnisse des Projektes

Ziel dieses Projektes im Triennium 1010 - 2012 war es als österreichischer Vertreter in Task 38 teilzunehmen, österreichische Beiträge einzubringen und Task-Ergebnisse in Österreich zu vermitteln. Die Task entwickelt ihre Standard-Methode zur Berechnung von THG-Bilanzen von Biomasse- und Bioenergiesystemen weiter (Details zu den Task 38 Zielen und den für Österreich definierten Arbeitspaketen siehe Kapitel 2.1). Zu folgenden zentralen Themen wurden im Berichtszeitraum österreichische Beiträge eingebracht: zeitlicher Aspekt der THG-Emissionen von forstlichen Bioenergiesystemen, Albedo-Effekt, Auswirkungen von Landnutzungsänderungen, Arbeiten im Rahmen der österreichische „Case Studies“ sowie Vernetzungs- und Verbreitungsaktivitäten.

3.1 Durchgeführte Arbeiten und Projektergebnisse

Im Folgenden werden die österreichischen Task 38 Arbeiten und Ergebnisse der Jahre 2010 und 2012 dargestellt:

3.1.1 Arbeitspaket 1 Österreichische Forschungsaktivitäten:

3.1.1.1 Österreichische Case Studies:

Es wurden zwei Case Studies abgeschlossen, eine mit dem Titel „Greenhouse Gas Benefits of a Biogas Plant in Austria“ (Woess-Gallasch et al, 2011) und eine weitere mit dem Titel „Greenhouse Gas and Energy Analysis of a Bioethanol-oriented Biorefinery in Austria based on wood” (Cherubini F. et al., 2013). Die Inhalte sind in Kapitel 3.2.4 dargestellt, und die Kurzfassungen in Anhang 1 und 2 dokumentiert. Weiters wurde ein Konzept für eine weitere Case Study basierend auf dem Projekt „SMART FORESTS“ (ein Projekt des Klima- und Energiefonds, ACRP Nr. K10AC1K00023) ausgearbeitet. Für zwei verschiedene Bioenergiepfade, die auf der Nutzung forstlicher Biomasse beruhen, werden THG-Emissionsbilanzen berechnet, und deren zeitlicher Verlauf zu dokumentiert. Das Wissen der Task wurde in dieses Projekt eingebracht. SMART FORESTS wird für Österreich Informationen liefern, wie sich für mehrere Bioenergiepfade auf Basis von forstlicher Biomassenutzung die THG-Emissionen und deren Vorteile gegenüber fossiler Energieträger über den Zeithorizont entwickeln.

3.1.1.2 Adaptierung der Task 38 Standard-Methode:

Die drei zentralen Themen mit denen sich die Task intensiv auseinandersetzte, waren der zeitliche Aspekt der THG-Bilanzierung forstlicher Bioenergiesysteme („Timing“), der Albedo-Effekt und durch Landnutzungsänderung verursachte THG-Emissionen. Alle drei Themen bilden die Grundlage für eine weitere Adaptierung der Task 38 Standard-Methode im Sinne einer Aktualisierung:

Zeitaspekt der THG Bilanzierung forstlicher Biomasse: Diese Fragestellung war weiterhin einer der Schwerpunkte, mit dem sich die Task 38 intensiv befasste. Auf nationaler Ebene wurden 2010 und 2011 drei Task 38 Round Tables mit dem Titel „“Energetische Nutzung der forstlichen Biomasse und zeitliche Betrachtung der Kohlenstoffneutralität“ in Wien organisiert (25. 11. 2010, 31. Januar und 7. April 2011). Die Ergebnisse wurden in Form eines Protokolls in Deutsch (Anhang 3) und Englisch dokumentiert. Auf internationaler Ebene wurde für die 19. EU Biomassekonferenz, ein Vortrag und ein Papier mit dem Titel „The timing of GHG emissions from bioenergy systems: Using financial type indicators and terminology to discuss emission profiles from bioenergy“ (Bird D. N, et al., 2011) ausgearbeitet, eingebracht und präsentiert (Anhang 4). Zahlreiche weitere Vorträge wurden in den verschiedenen internationalen Task 38 Meetings zu diesem Thema gehalten. Die österreichischen Arbeiten am Projekt „SMART FORESTS“ (Klima- und Energiefonds, ACRP Nr. K10AC1K00023) schreiten voran. Weiters wurden von der Task „Draft Statements“ für IEA Bioenergy ExCo69 und ExCo70 mit dem Titel „On the timing of mitigation benefits of Forest-Based Bioenergy“ ausgearbeitet.

Albedo: Auf Basis einer Publikation (Schwaiger H. et al., 2010) wurden im Rahmen des EU Projektes „GHG-Europe“ vom JOANNEUM RESEARCH konkrete Forschungsaufgaben zum Thema Albedo gestartet (www.ghg-europe.eu/). Es werden im Rahmen dieses Projektes die Literaturdaten der oben erwähnten Publikation durch echte Daten ersetzt und analysiert. Die Arbeiten laufen, der Projektabschluss ist für Herbst 2013 geplant (mehr Information dazu siehe Kapitel 3.2.2). Neueste Erkenntnisse zu Albedo wurden in diversen Veranstaltungen in die Task 38 eingebracht und diskutiert. Auf Basis dieser Erkenntnisse hat Task 38 entschieden, den Albedo Aspekt offiziell in das Task 38 Arbeitsprogramm von 2013-2015 aufzunehmen. Dem Rechnung tragend wird der Titel der Task 38 im neuen Triennium geändert in „Climate Change Effects of Biomass and Bioenergy Systems“.

THG Emissionen aus direkter und indirekter Landnutzungsänderung: Es wurden die Entwicklungen auf internationaler Ebene zu diesem Thema weiterverfolgt und Erkenntnisse, die im Rahmen der Task 38 entwickelt wurden, eingebracht. Bei der IEA Bioenergy ExCo Broschüre mit dem Titel „Bioenergy, Land Use Change and Climate Change Mitigation“ (Berndes G. et al., 2010) wurden maßgeblich die Kenntnisse der Task 38 zum Thema Landnutzungsänderung (engl. „Land Use Change LUC) integriert. Die Task organisierte mehrere internationale Workshops mit Inhalten zum Themenbereich:

- Helsinki, 2009 “Land use changes due to bioenergy: Quantifying and managing climate change and other environmental impacts”,
- Brüssel, Belgien 2010 “Greenhouse gas emissions from bioenergy systems: impacts of timing, issues of responsibility”
- Campinas, Brasilien Quantifying and managing land use effects of bioenergy (gemeinsam mit Task 40 und Task 43, Information dazu siehe Kapitel 3.1.3).

Im Rahmen des Task 38 Management wurden einige Vorträge der Workshops in Helsinki und Brüssel in einer „Special Section“ der wissenschaftlichen Zeitschrift, „Biomass and Bioenergy“, Elsevier, mit dem Titel „“Land use impacts of bioenergy - selected papers from the IEA Bioenergy“ als Artikel veröffentlicht (Woess-Gallasch S. et al., 2011). Auf nationaler Ebene wurde auf Einladung der Wirtschaftskammer Österreich und der ARGE Biotreibstoffe in einem Vortrag zum Thema „Indirekte Landnutzungsänderung: Methoden und Modelle zur Implementierung“ die Thematik und Methodik dazu dargestellt, einige Modellergebnisse präsentiert und auf mögliche Lösungsansätze verwiesen.

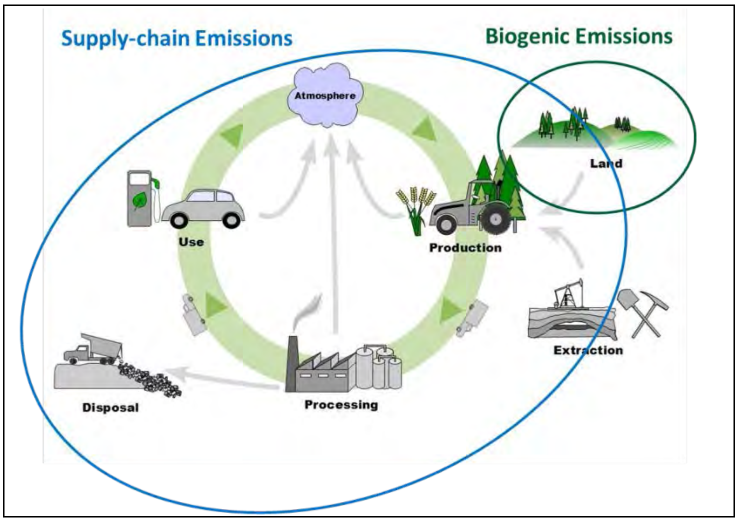

Abbildung 2: Vereinfachte Darstellung der wichtigsten Lebenszyklus Prozessketten: In Blau die Emissionen aus der klassischen LCA Analyse und in Grün die biogenen Emissionen, die sich aus der Landnutzungsänderung und aus dem Albedo-Effekt ergeben (Bird D. N. et al., 2011).

Die neuen Erkenntnisse zu diesen drei zentralen Themen werden in die Task 38 Standard-Methode zur Berechnung der THG-Bilanzen von Biomasse- und Bioenergiesystemen integriert werden. Dazu dient das in der Task derzeit in Ausarbeitung befindliche Dokument mit dem Titel „Updating the Standard Methodology for Comparing the Greenhouse Gas

Balances of Bioenergy Systems and Fossil Energy Systems“. Ein Entwurf liegt dazu vor, deren Fertigstellung ist für 2013 geplant. Eine Vorarbeit dazu stellt das Task 38 Strategic Paper für ExCo mit dem Titel „Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy“ dar (Bird D.N. et al., 2011). Dort sind bereits umfangreiche Informationen zur Task 38 Standard-Methode im generellen und zu den drei oben angeführten zentralen Themen enthalten (Anhang 5).

3.1.1.3 Sonstige Task 38 Forschungsarbeiten mit österreichischer Beteiligung:

Es wurde ein Task 38 Paper mit dem Titel „The influence of Emissions Trading Schemes on bioenergy use“ (Türk A. et al., 2011) verfasst. Es wurde untersucht ob und unter welchen Bedingungen der Emissionshandel ein geeignetes Instrument ist, um mehr Biomassenutzung zu stimulieren. Dabei bildete das Europäische Emissionshandelssystem (Emission Trading Systems - ETS) einen Schwerpunkt, aber auch andere weltweit entstehenden ETS-Systeme in den USA, Australien und in Neuseeland, wurden in dieser Arbeit abgehandelt. Darüber hinaus wurde untersucht, ob und wie Anreize zur verstärkten Biomassenutzung entstehen, wenn verschiedene ETS-Systeme weltweit verknüpft werden („linking“), und welche Barrieren vorhanden sind.

3.1.2 Arbeitspaket 2 Nationale Vernetzungs- und Verbreitungsaufgaben

Die österreichischen Vertreter der Task nahmen im vergangenen Triennium an zahlreichen österreichischen Fachveranstaltungen teil, um Task 38 Wissen einzubringen und um Vernetzungsaufgaben zu übernehmen:

- Der IEA-EUWP Workshop “From Energy Efficient Buildings to Smart Cities” in Wien, 26. März 2012 (Teilnahme von Woess-Gallasch);
- Austropapier/OZEPA-Vorstandsseminar am 26.3.2012 (Vortrag von D.N. Bird und H. Schwaiger zum Thema CO_2 Bilanz der Bioenergie);
- Wirtschaftskammer, ARGE Biotreibstoff Versammlung am 23. Mai 2012 (Vortrag von S. Woess-Gallasch zum Thema Indirekte Landnutzungsänderung: Methoden und Modelle zur Implementierung);
- Fachgespräch Bioenergie, in Graz, 7. November 2012 (Präsentation von S. Woess-Gallasch);
- TU-Wien-EEG Workshop zum Thema „Bioenergie-Technologie Ressourcen und Nachhaltigkeit: Lokale und globale Herausforderung“ am 6.12.2012 (Teilnahme von S. Woess-Gallasch).
- Das IEA – Vernetzungstreffen in Wien, 9.März 2011(Teilnahme von S. Woess-Gallasch);
- Die „Highlights der Bioenergieforschung“ und „Transportation Biofuels Research in Austria 2011“ in Wieselburg, 30 – 31 März 2011, „IEA Energy Technology Network“ Diskussion (Präsentation und Teilnahme von D.N. Bird);
- NOEST Energy Lunch in Graz am 8.Juni 2011: (Präsentation S. Woess-Gallasch Task 38 Biogas „case study“);
- Das Fachgespräch BIOENERGIEFORSCHUNG des BMVIT in Wien, 14. November 2011(Präsentation S. Woess-Gallasch zum Thema IEA Bioenergy – das neue Triennium 2013-2015);
- ExpertInnen Workshop des Umweltbundesamtes und der Landesumwelt-anwaltschaften zum Thema „Nachhaltige Bioenergieproduktion in Österreich“ in Wien am 28.11.2011 (Teilnahme S. Woess-Gallasch).
- Die „Highlights der Bioenergieforschung“ in Güssing (9 – 10 Juni 2010): Es wurde eine Präsentation zum Thema „THG Bilanzierung und andere Erfolgsfaktoren zur nachhaltigen Nutzung der Biogastechnologie“ eingebracht (Vortragende: S. Woess-Gallasch und J. Pucker), verfügbar unter: http://www.energytech.at/results.html/id6021.

Diese Präsentation umfasste zwei Projekte zum gleichen Thema, einerseits die Task 38 Case Study, die die Biogasanlage Paldau untersuchte, und andererseits die Ergebnisse eines JR Projektes, das mehrere Biogasanlagen zum Gegenstand hatte.

- Fachgespräch „Bioenergieforschung“ in Güssing (9. Juni 2010) zum Thema „IEA Bioenergy – Das neue Triennium 2010 – 2012“: Es wurden die geplanten Task 38 Aktivitäten von S. Woess-Gallasch präsentiert.
- Die „Highlights der Bioenergieforschung“ in Wien (2. Dezember 2010) mit dem Schwerpunkt „Technologiepfade der Bioraffinerie“ (Teilnahme S. Woess-Gallasch).

Auf nationaler Ebene wurden 2010 und 2011 drei Task 38 „Round Tables“ mit dem Titel „“Energetische Nutzung der forstlichen Biomasse und zeitliche Betrachtung der Kohlenstoffneutralität“ in Wien organisiert (25. 11. 2010, 31. Januar und 7. April 2011), deren Ergebnisse in einem Protokoll in Deutsch (Anhang 3) und Englisch dokumentiert sind.

Weitere Basisinformationen umfassen die aktualisierte Darstellung der Task 38 auf der Webseite des BMVIT „Nachhaltig Wirtschaften“ sowie Beiträge und Artikel zur Informationsverbreitung in österreichischen Newsletters und Zeitschriften: Im BLT Mitteilungsblatt „Nachwachsende Rohstoffe“ und im NOEST Newsletter „Energie- und Umwelttechnik“. Das nationale Task 38 Team wurde außerdem regelmäßig durch Email Aussendungen über die Task 38 Aktivitäten (Veranstaltungen, Publikationen etc.) informiert und zur Teilnahme an den Task 38 Veranstaltungen eingeladen.

3.1.3 Arbeitspaket 3 Task 38 Workshops und Expert Meetings:

2012:

Im April 2012 organisierte das Task 38 Management in Argonne National Laboratory, Chicago, USA, einen Task 38 Expert Workshop zum Thema **“How to present the timing of emissions from bioenergy in LCA and GHG accounting”,** an dem zahlreiche Wissenschaftler aus aller Welt teilnahmen. Alle Präsentationen dieses Workshops sind auf der Task 38 Webseite verfügbar unter:

www.ieabioenergy-Task 38.org/workshops/argonne12/

In Rahmen der IEA Bioenergy Conference 2012 in Wien, (13 - 15 November) organisierte das Task 38 Management die „Session VIII**“**. Alle Vorträge sind auf der Task 38 Webseite verfügbar unter:

www.ieabioenergy-Task 38.org/workshops/vienna12_I/

Im Anschluss an die IEA Bioenergy Conference organisierte das Task 38 Management ein weiteres internationales Expertentreffen zum Thema **„Impact of timing of GHG emissions“** (16 - 17 November). Es wurden zahlreiche Präsentationen zu den Themen

- Der Zeitaspekt in der THG-Bilanzierung von Biomassesystemen und
- Der Stellenwert von Referenzsystemen zur klimatischen Bewertung von Biomassesystemen

erläutert und diskutiert. Zwölf der Präsentationen sind auf der Task 38 Webseite verfügbar unter: http://www.ieabioenergy-Task 38.org/workshops/vienna12_II/

Es ist geplant, die Ergebnisse dieser Veranstaltung und jener in Argonne, USA, in zwei Publikationen zusammenzufassen:

- The Role of Timing in Impact Assessment of Bioenergy, draft paper 1 (Chum E. et al., 2012);
- Reference Systems for evaluating climate effects of bioenergy, draft paper 2,(Bird D.N. et al., 2012).

Der Abschluss dieser Publikationen ist für 2013 geplant.

2011:

Im September 2011 wurde von Task 38 gemeinsam mit Task 40 und Task 43 in Campinas, Brasilien ein internationaler Workshop (und Exkursion) zum Thema **"Quantifiying and managing land use impacts of bioenergy"** organisiert (19 - 21 September). 46 Vortragende und über 90 Teilnehmer aus aller Welt kamen zusammen um sich über folgende Fragestellungen auszutauschen:

- Methoden zur Abschätzung und Quantifizierung von durch die Bioenergie verursachte Landnutzungsänderungen: Methodische Fragestellungen, Modelle und konkrete Anwendungsbeispiele;
- Auswirkungen von Bioenergiesystemen auf die THG-Bilanz und auf andere umweltrelevante Bereiche wie Boden, Wasser, Biodiversität sowie auf soziale Aspekte;
- Möglichkeiten der Integration von Effekten der Landnutzungsänderung in einen weiteren Bewertungsrahmen;
- Politische Instrumente zur Minderung dieser Effekte, inklusive Bioenergiepolitik, integrierte Landnutzungsstrategien und Zertifizierung von Bioenergieprodukten.

Alle Präsentationen sind auf der Task 38 Webseite verfügbar unter: http://www.ieabioenergy-Task 38.org/workshops/campinas2011/.

Bei der Exkursion am 21. September 2011 gab es die Möglichkeit

- eine Zuckerfabrik mit integrierter Bioethanol Erzeugung zu besichtigen und bei der Zuckerrohrernte dabei zu sein
- oder eine Eukalyptus Plantage zu besichtigen.

2010:

Das Task 38 Management organisierte im März 2010 einen internationalen Task 38 Workshop in Brüssel, Belgien, (8 - 10 März) zum Thema „**Greenhouse gas emissions from bioenergy systems: impacts of timing, issues of responsibility**". Kompetente Vortragende aus Wissenschaft, Wirtschaft und Verwaltung übermittelten aktuelle Erkenntnisse, Ansätze und Problemlösungen zur nachhaltigen Bioenergienutzung im Hinblick auf die THG-Bilanzierung, auf methodische Fragestellungen und praktische Ansätze. Ein Schwerpunkt stellte der zeitliche Aspekt von Bioenergiesystemen auf der Basis der Nutzung forstlicher Biomasse und deren Berücksichtigung in der THG-Bilanzierung bzw. deren Beitrag in der Klimapolitik dar. Alle Präsentationen und ein „Final Workshop Summary" sind auf der IEA Bioenergy Task38 Webseite verfügbar:

http://www.ieabioenergy-task38.org/workshops/brussels2010/.

Im Herbst 2010 wurde vom Task 38 Management ein Graz Group Expert Meeting organisiert mit dem Titel **„Timing of emissions from wood-based bioenergy"** (4 – 5 Oktober). Auch in dieser Veranstaltung stand der zeitliche Aspekt der energetischen Nutzung forstlicher Biomasse und die Frage welche Bioenergiepfade vorrangig zu untersuchen sind zur Diskussion. Es wurden verschiedene Ansätze der THG-Bilanzierung von Bioenergiepfaden auf Basis forstlicher Biomasse mit Berücksichtigung des zeitlichen Verlaufes vorgestellt. Weiters wurde das Thema der Materialsubstitution und der kaskadischen Nutzung von Biomasse anhand eines konkreten Falles in Schweden diskutiert.

3.2 Darstellung der zentralen inhaltlichen Ergebnisse

Im Triennium 2010 - 2012 wurden inhaltlich vor allem in den folgenden Bereichen

- THG-Emissionen aus der Landnutzungsänderung,
- Albedo-Effekt,
- Zeitaspekt der THG-Bilanzierung forstlicher Bioenergiesysteme - „Timing“ und
- Case Studies: österreichische Case Study einer Biogasanlage und eines Bioethanol-Konzeptes für Österreich

neue Erkenntnisse gewonnen, die im folgendem zusammenfassend dargestellt werden.

3.2.1 THG-Emissionen aus der Landnutzungsänderung

Es wurden in der Task die Entwicklungen auf internationaler Ebene zu diesem Thema weiterverfolgt, das Wissen der Task in die internationale Diskussion eingebracht, Veranstaltungen organisiert und entsprechende Ergebnisse dokumentiert (Berndes G. et al., 2010, Woess-Gallasch S. et al., 2011). Auch auf österreichischer Ebene wurde entsprechendes Wissen an Entscheidungsträger (z. B Wirtschaftskammer Österreich, Task 38 Verteilerliste) weitergegeben.

Die EU hat sich mit dieser Thematik im Rahmen der EU-Richtlinie für Erneuerbare Energien (EC 2009), die unter anderem Nachhaltigkeitskriterien für Biotreibstoffe sowie Regeln zur Berechnung der THG Bilanzen beinhaltet, intensiv beschäftigt, die Task 38 war in diesem Prozess eingebunden.

Abbildung 3 (EC, 2012) gibt einen guten Überblick über die Ergebnisse mehrerer internationaler Studien zur Berechnung von THG-Emissionen aus der Landnutzungsänderung, die durch eine weltweit forcierte Erzeugung von Biotreibstoffen und der damit verbundenen Ausdehnung der Anbauflächen und den zusätzlichen Landnutzungsbedarf verursacht werden. THG-Emissionen aus Landnutzungsänderungen sind nicht vernachlässigbar, auch wenn die Modelle Unsicherheiten aufweisen. Bei diesen weltweiten Modellansätzen kann nicht mehr zwischen direkter Landnutzungsänderung (dLUC) und indirekter (iLUC) unterschieden werden, sondern es werden die durch weltweite Landnutzungsänderungen insgesamt verursachten THG-Emissionen der Biotreibstoffe ermittelt.

Auch wenn die Unsicherheiten relativ groß sind, können insbesondere die Ergebnisse aus den aktuellsten Modellberechnungen als beste Näherungswerte angesehen werden. Insbesondere die Ergebnisse des „MIRAGE“ Modells des „International Food Policy Research Institute“ (IFPRI), in dem entsprechende Anforderungen aus europäischer Sicht berücksichtigt wurden (siehe Abbildung 3) werden von der Europäischen Kommission als die verlässlichsten Resultate eingestuft (EC, 2012).

Die internationale Diskussion wie durch indirekte Landnutzungsänderung der energetischen Biomassenutzung verursachte THG-Emissionen zu quantifizieren sind, ist noch nicht abgeschlossen. Die Task wird sich weiterhin mit diesem Thema auseinander setzen, allerdings keine eigenen Berechnungen anstellen. Die Task zeigte auch Möglichkeiten auf, wie diese Emissionen verringert bzw. vermieden werden können.

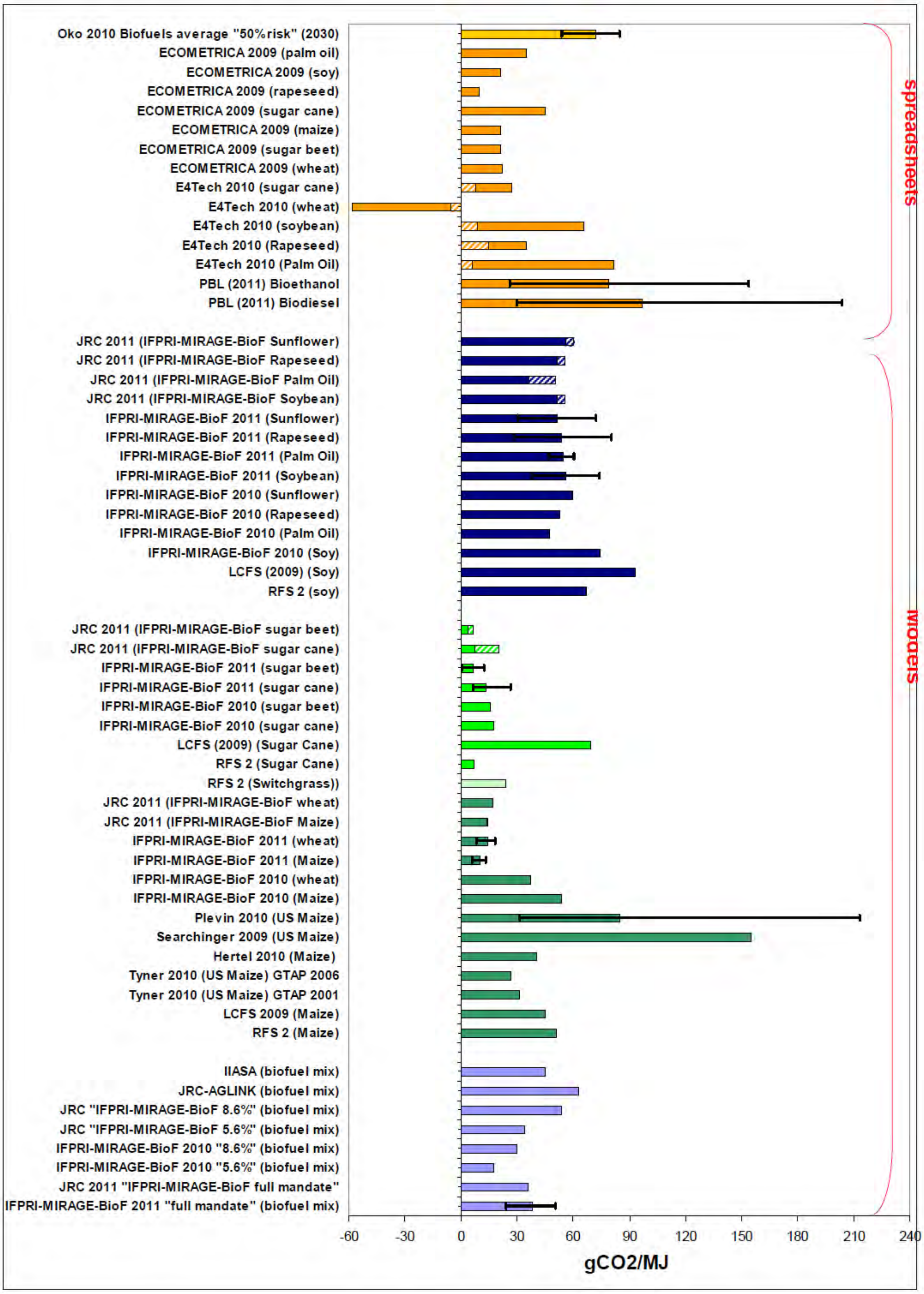

Abbildung 3: LUC-Ergebnisse verschiedener Modelle – Szenarien für 2009 (in g CO2/MJ), Quelle: EC Staff Working Document SWD (2012) 343 final.

3.2.2 Der Albedo-Effekt

Der Albedo-Effekt ist keine THG-Emission sondern ein Effekt, der das Klima durch den Strahlungsantrieb (= „radiative forcing“) beeinflusst. Bird und Schwaiger entwickelten ein Konzept indem die zu- und abnehmenden Effekte des Strahlungsantriebes durch die Albedo in CO_2-Äquivalente ausgedrückt werden können. Erste Untersuchungsergebnisse zeigen auf (Schwaiger H. and Bird D.N., 2010). in welcher Form die Veränderung der Albedo auf Grund von Landnutzungsänderungen in ein bestehendes Kohlenstoffmodell eingebaut werden kann, um so den Gesamteffekt auf das Klima besser darstellen zu können.

Angewandt auf eine Fallstudie in Südeuropa wird ein atmosphärisches Modell mit einem Kohlenstoffmodell kombiniert, um einerseits die Reflexionsveränderung und andererseits die Änderung der Kohlenstoff (C)-Speicherung einer Aufforstungsfläche in einer kombinierten Strahlungsbilanz über die Zeit darzustellen.

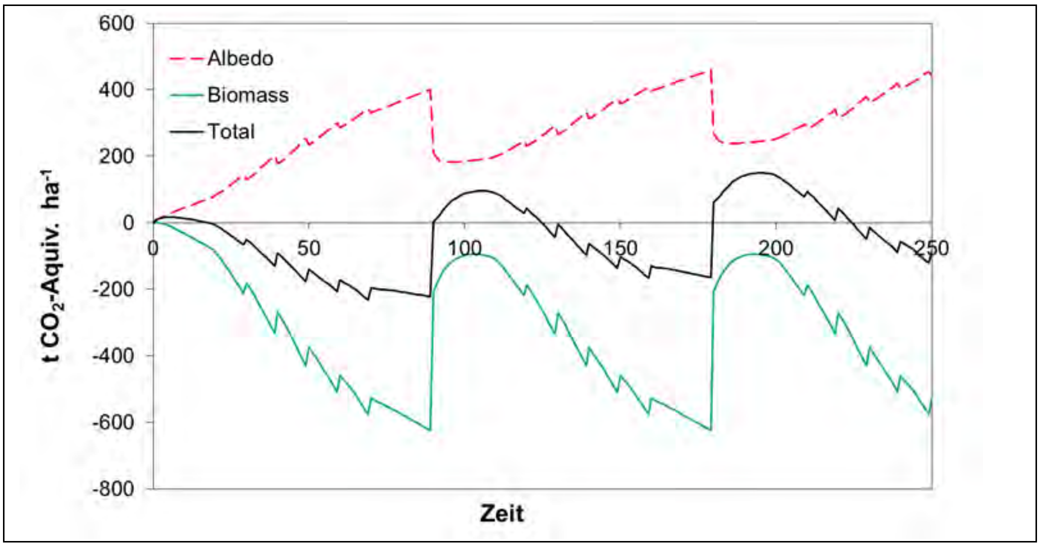

Abbildung 4: Kombination von C-Modellierung und Albedo (Basis CO_2-Äquivalent) für Fallbeispiel „Sierra Guadarrama“, Spanien. (Schwaiger H. et al., 2010).

Die Ergebnisse zeigen, dass Maßnahmen wie Aufforstungen und Wiederaufforstungen in Gebieten mit Schneebedeckung und vielen Sonnenstunden (und wenig Bewölkung) im Winter nicht mehr nur als einfache, positive Aktivitäten gesehen werden können den Klimawandel zu bekämpfen, da die C-Anreicherung durch das Waldwachstum via CO_2-Bindung (bis zu 6x10-6 Watts ha-1 zum Ende der Umtriebszeit) durch die Veränderung der Albedo zum Teil neutralisiert wird.

Derzeit werden vom JOANNEUM RESEARCH im Rahmen des EU Projektes „GHG-Europe“ die Auswirkungen verbesserter Eingangsparameter, durch die Anwendung von tatsächlichen, aus Satellitenbildern gemessenen Albedo-Daten (z.B. MODIS) und Wetterdaten (ISCCP) überprüft. Das Untersuchungsgebiet dieses Projektes umfasst Ostösterreich (Steiermark, Burgenland Niederösterreich Wien), Slowenien, Slowakei, Tschechien und Ungarn.

Es zeigt sich, dass die Berechnung der C-Speicherveränderungen im Zuge einer Landnutzungsänderung alleine nicht ausreicht, um den gesamten Einfluss auf das Klima widerzuspiegeln. Zukünftige THG-Bilanzen von Landnutzungssystemen und Produkten (z.B.

Biomasse, Biotreibstoffe) mittels LCA sollten demnach nicht nur die C-Bilanzen der direkten und indirekten Landnutzungsänderung berücksichtigen, sondern auch diese zusätzlichen Albedo-Effekte inkludieren.

3.2.3 Zeitaspekt der THG-Emissionen forstlicher Bioenergiesysteme

Die THG-Bilanz der Bioenergienutzung ist überwiegend durch die im C-Kreislauf stattfindenden Wachstums-, Speicher- und Zerfallsprozesse bestimmt. Bei forstlichen Rohstoffen haben diese Prozesse - im Vergleich zu landwirtschaftlichen Rohstoffen - lange Zeitkonstanten.

Erfolgt zum Beispiel im Rahmen eines Bioenergiesystems zunächst eine Bepflanzung mit schnellwachsenden Hölzern (Kurzumtriebs-Plantagen mit Umtriebszeiten von ca. 3-10 Jahren) und danach eine energetische Nutzung der gespeicherten Biomasse, dann verursacht das Bioenergiesystem nach einer „Einschwingzeit“ keine C-Emissionen, wodurch die C-Emissionen des ersetzten fossilen Energiesystems vermieden werden.

Im Falle der energetischen Nutzung von Biomasse aus einem bestehenden Wald, der wieder aufgeforstet wird, liegt zunächst eine Freisetzung von C-Emissionen in der Höhe des ersetzten fossilen Energiesystems vor. Anschließend erfolgt durch das Nachwachsen des Waldes wieder eine Kohlenstoffbindung. Wenn der Wald vollständig nachgewachsen ist, sind die Netto-C-Emissionen Null. In beiden Fällen ergibt sich somit eine Zeitverschiebung der angestrebten C-Emissionsreduktion deren Dauer abhängig von den jeweiligen Wachstumsraten ist. In der Bilanzierung wirkt sich das wie folgt aus: Im Fall der Kurzumtriebs-Plantagen wird die bis zur Verbrennung gespeicherte Biomasse in die Bilanzierung aufgenommen und im Fall der Nutzung bestehender Wälder wird die nachwachsende Biomasse in ihrem zeitlich auftretenden Ausmaß aufgenommen.

Im Fall einer energetischen Nutzung von Reststoffen der Forst/Holz/Platte/Papier-Kette (Produktionsabfälle, Altholz, Papier) kommt es durch den Verbrennungsprozess zu einer im Vergleich zum Zerfall bei Nicht-Nutzung „vorgezogenen“ Emission des Kohlenstoffs. Beispiel: Wird Schlagrücklass energetisch verwertet, so ist davon auszugehen, dass diese Reststoffe andernfalls im Wald verbleiben und dort langsam zu CO_2 abgebaut werden.

Nach den bestehenden politischen Zielen soll eine Nettoreduktion der CO_2-Emissionen bis 2020 um 20 % erreicht werden und bis 2050 Maßnahmen gesetzt werden, durch die die Klimaerwärmung bei max. + 2°C stabilisiert wird. Zur Erreichung dieser Ziele soll der Ersatz fossiler Energieträger durch Biomasse beitragen. Bei der Überprüfung der Zielerreichung werden die THG-Emissionen des Bioenergiesystems einem Referenzsystem gegenübergestellt.

In dem in Abbildung 5 dargestellten Beispiel mit der Nutzung von Reststoffen wird für das Referenzsystem angenommen, dass die benötigte Energie durch ein fossiles Energiesystem erzeugt wird und dass der in den Reststoffen enthaltene Kohlenstoff länger gebunden bleibt und nur langsam an die Atmosphäre abgegeben wird. Die Abbildung zeigt den zeitlichen Verlauf der C-Emissionen aus der Verbrennung von Biomasse (rot), aus der Verbrennung von fossilen Brennstoffen (schwarz) und aus dem vermiedenen Zerfall der Reststoffe (blau). Dargestellt ist beispielhaft eine Jahresmenge an Biomasse bzw. an fossilen Brennstoffen beim Umstieg auf die Bioenergieanlage. Zum Zeitpunkt T_0 wird Biomasse verbrannt mit den entsprechenden Kohlenstoffemissionen aus der Biomasse. Jene der fossilen Energieträger fallen auf null ab, da sie durch die Biomasse substituiert werden. Zu diesem Zeitpunkt beginnt auch die Vermeidung des sich über den Zeitraum DT erstreckenden Zerfalls der Biomasse. Zum Zeitpunkt T_0 + DT hat das System seine volle Emissionsminderung erreicht.

Die Nettoemissionen im weiteren Verlauf des Betriebs der Bioenergieanlage ergeben sich durch die Addition der jeweiligen Jahresverläufe.

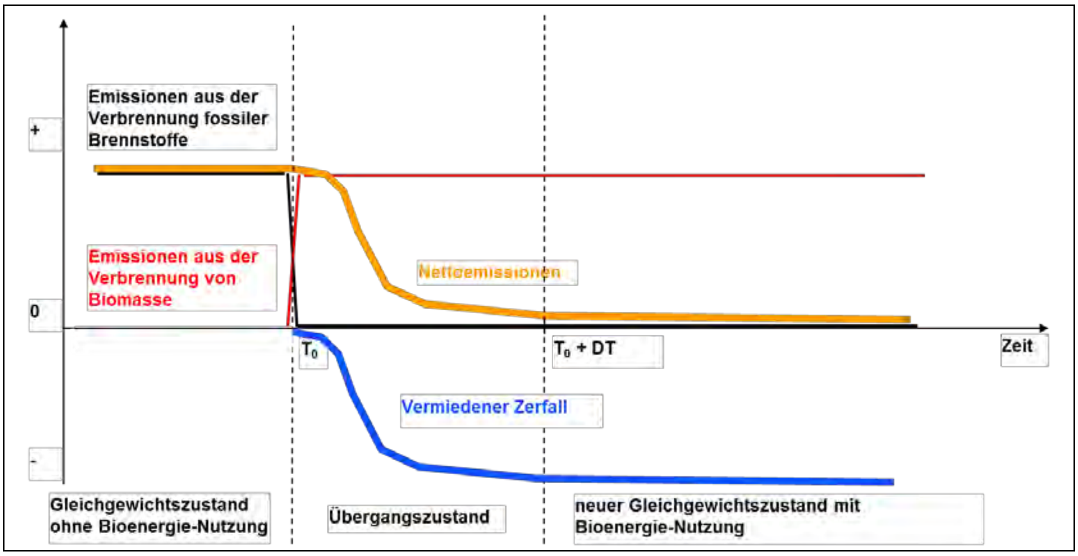

Abbildung 5: Kohlenstoffemissionen der Biomassenutzung aus Reststoffen. T_0: Zeitpunkt der Verbrennung der Biomasse, DT: Dauer des (vermiedenen) Zerfalls der Biomasse.

Die Zeitverzögerung bei der Emissionsreduktion spielt insbesondere bei Bioenergieanlagen, die forstliche Rohstoffe verbrennen, eine Rolle. Die Signifikanz der Zeitverzögerung besteht darin, dass die „sofortige“ Wirkung nicht eintritt und somit formale (Kyoto, „2020“) und klimabezogene (+2°C-Stabilisierung bis 2050) Ziele nur in einem verminderten Ausmaß erreicht werden. Selbst in einem nachhaltigen Biomassesystem (und dies ist im Falle des Österreichischen Waldes auch unumstritten) setzt sich die C-Anreicherung der Atmosphäre beim Umstieg auf Biomassenutzung zunächst fort, klingt aber allmählich auf null ab.

Im Rahmen einer LCA müssen zusätzlich auch die THG-Emissionen aus den verschiedenen Prozessketten (Biomasserohstoffgewinnung, Transport, Errichtung, Betrieb und Entsorgung etc.) berechnet werden. Zur Dokumentation des Zeitablaufes der gesamten THG-Emissionen eignen sich von der Methodik her Ansätze aus der Ökonomie, wie beispielsweise die Amortisationszeit, in diesem Falle die Amortisationszeit der THG-Emissionen: Siehe dazu das in der Folge dargestellte Beispiel der österreichischen „Case Study“ eines Bioethanol Konzeptes.

Das Thema des Zeitaspektes der THG-Emissionen forstlicher Bioenergiesysteme war eines der Hauptaufgaben der Task 38 im Triennium 2010 - 2012, sowohl auf internationaler (Anhänge 2, 4) als auch auf nationaler Ebene (Anhänge 2, 3).

3.2.4 Task 38 Case Studies

Die „Case Studies“ der Task 38 dienen einerseits dazu, ausgewählte Biomasse- und/oder Bioenergiesysteme hinsichtlich der THG-Emissionen zu bilanzieren und deren Minderungspotentiale aufzuzeigen, aber auch als Instrument um neue methodische Erkenntnisse der Task 38 zu testen und erstmals anzuwenden. Anhand der österreichischen Case Studies, die im Triennium 2010 – 2012 abgeschlossen wurden, werden beispielhaft zu erwartende Ergebnisse präsentiert.

3.2.4.1 Österreichische Case Study eines Bioethanol Konzeptes

Anhand der österreichischen Case Study mit dem Titel „Greenhouse gas and energy analysis of a bioethanol oriented biorefinery concept for Austria based on forest wood“

(Cherubini et al, 2013), wird das Konzept des zeitlichen Aspektes von THG-Emissionen aus der Nutzung forstlicher Bioenergiesysteme aufgezeigt (Anhang 2).

Es werden die THG Emissionen für ein österreichisches Bioraffinerie-Konzept auf Basis einer LCA untersucht. In der Anlage wird forstliche Biomasse in Form von Waldhackgut eingesetzt und Bioethanol der zweiter Generation, sowie andere Energieträger (Elektrizität, Wärme und Biogas) und Chemikalien (Phenole) erzeugt. Das Referenzsystem, mit dem das Bioraffineriesystem verglichen wird, erzeugt die gleichen Produkte aus fossilen Rohstoffen. Als Ergebnis wurden die THG-Emissionen und der kumulative Primärenergieverbrauch für verschiedene Zeiträume berechnet: Für 2020 aufgrund der Energiepolitik der EU, für 2050 aufgrund internationaler Klima-und Energiepolitik und als langfristige Betrachtung über 100 Jahre bis 2110.

Methodisch wurde hier der aus der Ökonomie stammende Ansatz der Amortisationszeit angewandt. Die Ergebnisse zeigen, dass vom Startpunkt im Jahr 2012 bis 2024 durch dieses Bioraffineriesystem im Vergleich zum fossilen Referenzsystem mehr THG-Emissionen an die Atmosphäre abgegeben werden. Danach allerdings vermindern sich die THG-Emissionen von Jahr zu Jahr zunehmend durch die Absorption von Kohlenstoff aus der Atmosphäre im wieder nachwachsenden Wald. Bis 2050 sind die kumulativen THG-Emissionen des Bioraffineriesystems im Vergleich zum fossilen Referenzsystem um ungefähr 40% niedriger. Die Bewirtschaftungsänderung ist für 84% der THG-Emissionen verantwortlich, die Produktion der Rohmaterialien verursacht 15% der THG-Emissionen.

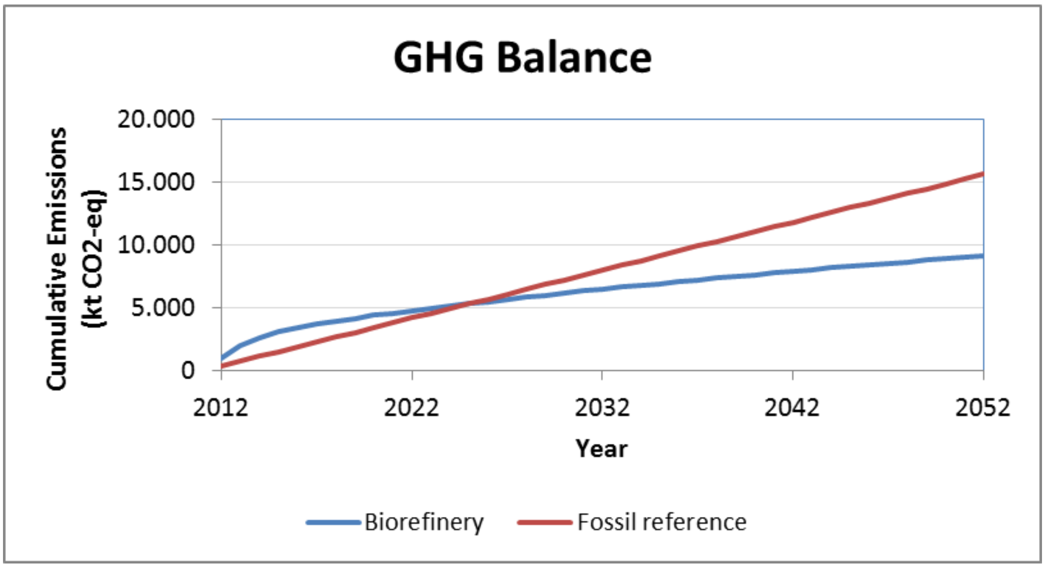

Abbildung 6: Kumulative THG-Emissionen der Bioraffinerie und des fossilen Referenzsystems. Ab 2026 sind die THG-Emissionen der Bioraffinerie im Vergleich zum fossilen System niedriger (Cherubini F. et al., 2013).

Diese Case Study zeigt auf, wie die zeitliche Dimension der THG-Reduzierung forstlicher Bioenergiesysteme dargestellt werden kann. Das ist eine der neuen Anforderungen, die die Task 38 in ihre Standard-Methode bei der Berechnung von THG-Emissionsbilanzen von Bioenergiesystemen aufnimmt.

Die neuen Erkenntnisse zu den zentralen Themen 1 bis 3 werden in die Task 38 Standard-Methode zur Berechnung der THG-Bilanzen von Biomasse- und Bioenergiesystemen integriert. Dazu dient das in der Task 38 derzeit in Ausarbeitung befindliche Dokument mit dem Titel „Updating the Standard Methodology for Comparing the Greenhouse Gas Balances of Bioenergy Systems and Fossil Energy Systems“, deren Abschluss nun für das Jahr 2013 geplant ist. Vorarbeiten dazu wurden bereits in der ExCo Broschüre mit dem Titel „Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy. IEA Bioenergy, ExCo 2011:03. (Bird D.N. et al., 2011) dokumentiert (Anhang 5). Die praktische Anwendung der Task 38 Standard-Methode wird in den Case Studies getestet.

3.2.4.2 Österreichische Case Study der Biogasanlage Paldau

Anhand der Biogasanlage der NegH Biostrom KEG in Paldau (Steiermark), die ein abgedecktes Endlager hat, wurden in der „Case Study“ mit dem Titel „Greenhouse Gas Benefits of a Biogas Plant in Austria“ (Woess-Gallasch S. et al., 2011) die Auswirkungen eines abgedeckten Endlagers im Vergleich zu einem offenen untersucht. In dieser Anlage werden Maiskorn (3.120 t/a), Maissilage (2.670 t/a), Grassilage (700 t/a), Schweinegülle (3.040 m^3/a) und Rindergülle (300 m^3/a) eingesetzt. Die Anlage hat zwei Hauptfermenter (je 1000 m^3) und zwei Nachfermenter (je 1100 m^3). Zwei BHKW erzeugen jährlich rund 4 GWh Strom und 7 GWh Wärme.

Durch Messungen der Biogasbildung im abgedeckten Endlager über ungefähr ein halbes Jahr wurde ein Vergleich mit der möglichen Situation bei einem offenen Endlager durchgeführt. Dieser Vergleich ermöglichte eine Aussage über die durch die Abdeckung des Endlagers vermiedenen Methan-Emissionen und über die damit verbundene Erhöhung des Biogasertrags zur Strom- und Wärmeerzeugung. Der Mittelwert des gemessenen Biogasertrags aus dem Endlager betrug 3,9 Nm_3/h, der Methanertrag im Endlager umfasst hochgerechnet auf ein Jahr 15,6 t CH_4.

In der LCA wurden die THG-Emissionen Kohlendioxid (CO_2), Methan (CH_4) und Lachgas (N_2O) sowie deren CO_2-Äquivalente ermittelt. Auch die Beiträge aus der Errichtung, dem Betrieb und der Entsorgung der Anlagen, aus dem Anbau, der Ernte sowie dem Transport der eingesetzten Rohstoffe sowie aus der Verwertung der Nebenprodukte wurden berücksichtigt. Ergänzend wurden die aus der direkten Landnutzungsänderung resultierenden CO_2-Emissionen berechnet.

Letztendlich wurden drei Fälle untersucht: Die bestehende Biogasanlage in Paldau mit einem geschlossenen Endlager, eine „angenommene Biogasanlage mit einem offenen Endlager“ und das Referenzsystem ohne Biogasanlage, mit Bereitstellung der gleichen Menge an Strom aus Erdgas und an Wärme aus Heizöl und Holz.

Als Ergebnis zeigt sich (siehe Abbildung 7), dass durch die Abdeckung des Endlagers der Biogasertrag erhöht und die THG-Emissionen verringert werden und dass für beide Biogas Varianten Vorteile gegenüber dem Referenzsystem bestehen:

- Der Biogasertrag wäre mit offenem Endlager um 1,4% niedriger, die Strom-erzeugung würde sich um 1,9% reduzieren (minus 70 MWh Strom pro Jahr);
- Mit offenem Endlager sind die THG-Emissionen gegenüber dem geschlossenen Endlager um 29% höher (Hauptgrund: CH_4-Emissionen vom Endlager);
- Mit geschlossenem Endlager ergeben sich minus 44% THG Emissionen gegenüber Referenzsystem;
- Mit offenem Endlager ergeben sich nur mehr minus 27% THG-Emissionen gegenüber Referenzsystem.

Aus der direkten Landnutzungsänderung ergibt sich über zwanzig Jahre ein positiver Effekt von minus 48 t CO_2 pro Jahr.

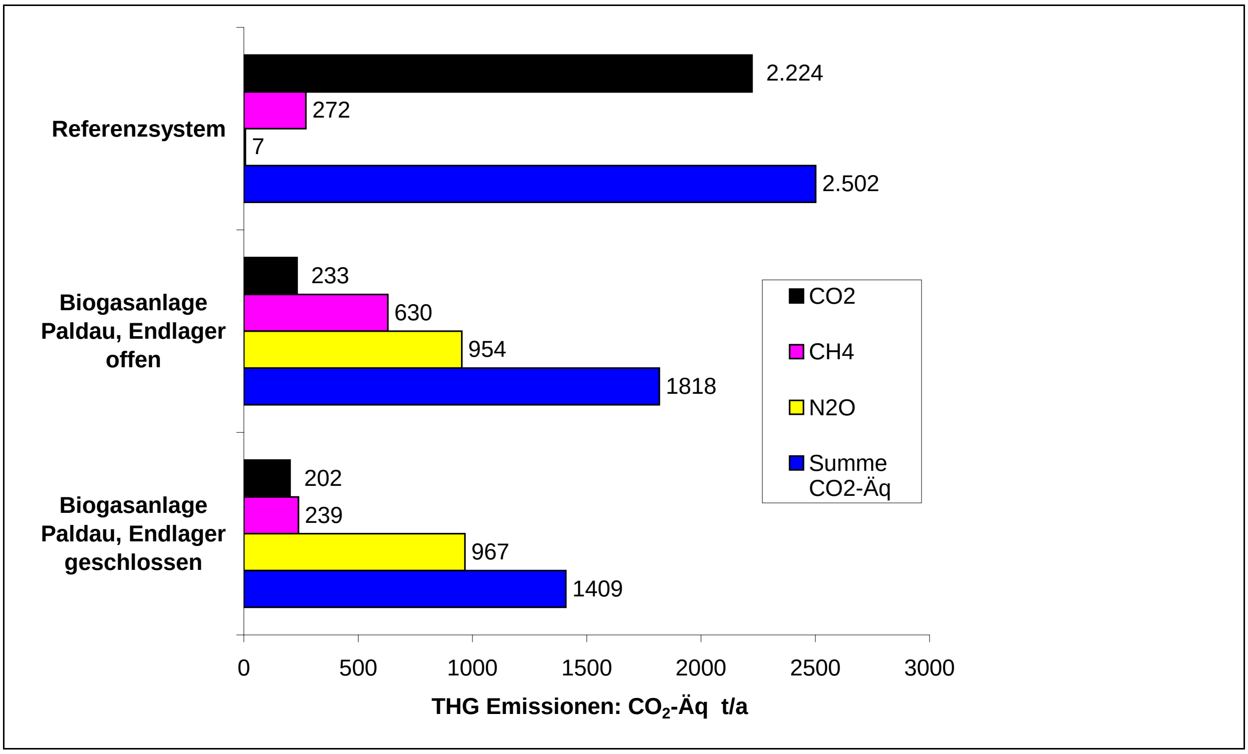

Abbildung 7: Case Study Austria - Biogasanlage Paldau: THG-Emissionen (CO_2-Äquivalente) im Vergleich zu Biogasanlage mit offenem Endlager und zum Referenzsystem (Woess-Gallasch S. et al., 2011).

Der englische Bericht und die Broschüre (Anhang 1) sind auf der Task 38 Webseite unter www.ieabioenergy-task38.org/projects/ und auf der Webseite des BMVIT unter www.nachhaltigwirtschaften.at/iea/results.html/id1980 verfügbar.

3.2.4.3 Sonstige „Case Studies“

Folgende „Case Studies“ wurden von anderen teilnehmenden Ländern der Task im Triennium 2010 – 2012 durchgeführt und sind oder werden in Kürze abgeschlossen:

- Australien: Biokohle („biochar“) aus verschiedenen Biomasseressourcen (Cowie A. L. et al, 2013): Langfassung und Kurzfassung als Entwurf vorliegend (derzeit Review-Prozess laufend);
- Brasilien: Bewertung verschiedener Alternativen der energetischen Nutzung von Zuckerrohr Rückständen hinsichtlich der THG-Bilanzierung (Leal M.R. et al, 2013): Langfassung und Kurzfassung als Entwurf vorliegend (derzeit Review-Prozess laufend);
- Deutschland: Fischer Tropsch (FT) Biodiesel aus forstlicher Biomasse: seit Oktober 2012 abgeschlossen (Rödl A., 2012);
- Schweden: Integrierte Erzeugung von FT und Di-Methyl-Ether (DME) Biotreibstoffen in einer Schwedischen Papierfabrik: seit März 2013 abgeschlossen (Gustavsson L. et al, 2013).
- Finnland: Biodiesel aus forstlicher Biomasse: seit März 2013 abgeschlossen (Forsström J et al, 2013).

3.3 Veröffentlichungen

Bird N., Cowie A., Strømman A. and Frieden D. (2011): The timing of GHG emissions from bioenergy systems: Using financial type indicators and terminology to discuss emission profiles from bioenergy. Proceeding, 19th EU Biomass Conference Exhibition, 6-10 June 2011, p. 2572-2575 Berlin, Germany (Task 38 Web: www.ieabioenergy-Task 38.org/publications/).

Synopsis: Zur Darstellung des zeitlichen Verlaufes der THG-Emissionen bei energetischer Nutzung von forstlicher Biomasse wird in dieser Publikation der aus der Ökonomie stammende Ansatz der Amortisationszeit angewandt und zur Diskussion gestellt.

Bird N., Cowie A., Cherubini F. and Jungmeier G. (2011): Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy, IEA Bioenergy ExCo 2011:03 (IEA Bioenergy web: http://www.ieabioenergy.com/LibItem.aspx?id=7096)

Synopsis: Dieser Bericht informiert über die zentralen methodischen Aspekte wie THG-Bilanzen von Bioenergiesystemen auf Basis einer LCA durchzuführen sind.

Cherubini F. Jungmeier G. and Bird D.N. (2013): GHG and energy analysis of a bioethanol oriented biorefinery concept in Austria, IEA Bioenergy Task 38 Case Study Report and Brochure. 2013. (Task 38 Web: http://www.ieabioenergy-task38.org/projects/)

Synopsis: In dieser Case Study werden die THG-Emissionen für ein österreichisches Bioraffinerie-Konzept auf Basis einer LCA untersucht und beispielhaft das Konzept des zeitlichen Verlaufes von THG-Emissionen aus der Nutzung forstlicher Bioenergiesysteme aufgezeigt.

Cowie A. L. and Cowie A. J. (2013): Life cycle assessment of greenhouse gas mitigation benefits of biochar in Australia. IEA Bioenergy Task 38 Case Study Report and Brochure, draft 2013.

Synopsis: Für verschiedene Varianten von Biokohlesystemen aus verschiedenen Biomasseressourcen und unter verschiedenen Pyrolyse-Konditionen wurden die THG-Emissionen der in Kombination erzeugten Energie und der Biokohle zur Bodenverbesserung evaluiert.

Forsström J., Pingoud K., Pohjola J., and Vilén T. (2013): Wood-based biodiesel in Finland: Market-mediated impacts on emissions. IEA Bioenergy Task 38 Case Study Brochure, 2013.
Synopsis: Basierend auf der Nutzung forstlicher Biomasse wurde anhand eines Modelles eine Biodieselstrategie für Finnland mit den Auswirkungen auf die THG-Bilanz analysiert.

Gustavsson L. and Joelsson J. (2013): Reductions in greenhouse gas emissions and oil use through di-methyl ether and Fischer-Tropsch diesel production in Swedish chemical pulp mills. IEA Bioenergy Task 38 Case Study Brochure, 2013.
Synopsis: Es werden THG-Minderungspotentiale der integrierten Erzeugung von FT und DME Biotreibstoffen in einer Schwedischen Papierfabrik evaluiert.

Leal M.R., Seabra J. E. and Penha T. (2013): Alternatives to Use Sugarcane Residues to Reduce GHG Emissions. IEA Bioenergy Task 38 Case Study Report and Brochure, draft, 2013.

Synopsis: Es werden verschiedene Alternativen der Verwendung von Zuckerrohrrückständen (Bagasse und Stroh) zur Produktion von Biotreibstoffen oder Strom hinsichtlich des THG-Minderungspotential im Vergleich zur traditionellen Verwendung bewertet.

Rödl A. (2012): Environmental Assessment of Liquid Biofuel from Woody Biomass. IEA Bioenergy Task 38 Case Study Report and Brochure, 2013.
Synopsis: Die THG-Emissionen und andere ausgewählte Umweltaspekte (Versauerung, Eutrophierung und photochemischen Ozonbildung) aus der Produktion von FT Biodiesel und dessen Verbrauch werden im Vergleich zum fossilen Energiesystem bewertet.

Pingoud K., Cowie A., Bird D.N., Gustavsson L., Rüter S., Sathre R., Soimakallio S., Türk A., Woess-Gallasch S. (2010): Bioenergy: Counting on Incentives. Letters to Science. 327, 5 March 2010.
Synopsis: Zum Thema der internationalen und der im Kyoto Protokoll festgelegten Methodik der THG- Bilanzierung und in Reaktion auf einen Artikel von Searchinger D. (Searchinger D. et. al., Science 2009; 326:527-8) wurde von den oben angeführten Task 38 Mitgliedern eine auf diesen Artikel bezogene Stellungnahme ausgearbeitet.

Protokoll zum Round Table (2011): Energetische Nutzung der forstlichen Biomasse und zeitliche Betrachtung der Kohlenstoffneutralität. Veranstaltet im Rahmen der österreichischen Teilnahme an Task 38 von IEA Bioenergy in Form dreier Gesprächsrunden in Wien am 25. November 2010, am 31. Jänner 2011 und am 8. April 2011, offizielle deutsche Version (Webseite des BMVIT Nachhaltig Wirtschaften:

http://www.nachhaltigwirtschaften.at/iea_pdf/task38_rt_protokoll_de.pdf.

Synopsis: Der österreichische „Round Table“ der IEA Bioenergy Task 38 bewertete den Einsatz von biogenen Rohstoffen aus dem Wald im Hinblick auf die Auswirkungen auf den Kohlenstoffkreislauf.

Schwaiger H.P. and Bird D. N. (2010): Integration of albedo effects caused by land use change into the climate balance: Should we still account in greenhouse gas units? Forest Ecology and Management 260 (2010) p. 278-286.

Synopsis: Die Arbeit untersucht die Einflüsse nicht treibhausgasrelevanter Effekte wie z.B. Albedo auf die gesamte Klimabilanz einer Landnutzungsänderung wie beispielsweise Aufforstung.

Türk A., Cowie A., and Leopold A. (2011): The influence of Emissions Trading Schemes on bioenergy use. Task 38 Paper, March 2011 (unter Task38 Web: www.ieabioenergy-Task 38.org/publications/)

Synopsis: Dieses Papier untersucht einerseits ob und unter welchen Bedingungen der Emissionshandel ein geeignetes Instrument ist, um mehr Biomassenutzung zu stimulieren und ob und wie Anreize zur verstärkten Biomassenutzung entstehen, wenn ETS-Systeme weltweit verknüpft werden.

Woess-Gallasch S., Bird N., Cowie A, guest editors (2011): Land use impacts of bioenergy: Selected papers from the IEA Bioenergy Task 38 meetings in Helsinki, 2009 and Brussels, 2010. Biomass Bioenergy, Volume 35, Issue 12, 2011. (Web: http://www.sciencedirect.com/science/journal/09619534/35, und http://www.ieabioenergy-task38.org/publications/Woess%20et%20al%2020111%20T38%20Special%20Section%20editorial%20web.pdf

Synopsis: In dieser „Special Section“ werden mehrere Vorträge zweier internationaler Task 38 Workshops (Helsinki 2009 und Belgien 2010) zum Thema Landnutzung und Bioenergie als Artikel veröffentlicht und in einem Editorial in das Thema eingeführt.

Woess-Gallasch S. Bird N., Enzinger P., Jungmeier G., Padinger R., Pena N., and Zanchi G.: Greenhouse gas benefits of a biogas plant in Austria. IEA Bioenergy Task 38 Case Study Report and Brochure 2011 (Task 38 Web: http://www.ieabioenergy-Task38.org/projects/).

Synopsis: Anhand der Biogasanlage der NegH Biostrom KEG in Paldau, die ein abgedecktes Endlager hat, wurden die THG-Emissionen eines abgedeckten Endlagers im Vergleich zu einer Biogasanlage mit einem offenen Endlager und zu einem Referenzsystem untersucht und die daraus resultierenden THG-Minderungspotentiale aufgezeigt.

3.4 Geplante Veröffentlichungen (Entwürfe vorhanden)

Bird D. N., Cowie A and Task 38 ntls (2012): Updating the Standard Methodology for Comparing the Greenhouse Gas Balances of Bioenergy Systems and Fossil Energy Systems. Draft,2012.

Chum E. et al (2012): The Role of Timing in Impact Assessment of Bioenergy. Draft paper 1, Task 38 Expert Meeting Vienna, 2012.

Bird D. N. et al (2012): Reference Systems for evaluating climate effects of bioenergy. Draft paper 2, Task 38 Expert Meeting Vienna, 2012.

4 Bezug auf die Forschungskooperation Internationale Energieagentur (IEA)

4.1 Relevante österreichische Zielgruppe

Im österreichischen Task Team sind alle relevanten Zielgruppen der österreichischen Forschungsszene (z.B., TU Wien, TU Graz, BOKU Wien, UNI Wien, Graz und Klagenfurt, IIASA Laxenburg, ARC Seibersdorf, BFW, AEA, Wegener-Center, WIFO, IFA-Tulln, HBLFA Francisco-Josephinum, JOANNEUM RESEARCH), die Fachleute aus der Verwaltung sowie energiepolitische Entscheidungsträger (z.B. BMVIT, BMLF, UBA, BLT, LEV Steiermark), Interessensvertreter (z.B. Biomasseverband, Propellets, Wirtschaftskammer Österreich) und die einschlägige Industrie (z.B. Papier- und Zellstoffindustrie, Holzverarbeitende Industrie, Energiewirtschaft) eingebunden.

Die Rolle des NTL ist integrativ, indem er einerseits nationale Experten über die Tätigkeiten der Task informiert und deren Beteiligung an den Task Aktivitäten anregt. Es wurden einerseits das Task Management über die im eigenen Land laufenden Forschungsaktivitäten informiert und entsprechende Informationen darüber dort eingebracht. Neben Email Listen zur Verbreitung von Informationen hat die Erfahrung gezeigt, dass direkte Kontakte zwischen dem nationalen Team sinnvoll sind. Das österreichische Task 38 Team wird über alle internationale und nationale Task 38 Veranstaltungen informiert und – soweit möglich – auch zur Teilnahme eingeladen. Nationale Veranstaltungen wie in diesem Triennium der Task 38 Round Table zum Thema der zeitlichen Dimension der THG-Bilanzierung forstlicher Bioenergiesystemen ermöglichen sich im Detail mit aktuellen Themen zu befassen und Ergebnisse auszuarbeiten.

4.2 Relevanz und Nutzen

Der Nutzen der österreichischen Beteiligung an IEA Bioenergy besteht vor allem darin, dass IEA Bioenergy auf einen aktiven Informationsaustausch in einem Netzwerk zugeschnitten ist und - über die EU-Forschungsnetzwerke hinausgehend - weltweite Kooperationen (Australien, USA) ermöglicht. Damit werden Informationen über zukunftsweisende Projekte verfügbar, die für die österreichische Forschungs-landschaft nützlich sind. Weiters ist eine Standortbestimmung für die österreichischen Aktivitäten in der internationalen Bioenergieforschung möglich. Die in Task 38 verfügbaren Dokumente sind auf der Task 38 Webseite gesammelt und stehen allen Interessenten aus Forschung und Industrie in Österreich zur Verfügung: http://www.ieabioenergy-task38.org/.

Der Innovationsgehalt der Task umfasst folgende Schwerpunkte:

- Verbesserung und Integration neuer Anforderungen in die Task 38 Standard-Methode zur Bilanzierung der THG- Emissionen von Biomasse und Bioenergie-systemen: Es wurden in diesem Triennium neue Erkenntnisse und Lösungsansätzen insbesondere in den Themenbereichen „Timing“ von THG-Emissionen aus der energetischen Nutzung forstlicher Biomasse, direkte und indirekte Landnutzungsänderung und Albedo-Effekt gewonnen.
- Dieses Task 38 Fachwissen wurde mit verschiedenen internationalen Organisationen, die sich mit der Nachhaltigkeit von Bioenergiesystemen beschäftigen, diskutiert, Lösungsansätze entwickelt und eingebracht (z.B. UNFCCC, EC DG ENER, ENV, EEA, IIASA, JRC, RSB, GBEP).
- Forcierte Verbreitung dieses Task 38 Fachwissens in Publikationen (siehe Kapitel 3.3), Arbeitsberichten, Vorträgen und Stellungnahmen (siehe auch Anhänge 1 - 5) und Beratungsaktivitäten für zahlreiche internationale (siehe oben) und nationale Organisationen, z.B. Wirtschaftskammer Österreich, Teilnehmer des Task 38 Round Table.
- Abschluss neuer Task Case Studies: Es wurden in diesem Triennium insgesamt sieben solcher Studien abgeschlossen (zwei davon sind in der Endphase). Integrierte Biomasse- und Bioenergiesysteme zur THG-Minderung wurden anhand der Task 38 Standard-Methode untersucht mit dem Ziel, auf positive innovative Beispiele auf internationaler Ebene im Sinne von Vorzeigeprojekten aufmerksam zu machen und ihre Verbreitung zu fördern. Die „Case Studies“ werden in Kürze auf der Task 38 Webseite verfügbar sein: http://www.ieabioenergy-task38.org/projects/.

5 Schlussfolgerungen zu den Projektergebnissen

Im Triennium 2010 - 2012 wurden in der Task 38 inhaltlich vor allem in den drei zentralen Bereichen THG-Emissionen aus der Landnutzungsänderung, Albedo-Effekt und Zeitaspekt der THG-Bilanzierung forstlicher Bioenergiesysteme, sowie im Rahmen der Task38 Case Studies neue Erkenntnisse und Kompetenzen aufgebaut.

THG-Emissionen aus der Landnutzungsänderung:

Folgende Schlussfolgerungen wurden gezogen:

- Emissionen aus LUC sind ernst zu nehmen und reduziert die THG-Einsparungen z.T. wesentlich;
- Biotreibstoffe tragen zumeist im Vergleich zu fossilen Energieträgern zur Reduktion der THG bei, selbst wenn LUC inkludiert wird, aber reduziert;
- Es bestehen große Unterschiede bei LUC Ergebnissen je nach verwendetem biogenem Rohstoff;
- Bioethanol hat vergleichsweise geringere THG-Emissionen als Biodiesel (abh. v. biog. Rohstoff)
- Unsicherheiten sind noch relativ hoch, aber die internationale Forschungsszene arbeitet an der Verbesserung der Modelle und Daten.
- Das Konzept sollte nicht auf Biotreibstoffe begrenzt angewandt werden, sondern auf andere energetische Bioenergiepfade erweitert werden. Dieser Weg wurde inzwischen mit der derzeit laufenden Änderung der EU Direktive 2009/28/EC eingeleitet (EC, 2012), eine Empfehlung, die Task 38 bereits 2008 im Rahmen eines Expertentreffens der Europäischen Umweltagentur vorgeschlagen hat. Auch eine Erweiterung auf andere Biomassenutzungen (Ernährung, stoffliche Nutzung) wäre im Sinne einer integralen Betrachtung anzustreben.

Zukünftige THG-Bilanzen von Biotreibstoffen und anderen Bioenergiepfaden aber auch von anderen Biomasseprodukten mittels LCA sollten demnach die C-Bilanzen der direkten und indirekten Landnutzungsänderung berücksichtigen. Die konkreten Werte sind weiterhin in Diskussion und werden in der internationalen Forschungsszene weiterhin analysiert und konkretisiert. Die Task wird daher auch in Zukunft die neuesten Entwicklungen verfolgen, natürlich auch im Hinblick, sie in die Task 38 Standard-Methode zu integrieren.

Albedo-Effekt: Die Ergebnisse zeigen, dass Maßnahmen wie Aufforstungen und Wiederaufforstungen in Gebieten mit Schneebedeckung und vielen Sonnenstunden (und wenig Bewölkung) im Winter nicht mehr nur als einfache, positive Aktivitäten gesehen werden können den Klimawandel zu bekämpfen, da die C-Anreicherung durch das Waldwachstum via CO_2-Bindung durch die Veränderung der Albedo zum Teil neutralisiert wird. Schlussfolgernd zeigt sich, dass die Berechnung der C-Speicherveränderungen im Zuge einer Landnutzungsänderung alleine nicht ausreicht, um den gesamten Einfluss auf das Klima widerzuspiegeln.

Zukünftige THG-Bilanzen von Landnutzungssystemen und Produkten (z.B. Biomasse, Biotreibstoffe) mittels LCA sollten demnach auch diese zusätzlichen Albedo-Effekte in Form von CO_2-Äquivalenten zu inkludieren. Dieses von JOANNEUM RESEARCH entwickelte Konzept wurde in die Task 38 eingebracht, und deren Integration in die Task 38 Standard-Methode ist geplant. Das Konzept liegt vor, erste Werte für gewisse Situationen (Landnutzungsänderungen durch Aufforstungen in Gebieten mit Schneebedeckung und vielen Sonnenstunden im Winter) sind vorhanden.

Durch die oben erwähnten zusätzlichen Untersuchungen im Rahmen des „GHG-Europe“ Projektes (Kapitel 3.2.2) werden in Kürze Resultate für das Untersuchungs-gebiet Ost-Österreich, Slowenien, Slowakei, Tschechien und Ungarn basierend auf echten Messwerten vorliegen. Die Task 38 wird sich weiterhin mit dieser Thematik befassen. Sie hat ihren Titel in diesem Zusammenhang im neuen Triennium entsprechend angepasst. Obwohl dieses

Thema von Österreich eingebracht wurde, kann die österreichische Expertise dazu nun nicht mehr in dem bisherigen Ausmaß eingebracht werden.

Zeitaspekt der THG-Bilanzierung forstlicher Bioenergiesysteme: Die Zeitverzögerung bei der Emissionsreduktion spielt insbesondere bei Bioenergieanlagen, die forstliche Rohstoffe verbrennen, eine Rolle. Die Signifikanz der Zeitverzögerung besteht darin, dass die erwartete „sofortige“ Wirkung nicht eintritt und somit formale (Kyoto, „2020“) und klimabezogene (+2°C-Stabilisierung bis 2050) Ziele nur in einem verminderten Ausmaß erreicht werden. Selbst in einem nachhaltigen Biomassesystem (und dies ist im Falle des Österreichischen Waldes auch unumstritten) setzt sich die Kohlenstoffanreicherung der Atmosphäre beim Umstieg auf Biomassenutzung zunächst fort, klingt aber allmählich auf null ab.

Im Rahmen einer LCA müssen zusätzlich auch die THG-Emissionen aus den verschiedenen Prozessketten (Biomasserohstoffgewinnung, Transport, Errichtung, Betrieb und Entsorgung etc.) berechnet werden. Zur Dokumentation des Zeitablaufes der gesamten THG-Emissionen stellte sich heraus, dass sich von der Methodik her Ansätze aus der Ökonomie eignen, wie beispielsweise die Amortisationszeit, in diesem Falle die Amortisationszeit der THG-Emissionen. Diese innerhalb der Task 38 entwickelte Methodik ist ein weiterer Baustein, der in die Task 38 Standard-Methodik Eingang finden wird.

Neue Task 38 „Case Studies: Mit den sieben finalisierten „Case Studies“ liegen umfangreiche neue Erkenntnisse hinsichtlich THG-Minderungspotentiale im Vergleich zu fossilen Referenzsystemen zu den folgenden Biomasse- und Bioenergiesystemen einiger der teilnehmenden Länder von Task 38 vor:

- Bioethanol aus forstlicher Biomasse in Österreich;
- Biogas aus Mais, Gras und Gülle in Österreich;
- Biokohle aus verschiedenen Biomasseressourcen in Australien;
- Energetischen Nutzung von Zuckerrohr Rückständen in Brasilien;
- FT Biodiesel aus forstlicher Biomasse in Deutschland;
- FT und DME Biotreibstoffe aus forstlicher Biomasse in Kombination mit Papierherstellung in Schweden;
- Nationale Strategie für Biodiesel aus forstlicher Biomasse in Finnland.

Die Ergebnisse der österreichischen „Case Studies“ sind in Kapitel 3.2.4 ausführlich dokumentiert. Im neuen Triennium sind weitere „Case Studies“ zu bisher noch nicht untersuchten Bioenergiepfaden vorgesehen.

6 Ausblick und Empfehlungen

Die internationale Diskussion aller drei zentralen Task 38 Themen

- Landnutzungsänderung,
- Albedo-Effekt und
- Zeitaspekt der THG-Bilanzierung forstlicher Bioenergiesysteme

ist noch nicht abgeschlossen und deren wissenschaftliche Befassung ist daher fortzusetzen. Sie wurden im Task 38 Arbeitsprogramm für das Triennium 2013 – 2015 aufgenommen. Die bereits neu gewonnenen Erkenntnisse sind nun in die Task 38 Standard-Methode konkret zu integrieren. Dieser Prozess ist noch nicht vollständig abgeschlossen. Dazu dient das in der Task 38 derzeit in Ausarbeitung befindliche Dokument mit dem Titel „Updating the Standard Methodology for Comparing the Greenhouse Gas Balances of Bioenergy Systems and Fossil Energy Systems“, deren Abschluss nun für das Jahr 2013 geplant ist.

Die Task 38 erhält im neuen Triennium durch die offizielle Aufnahme des Albedo-Effektes als Bestandteil der Task 38 Standard-Methode folgenden neuen Titel: „Climate Change Effects of Biomass and Bioenergy Systems“. Hinsichtlich Albedo wurde mit den CO_2-Äquivalenten ein theoretisches Konzept entwickelt, das in die Berechnung der THG-Bilanz von forstlichen Bioenergiesystemen problemlos integriert werden kann. Es wurden dabei für ganz spezifische geographische Ausgangssituationen entsprechende Werte ermittelt. Basierend auf MODIS Satelliten- und ISCCP Wetter-Messdaten werden in Kürze erste Ergebnisse im Zuge des „GHG-Europe“ Projektes für osteuropäische Waldgebiete vorliegen (siehe Kapitel 3.2.2). Eine umfassendere Berücksichtigung des Albedo-Effektes setzt aber die Analyse von weiteren, zusätzlichen Untersuchungsgebieten voraus.

Die „Case Studies“ für das Triennium 2013-2015 sollen auf vielversprechende Bioenergietechnologien, die Biomasseabfälle verwerten und/oder eine integrierte Landnutzung beinhalten, ausgerichtet werden. Es war geplant, das von Österreich eingebrachte Konzept einer neuen Case Study - auf dem Projekt „SMART FORESTS aufbauend - zum Thema forstlicher Bioenergiepfade durchzuführen, da aber Österreich im neuen Triennium nicht mehr teilnimmt, wird diese Studie voraussichtlich nicht umgesetzt.

Task 38 beabsichtigt im neuen Triennium verstärkt mit anderen Tasks zu kooperieren. In dem neu anlaufenden Intertask Projekt mit dem Titel “Mobilising sustainable supply chains”, wird Task 38 gemeinsam mit den Tasks 39, 40, 42 und 43 anhand von konkreten „Case Studies“ nachhaltige Bioenergiepfade identifizieren, die internationalen Standards entsprechen. Die Mitarbeit der Task 38 wird sich dabei auf die THG-Bilanzierung, inklusive auf den Zeitaspekt („Timing“) soweit forstliche Biomasse als Rohstoff eingesetzt wird, konzentrieren. Die Task 38 kann dabei auf die in den letzten Jahren gewonnenen Erkenntnisse und Kompetenzen aufbauen und diese einbringen. Darüber hinaus plant die Task 38 im neuen Triennium, die Tasks 34, 36 und 37 bei ihren THG-Emissionsbewertungen von Technologien wie zum Beispiel von Pyrolyse, Müllverbrennung und Biogas zu unterstützen.

7 Literatur- Abbildungs- Tabellen- und Abkürzungsverzeichnis

Dieser Bericht wird auf der Webseite des BMVIT „Nachhaltig Wirtschaften“ veröffentlicht werden unter: http://www.nachhaltigwirtschaften.at/results.html/id1980

Die aus der Zusammenarbeit in Task 38 verfügbaren Dokumente sowie Vorträge der Task 38 Veranstaltungen sind auf der Task 38 Webseite gesammelt und stehen allen Interessenten zur Verfügung: http://www.ieabioenergy-task38.org/.

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7.2 Abbildungsverzeichnis

7.3 Tabellenverzeichnis

7.4 Abkürzungsverzeichnis

AUS	Australia
AUT	Austria
BMVIT	Bundesministerium für Verkehr, Innovation und Technologie
C	Kohlenstoff
CH_4	Methane emissions (Methan-Emissionen)
CO_2	Carbon Dioxide emissions (Kohlendioxid-Emissionen)
CO_2-Äq	CO_2-Äquivalente
dLUC	direct Land Use Change (direkte Landnutzungsänderung)
DG ENER	Directorate-General for Energy
DME	Di-Methyl-Ether
EC	European Commission
EEA	European Environment Agency (Copenhagen Denmark)
EU-ETS	European Union Emission Trading System
EU-RED	European Union Directive on the promotion of the use of energy from renewable sources (“EU Renewable Energy Directive”)
ExCo	Executive Committee (of IEA Bioenergy)
FIN	Finland
FJ-BLT	Francisco Josephinum Wieselburg – Biomass Logistics Technology
FT	Fischer-Tropsch
GBEP	Global BioEnergy Partnership
GER	Germany
GHG	GreenHouse Gases (Treibhausgase)
iLUC	indirect Land Use Change (indirekte Landnutzungsänderung)
IEA	International Energy Agency
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
JR	JOANNEUM RESEARCH Forschungsgesellschaft mbH
JRC	Joint Research Centre of European Commission
LCA	Life Cycle Assessment (Lebenszyklusanalyse)
LUC	Land Use Change (Landnutzungsänderung)
NOEST	Netzwerk Öko-Energie Steiermark (Graz, Österreich)
N_2O	Nitrogen Oxide emissions (Lachgas-Emissionen)
RSB	Roundtable on Sustainable Biofuels (Lausanne Switzerland)
SWE	Sweden
THG	Treibhausgase
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
VTT	Technical Research Centre of Finland

8 Anhänge

Anhang 1: Woess-Gallasch S. et al.: Greenhouse Gas Benefits of a Biogas Plant in Austria. IEA Bioenergy Task38 Case Study Long Version and Brochure JR, Graz, June 2011.

Anhang 2: Cherubini F. Jungmeier G. and Bird D.N.: GHG and energy analysis of a bioethanol oriented biorefinery concept in Austria, IEA Bioenergy Task38 Case Study Brochure. 2013.

Anhang 3: IEA Bioenergy Task 38, Protokoll zum Round Table: Energetische Nutzung der forstlichen Biomasse und zeitliche Betrachtung der Kohlenstoffneutralität, Wien, 8. April 2011(deutsche Version).

Anhang 4: Bird N, Cowie A, Strømman A. and Frieden D.: The timing of GHG Emissions from bioenergy systems using financial type indicators and terminology to discuss emission profiles from bioenergy. Proceeding, 19th EU Biomass Conference 6-10 June 2011, p. 2572-2575 Berlin, Germany.

Anhang 5 Bird N., Cowie A., Cherubini F. and Jungmeier G.: Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy. IEA Bioenergy, ExCo 2011:03.

IEA Bioenergy

Task 38

Greenhouse
Gas Balances
of Biomass and
Bioenergy Systems

Greenhouse Gas Benefits of a Biogas Plant in Austria

Summary

The goal of this study was to quantify the greenhouse gas (GHG) and energy impacts of a biogas plant with closed storage of digested materials. The plant of “NegH Biostrom KEG” in Paldau in the state of Styria, Austria, was chosen because this plant uses closed storage facilities to store the material after removal from the digester. Feedstocks used are primarily crops, secondarily grass silage and animal manure. The study used life-cycle assessment (LCA) to determine the GHG and efficiencies of energy output of biogas plants, with and without closed storage.

Methane (CH_4) produced in the digesters and storage is used to produce 4 GWh electric energy and 7 GWh heat per year. Only 17 % of the heat is currently used. The total biogas production and methane concentration from the closed storage were measured for half a year and the annual production of 15.6 tons of CH_4 per year was estimated. A theoretical case was considered of a biogas plant using the same feedstocks but storing digested biomass in an open storage. It was assumed that open storage would result in CH_4 emissions to the atmosphere equal to those produced in the closed storage.

Carbon dioxide (CO_2), CH_4 and nitrous oxide (N_2O) emissions of the two biogas plants were compared to reference system I which delivered equivalent amounts of electricity and heat. The study also looked at CO_2-equivalent (CO_2-eq) emissions. In reference system electricity is assumed to be produced from a natural gas plant, and heat from oil and wood.

LCA results showed that GHG emissions of a biogas plant with open storage are 29 % higher than for one with a closed storage and approximately 2 % less energy is produced. The biogas plant with closed storage results in 1 k tons of CO_2-eq per year, 44 % less GHG emissions than the reference system I. The mitigation benefit is reduced to 27 % with open storage. Direct land use changes (changes in land use and related soil carbon changes on the site used for feedstock production) sequester 48 tons of CO_2 per year, reducing total GHG emissions in the Paldau biogas plant by 3.4 %.

For each ton of biomass feedstock used in the biogas plant with the closed storage, 292 grams of CO_2-eq are avoided. The biogas plant with an open storage, however, might avoid only 183 grams of CO_2-eq.

A sensitivity analysis showed that if even relatively small amounts of CH_4 (e.g. 5 %) escape from the storage or digesters, the GHG benefits of biogas plants are substantially reduced. A reference system II was developed to include total use of heat from the biogas plant Paldau. As a consequence GHG emission benefits increase significantly.

Biogas Plant Paldau (Photo: P. Enzinger)

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Scope

One reason for using biogas is to reduce GHG emissions. Biomass is a “carbon neutral” energy source from the perspective that CO_2 released in combustion is taken up again by growing plants. However, its use for energy may release additional GHG emissions, such as CH_4 from open storage of digestate, or N_2O from fertilised soils used for biomass production. In Austria, many new biogas plants use crops as feedstock, because farmers are seeking new markets for products. Due to feed-in tariffs in Austria, biogas is mainly used for production of electricity. The co-produced heat is not always used.

This study examined the GHG benefits of a biogas plant with closed storage, based on LCA. The main objectives of the study were to:

- Evaluate the effect of a closed-storage on GHG emissions and energy production from a biogas plant,
- Analyse GHG benefits of biogas plants using primarily crops in comparison to a reference system I in which electricity comes from a natural gas plant and heat from a mix of oil and wood.

The plant of “NegH Biostrom KEG“ in Paldau in the state of Styria, Austria, was chosen for this study. All plant components – including the storage for digested materials – are sealed to prevent loss of gas and odours. The plant is operated with renewable feedstock, mainly crops (corn 2,028 t_{DM}/yr, maize silage 1,175 t_{DM}/yr and grass silage 370 t_{DM}/yr), plus a smaller amount of animal manure (pig manure 152 t_{DM}/yr, cow manure 18 t_{DM}/yr). Currently only 17 % of the heat produced by the plant is utilized.

Method

Measurements in the biogas plant storage

The methane production in the closed storage was measured over half a year, using a methane flow meter installed in the pipe connecting the gas storage bag with the digesters and storage. The measurements of the biogas produced showed an average value of 3.9 Nm^3 per hour, equivalent to 34,160 Nm^3 per year. Emissions from the biogas plant with closed storage were compared to one with an open storage, which was assumed to release CH_4 emissions equal to CH_4 produced in the closed storage.

The so-called “methane slip”, which occurs due to incomplete combustion of biogas in the gas engines, was not measured directly, but taken into account using data from literature.

Biogas Flow Meter (Photo: P. Enzinger)

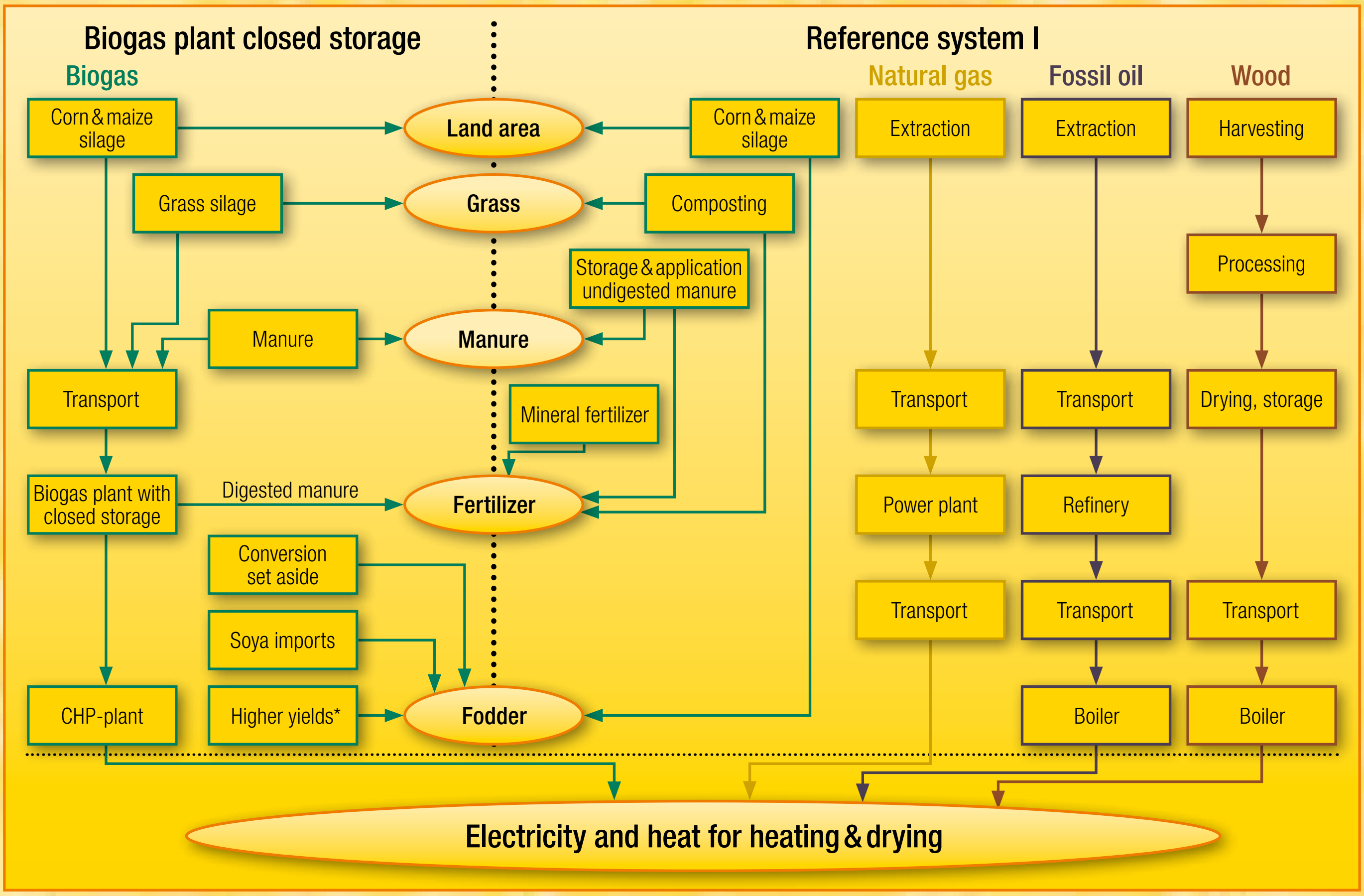

Figure 1: Process chains of the biogas pant with closed storage and of reference system I (this box includes additional fertilizer for increased yield of corn and maize silage)*

Courtesy of JOANNEUM RESEARCH

Calculation of GHG emissions

The GHG calculations are based on an LCA following the international standards ISO 14 040 and 14 044 and the standard methodology for GHG balances of bioenergy systems, as developed in IEA Bioenergy Task 38. The software tool GEMIS (**G**esamt-**E**missions-**M**odell **I**ntegrierter **S**ysteme) developed by the Öko-Institut in Darmstadt / Germany was used for the calculations.

In the LCA, emissions of the GHGs carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were calculated. Emissions of CH_4 and N_2O were expressed as CO_2-equivalent (CO_2-eq), using 100 year global warming potentials (Forster P. et al, 2007).

The LCA assumes a 20-year life time for the Paldau plant. CO_2 removed from the atmosphere through photosynthesis is assumed to balance CO_2 released during combustion of biomass, therefore no emissions are counted at the point of combustion, in accordance with the Guidelines of the IPCC (IPCC 2006).

In addition to CO_2 emissions due to cultivation and harvesting of crops, transportation, and construction and dismantling of plants, calculations included carbon stored due to direct land-use change (dLUC)[1]. In both biogas systems analyzed, dLUC occurs because set-aside land is converted to cultivate maize. Only changes in soil carbon were considered. For these calculations the Styrian Soil Carbon Database was used (Amt der Stmk. Landesregierung, 2004). In Austria set-aside land is often grassland so a grassland site was chosen to represent set-aside land. The conversion from grassland to cropland results in an increase in soil carbon because of low humus percentage in the grassland.

Emissions due to dLUC due to conversion of grassland to crop production were averaged over 20 years, which corresponds to the life-time of biogas plants such as Paldau. It was assumed that no dLUC occurs were wood is used for heat in reference system I, because it is assumed the wood is harvested from a sustainably managed forest. In the biogas systems, no CO_2 removals were attributed to the increased growth of forest compared to the reference system I enabled by the fact that the biogas plants supply heat previously supplied by wood. The reason is two-fold: the removals are negligible and Austria does not include carbon stock changes due to forest management in its Kyoto Protocol accounting.

Description of the three basic cases

The following three basic cases were analyzed:

- The existing Paldau biogas plant with a closed storage,
- A theoretical biogas plant similar to Paldau but with open storage,
- Reference system I: An equivalent amount of electricity is produced by a natural gas power plant and heat equivalent to heat use from biogas plant.

The lower biogas production in the biogas plant without closed storage results in lower electricity production. The electricity supply in the open storage is consequently supplemented with electricity from a natural gas power plant. Electricity from a natural gas power plant is also used in reference system I.

The quantity of heat produced in reference system I is the same as the quantity of heat currently used from the Paldau biogas plant (17 % of 7 GWh, ie 1.2 GWh). Heat is provided by four domestic oil heating systems and one domestic wood log heating system, the systems which were in use prior to the heat from the biogas plant. For the sensitivity analysis a reference system II was developed in which the amount of heat produced is equivalent to the total heat production of the Paldau plant.

System boundary

The process chains of the biogas plant with closed storage and of reference system I are documented in figure 1. Reference system I utilises the same amounts of: manure, land area and grass as the Paldau biogas plant and provides the same amounts of electricity, used heat and fodder. In the reference system I, the corn and maize silage is used for fodder instead of as an input to a biogas plant; undigested manure is used for fertilizer rather than as a biogas plant input, and grass silage is composted and used as a fertilizer instead of as biogas feedstock. In reference system I, set-aside land is mulched once a year. Heat and electricity are sourced from conventional energy sources. All the corresponding GHG emissions are considered in the LCA.

To account for the CH_4 and N_2O emissions to the atmosphere from the undigested manure, these were subtracted from the biogas plant calculations. As undigested animal manure is 20 percent less effective as fertilizer than digested manure, some synthetic fertilizer was included in the reference system I to provide equivalent fertilizer value as obtained from animal manure in the biogas system.

In the biogas systems the reduction in fodder supply is covered through a combination of conversion and fertilization of 53.6 ha of set-aside land, increased soya imports, and higher yields through additional fertilizer on original cultivated area (214 ha). Additional fertilizer plus additional land supply 60 per cent of the deficit, with the other 40 per cent addressed through soy imports (for more details, please see full report, pages 16 – 18: Woess-Gallasch et al, 2011). The digested grass from the biogas plants is also used as a fertilizer and is equivalent to the fertiliser value of the composted grass silage in the reference system I.

Functional unit

GHG emissions were calculated as tons per year. The values of the biogas plants were then calculated in terms of GHG emission reductions in comparison to reference system I, and expressed per unit of energy output (kWh) and per unit mass of biomass (t_{DM}).

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[1] Land-use change can be either direct or indirect. Land-use change is called direct if the change occurs on-site. This study only includes emissions from dLUC.

Courtesy of JOANNEUM RESEARCH

Results and discussion

Energy and biogas production

The biogas plant Paldau produces 270 Nm^3 of biogas per hour, equivalent to 2,365 Mio Nm^3 per year. The two 250 kW_{el} gas engines produce 4,300 MWh annually which is fed into the public grid. After subtracting the biogas plants' electricity requirements – 272 MWh – a net production of 4,029 MWh is achieved. The plant's gross heat production is 7,250 MWh, but heat available is only partly used (17 %).

The measurements of the biogas produced in the closed storage show a mean value of 3.9 Nm^3 per hour, or 34,160 Nm^3 per year. In the LCA calculations, the assumption was made that the storage remained closed also during material removal. The CH_4 concentration of the biogas in the storage was 63.8 % which is higher than that produced in the digester, which is 48.8 %. This means that 15.6 tons of CH_4 would be produced annually in the biogas plant storage under best management practices.

Greenhouse gas emissions

Table 1 shows the GHG emissions in tons per year.

Table 1: GHG emissions in tons per year

GHG emissions t/yr	**CO_2**	**CH_4**	**N_2O**	**CO_2-eq**
Biogas plant Paldau, closed storage	202	9.6	3.3	1,409
Biogas plant Paldau, open storage	233	25.2	3.2	1,818
Reference system I	2,224	10.9	< 0.1	2,502

Note: For calculation of total CO_2-eq emissions the global warming potentials of IPCC were used (Forster P. et al, 2007)

Figure 2 shows all these Greenhouse gas emissions. The biogas plant with closed storage has the lowest emissions, 1,409 t CO_2-eq/yr. If the emissions reductions due to dLUC are not considered, emissions from closed storage are 1,457 t CO_2-eq/yr (see Figure 3). Thus dLUC reduces total CO_2-eq emissions by 3.4 %. The biogas plant with an open storage results in 1,818 t CO_2-eq/yr. and the reference system I in 2,502 t CO_2-eq/yr.

Table 2 shows the GHG emissions per kWh produced, which is composed of 0.76 kWh_e and 0.24 kWh_{th}.

Table 2: GHG emissions in g per produced kWh

GHG emissions g/kWh	**CO_2**	**CH_4**	**N_2O**	**CO_2-eq**
Biogas plant Paldau, closed storage	38	2	1	266
Biogas plant Paldau, open storage	44	5	1	344
Reference system I	421	2	< 1	473
Reference system II more heat	806	2	< 1	930

Note: More information on reference system II please find below under "Sensitivity Analysis"

Table 3: GHG emission reductions of the biogas plant systems compared to the reference system I in g per produced kWh

GHG emission reductions to reference system I g/kWh	**CO_2**	**CH_4**	**N_2O**	**CO_2-eq**
Biogas plant Paldau, closed storage	382	< 1	-1	207
Biogas plant Paldau, open storage	376	-3	-1	129

Note: Each kWh is composed of 0.76 kWh_e and 0.24 kWh_{th} – negative values mean an increase of GHG emissions

Table 4: GHG emission reductions kg per t_{DM} of biomass feedstock compared to reference system I

GHG emission reductions to reference system I kg/t_{DM} biomass	**CO_2**	**CH_4**	**N_2O**	**CO_2-eq**
Biogas plant Paldau, closed storage	540	0.4	-0.9	292
Biogas plant Paldau, open storage	531	-3.8	-0.8	183

Note: Negative values mean an increase of GHG emissions

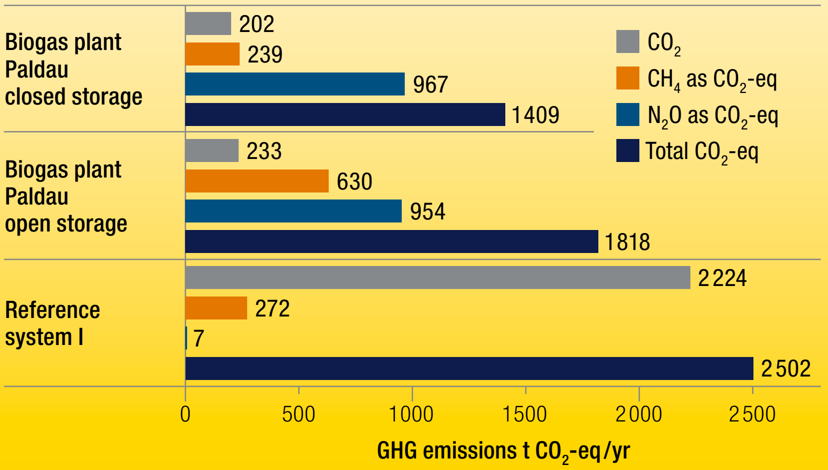

Figure 2: GHG emissions in CO_2-equivalent emissions per year.
Note: The CO_2 emission from biogas plants includes 48 tonnes of CO_2 sequestration from dLUC.

Table 3 shows the GHG emission reductions of the biogas plant systems compared to the reference system I in g per produced kWh.

In Table 4 the GHG emission reductions in comparison to reference system I have been calculated per ton of dry biomass feedstock (t_{DM}). For each tonne of biomass feedstock used in the biogas plant with the closed storage, 292 grams of CO_2-eq can be avoided. The biogas plant with an open storage, however, avoids only 183 grams of CO_2-eq.

Sensitivity analysis

In a sensitivity analysis, the effects of the following three parameters on GHG emissions have been estimated:

- Fraction of heat used: 100 % use of the heat generated by the biogas plant instead of only 17 % (optimized Paldau situation, reference system II),
- Feedstock mix: use of increased proportion of animal manure,
- Higher CH_4 emissions from open storage.

Figure 3 shows GHG emissions of reference system II and illustrates the impact of 100 % of heat use. Reference system II must supply more heat from fossil fuels and wood than reference system I to supply heat equivalent to full use of heat from the biogas plant. Consequently, reference system II has significantly greater GHG emissions than reference system I. The GHG emissions reduction of the Paldau biogas plant compared to reference system II is 3,511 t/yr of CO_2-eq, significantly higher if total available heat is used.

Where crops are the major feedstock and only a small percent of heat produced is used, relatively small increases in the percentage loss of methane can nearly nullify mitigation benefits from displacing the use of natural gas. If manure is used as the feedstock, greater methane losses (up to 18 percent) still bring benefits. The sensitivity analysis suggests that increased proportion of animal manure in the feedstock mix results in higher potential GHG emission benefits. These theoretical results need to be substantiated through further studies of biogas plants in operation and linked reference systems.

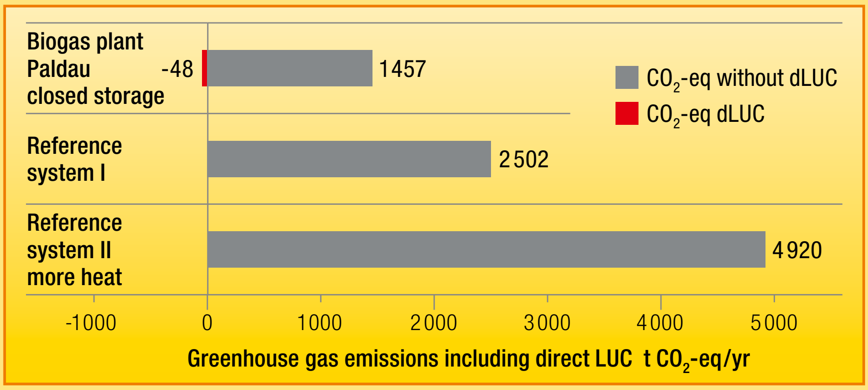

Figure 3: Total CO_2-equivalent emissions per year for the Paldau biogas plant and two reference systems (including 48 t CO_2 sequestered from dLUC for biogas plant).

Courtesy of JOANNEUM RESEARCH

Conclusions

Biogas plants can contribute to GHG emission mitigation. This analysis shows that GHG benefits are substantially higher if biogas plants have a closed storage and if all heat produced is utilised. The use of residues such as manure as feedstock results in higher emission reduction than use of crops that can cause GHG emissions, such as N_2O due to fertilizer application.

On basis of the results of this study it is recommended that new biogas plants have closed storage systems; that more priority is given to the selection of sites that enable the use of high percentages of heat produced, and that a high ratio of animal manure is used.

For more detailed information on this study, please see the full report (Woess-Gallasch et al, 2011), available at: www.ieabioenergy-task38.org/projects.

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IEA Bioenergy
Task 38

IEA Bioenergy (www.ieabioenergy.com) is an international collaborative agreement, set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy research, development and demonstration (RD&D) programs. IEA Bioenergy aims to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas (GHG) emissions from energy use.

IEA Bioenergy Task 38 brings together research work of national programs in all participating countries on GHG Balances for a wide range of biomass systems, bioenergy technologies and terrestrial carbon sequestration. Emphasis is placed on the development of state-of-the-art methodologies for assessing GHG balances; demonstrating the application of established methods, supporting decision-makers in implementing effective GHG mitigation strategies. As one example of work, case studies have been conducted by applying the standard methodology developed by Task 38. The case studies have assessed and compared GHG balances of different bioenergy and carbon sequestration projects in the participating countries, and this Austrian case study is one example.

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IEA Bioenergy

Task 38

Greenhouse Gas Balances of Biomass and Bioenergy Systems

Greenhouse Gas (GHG) and energy analysis of a bioethanol oriented biorefinery concept in Austria

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Summary

Most of the worldwide energy carriers and material products come from the fossil fuel refinery. This dependence on fossil fuels is causing environmental and political concerns given climate change and finite fossil energy reserves. In a biorefinery, biomass feedstock is converted to fuels and chemicals in an analogy to the petroleum refinery. Among the possible biomass raw materials, lignocellulosic feedstocks are particularly important, as they are locally available for many countries and abundant.

This case study deals with a Life Cycle Assessment (LCA) of a biorefinery system which produces ethanol, other energy carriers (electricity, heat, biomethane) and chemicals (phenols) from forest softwood residues. It is compared to a fossil reference system, which produces the same products. Since climate change mitigation and energy independence are the main driving forces behind biorefineries, the results focus cumulative primary energy demand and greenhouse gas emissions (GHGs) including those caused by forest management change (i.e. residues which are not anymore left in the forest but are collected and used as raw materials in biorefinery). The impacts of different allocation methods to share the total GHG emissions of the biorefinery system among the co-products are investigated.

The biorefinery system uses 84% less non-renewable energy. In 2020, the biorefinery produces 44% less GHGs annually than its fossil counterpart.

However, the cumulative emissions up to 2020 are 28% more for the biorefinery system. By 2050, the biorefinery will have saved 40% of cumulative GHGs when compared with a fossil reference system. Forest management change and production of raw materials account for 79% and 15%, of cumulative emissions by 2050, respectively.

Neste Oil Refinergy, Povoo, Finland (Photo D.N. Bird)

Scope

This work deals with a LCA of a conceptual biorefinery system which produces:

- Ethanol for the transportation service;
- Combined Heat and Power (CHP) from the combustion of lignin and process residues;
- Heat from the anaerobic digestion of wastewaters; and
- Phenols extracted from lignin.

According to the classification method for biorefinery systems, this concept can be labelled:

> *C5/C6 sugars, biogas, lignin/pyrolytic oil biorefinery for bioethanol, electricity and heat and chemicals from lignocellulosic residues*

This system is a combination of several conversion technologies which are jointly applied in order to produce biofuels and material products from lignocellulosic biomass. The biorefinery system is compared with a **fossil reference system** which produces the same amount of products / services. Namely:

- Gasoline for the transportation service;
- Electricity from natural gas (average among Austrian power plants);
- Heat from heavy oil and natural gas; and
- Phenols from a conventional oil refinery.

Description

The concept biorefinery is situated in Austria. It uses 530 kt dry from forest residues which include biomass not harvested or removed during forest management (e.g. harvest residues, pre-commercial thinnings, dead trees). If left in place, these residues naturally decay; may prevent forest regeneration and increase the risk of forest fire. However, increased residue use may negatively impact biodiversity and nutrient cycles (Janowiak and Webster, 2010, Bouget et al, 2012). As well, residues are generally more expensive than other biomass sources (Morris, 1999).

The yield of forest softwood residues is based on typical Austrian forests (Marschall, 1992) and tree component estimates (JRC, 2012). Collecting residues from forests requires fossil fuel inputs. The wood is assumed to be transported for 40 km (round trip, 16 t truck) to a facility where it is firstly dried using heat from a natural gas boiler and then pelletized using electricity supplied from the Austria grid. The pellets are transported 100 km to the biorefinery plant in 40 tonne-capacity trucks. For details of energy consumption factors please see the full report.

The pellets are processed using (Figure 1):

- Pretreatment (uncatalyzed steam explosion) in order to depolymerize hemicellulose and separate lignin;
- Enzymatic cellulose hydrolysis to glucose monomers;
- Fermentation and distillation of sugars to ethanol;
- Anaerobic digestion of wastewaters;
- Flash pyrolysis of lignin (20%) followed by phenol separation from the resulting pyrolytic oil; and
- Combustion (for heat and power production) of process residues (i.e. lignin that is not pyrolyzed, pyrolytic char and unrecovered pyrolytic oil).

This biorefinery system requires electricity (0.83 GJ/t dry feedstock, 0.03 GJ/GJ pyrolitic oil produced and 0.54 GJ/t dry matter in wastewater) and heat (0.40 GJ/GJ bioethanol produced and 110 MJ/t dry matter in wastewater). These energy needs are completely met by heat and power produced by combustion of lignin and residues. For details of energy consumption factors please see the full report.

Ethanol is transported 100 km to fuelling stations where it is used to fuel passenger cars. Emissions for combustion of the ethanol in cars (i.e. CH_4, N_2O) are also. Produced biomethane is fed to the national natural gas grid, where it can replace natural gas in all its existing applications. It is assumed that the biomethane is burnt in a boiler and the resulting emissions are estimated. The CO_2 resulting from the combustion of these biofuels it is included since the loss of carbon stocks in the forest is accounted for. Phenols are transported for 50 km to their final application. It is assumed that no carbon storage in products occurs, i.e. all the carbon is released to the atmosphere within the time of the functional unit (one year).

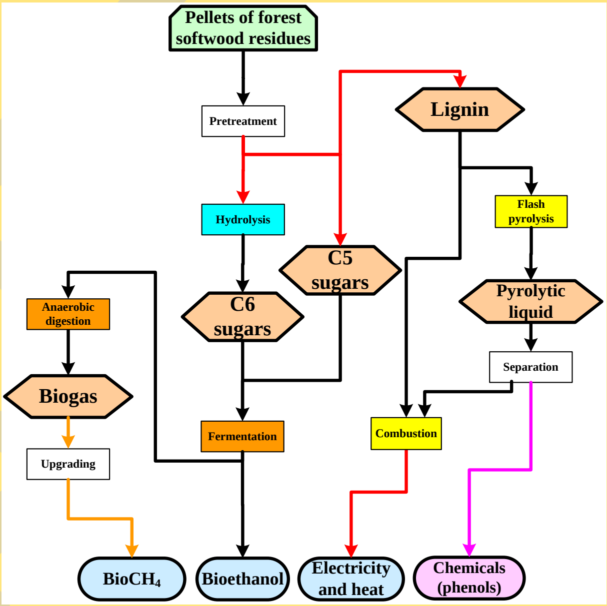

Figure 1 Main process steps of the biorefinery plant.

System boundary

In Figure 2 shows the system boundaries for the biorefinery and fossil reference system. The biorefinery chain starts with the forest residue resource in the middle of the diagram. At the end, the biorefinery provides products and services. All input and output flows occurring along the full chain are accounted for using a life cycle perspective. In contrast, the fossil reference system starts with consumption of non-renewable resources (i.e. fossil oil and natural gas). The reference system also includes a **reference land use** for the residues, i.e. left in the forest where a natural decomposition occurs. This forest management change from natural decay to use may cause a reduction in the carbon stocks of the forest and a consequent emission of CO_2.

Functional unit

The functional unit of the assessment is the amount of biomass treated per year, i.e. 530 kt dry of pellets from forest softwood residues.

Allocation

Allocation in LCA is carried out to attribute shares of the total environmental impact to the different products of a system. This concept is extremely important for biorefinery systems, as multiple energy and material products are produced. Scientific publications show benefits and disadvantages of several allocation methods (Cherubini et al 2011, Curran 2007; Ekval and Finnveden, 2001; Frischknecht 2000; Wang et al., 2004), but the issue of the most suitable allocation procedure is still open discussion.

Allocation methods can use physical characteristics or economic value of products for sharing the total GHG emissions. In this study, in addition to the substitution method, the following allocation procedures are used and compared:

- Energy;
- Exergy;
- Economic; and
- New method based on the shares of GHG avoided when compared with a fossil reference system.

In this assessment, the main product is assumed to be ethanol and the environmental benefits of co-products are assumed as credits. These credits (i.e. the GHG and fossil energy saved by the co-products) are then subtracted from the total GHG emissions and energy consumption of the whole system; the resulting environmental burdens are completely assigned to the main product.

Allocation based on energy content of products can be easily carried out but its application may result in misleading conclusions if there are some products which are not used as energy carriers (e.g. chemicals).

Allocation based on exergy overcomes this inconsistency but can difficult to apply because the exergy content of substances needs to be estimated. In this study, exergy content of products comes from a specific database (Ayres et al., 1996).

Allocation based on economic values focuses on external characteristics of the products and has the disadvantage that it does not take into account the physical properties of the products, because is based on their “value” in human societies. In addition, market values of products may vary according to the year, production chain and geographical location (Ekvall, 2001). Economic values of products have been estimated from an internet search.

The new allocation method shares the environmental burdens among co-products according to the respective shares of the fossil counterparts in the total GHG emissions of the fossil reference system. For instance, if gasoline contributes for 80% to total GHG emissions of the fossil reference system, 80% of total GHG emissions of the biorefinery system will be assigned to ethanol (which is assumed to replace conventional gasoline). The main advantages of this new allocation method are the following:

- environmental burdens are assigned according to the effective GHG savings of the products, thus giving more importance to those products which are responsible of the largest savings;
- it is not necessary to choose a main product; and
- it can be applied indifferently to energy or material products.

Leakage or indirect land use change

Leakage (or indirect land use change) is minimized since there is no competitive use for the residues.

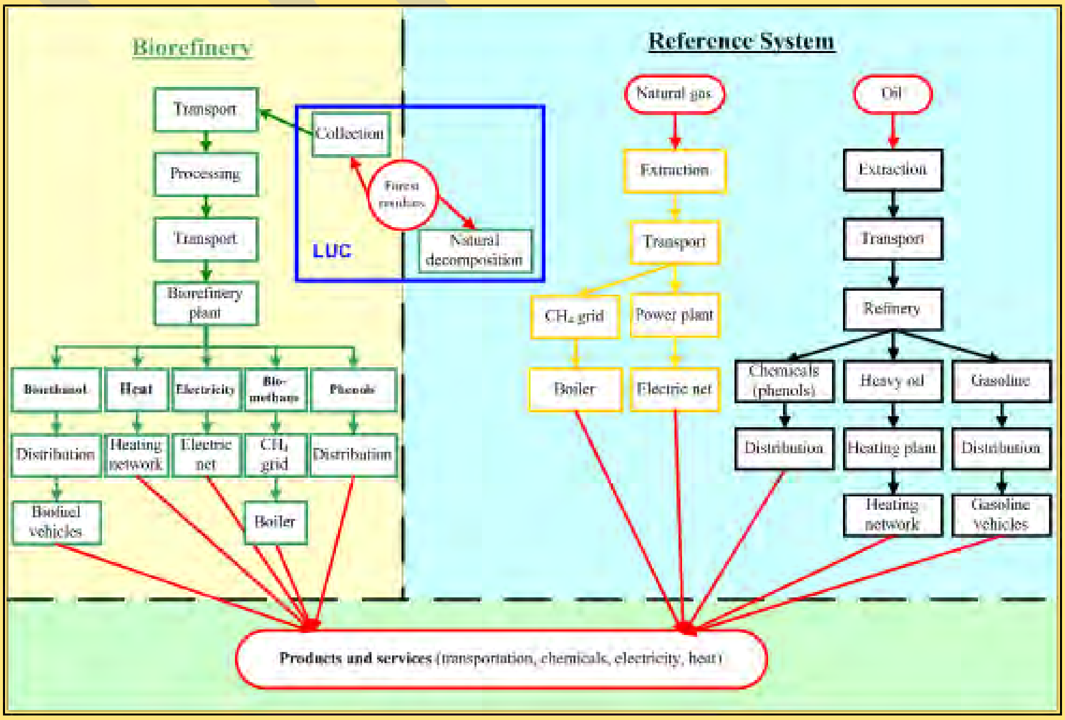

Figure 2: System boundaries of the biorefinery and fossil reference system

Method

This study is modelled by means of the LCA software tool SimaPro 7 (http://www.pre.nl/simapro/default.htm) and selected literature references are used to estimate input flows and specific emissions (GEMIS, 2009, NREL, 2009). Forest management change effects are estimated by means of a dedicated software tool (CO2FIX, http://www.efi.int/projects/casfor/). Since climate change mitigation and energy independence are the main driving forces for future biorefineries, results focus on GHG emissions (CO_2, CH_4 and N_2O) and cumulative primary energy demand, divided into non-renewable (fossil and nuclear), renewable (biomass) and other renewable (mainly hydropower). Total GHG emissions are expressed in t CO_2-eq. assuming the following global warming potentials (CO_2 = 1, CH_4 = 23, N_2O = 296). Total GHG emissions of the biorefinery system are then allocated to the products using different allocation criteria and the results are finally compared.

Results and discussion

Energy balances

The energy balances of the biorefinery and fossil energy system are illustrated in Figure 3. The biorefinery system requires more cumulative primary energy (11.4 PJ/a) than the fossil reference system (6.4 PJ/a), but it is provided mostly by renewable energy (90%, the energy content of the feedstock). The biorefinery saves 5.32 PJ/a of non-renewable resources, or approximately 11.2 GJ of non-renewable energy per tonne of dry biomass.

Greenhouse gas emission balances

The emissions from the biorefinery are time dependent (Table 1). The reason for the time-dependency is that removal of residues from the land in a given year causes a loss of carbon stocks. However, over time these residues would have decayed in the reference system. It is assumed that the carbon stocks in the reference system are in dynamic equilibrium. The use of these residues in the biorefinery causes the carbon stocks to decrease until the system reaches a new equilibrium. The biorefinery system releases more GHG emissions than the fossil reference system until 2025, but the longer the system is in operation, the more GHG emissions are saved (Figure 4). For the EU bioenergy target in 2020, the bioenergy system does not deliver any GHG emission savings. However, the average annual savings during the first 20 years (i.e. by 2032) are 125 kt CO_2-eq./a, or 33% of the fossil emissions during the same period.

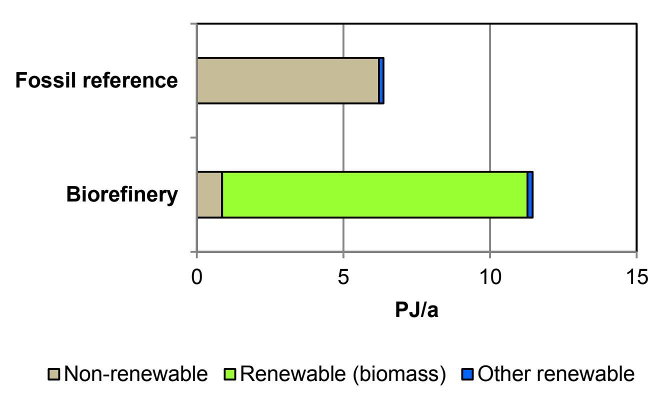

Figure 3: Cumulative primary energy demand of the biorefinery and fossil energy system.

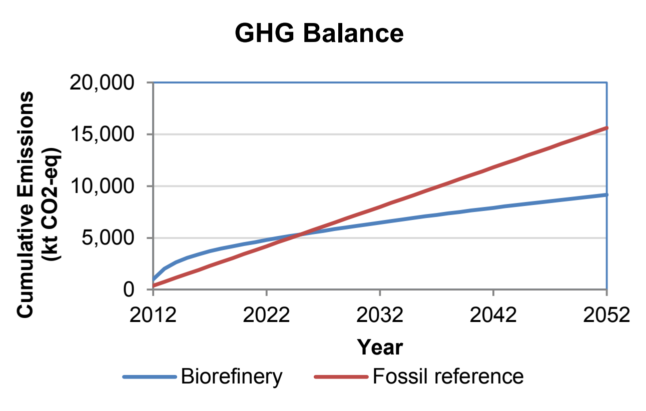

Figure 4: The cumulative emissions of the biorefinery and fossil reference systems. After 2025, the bioenergy system produces fewer emissions than the comparative fossil reference system.

Table 1: GHG balances of the biorefinery and fossil reference systems.

	Unit	Biorefinery				Fossil reference system
		2020	2032	2050	2100	
Average annual GHG emissions						
Total	kt CO_2-eq./a	435	256	176	104	381
CO_2	kt CO_2-eq./a	430	251	171	99	357
N_2O	kt CO_2-eq./a	1.45	1.45	1.45	1.45	7.42
CH_4	kt CO_2-eq./a	3.70	3.70	3.70	3.70	16.1
Average annual GHG savings						
per year	kt CO_2-eq./a	-	125	205	277	-
per year	%	-	33%	54%	73%	-
per input biomass	kg CO_2-eq./t_{dry}	-	236	387	523	-

Figure 5 shows contributions to total GHG emissions of the biorefinery system in 2032. In 2020, the emissions due to forest management change are 89% of total emissions. By 2032, this has decreased to 84%. The category "other" includes losses of CH_4 during from the handling and treatment of waste and wastewaters.

GHG emissions from pellet production have three main contributors:

- Collection of residues in the forest (35%)
- Transport of the residues from the forest to the pelletizing facility (31%)
- Energy required to produce the pellets (34%).

Concerning the fossil reference system, its total GHG emissions have the following contributions:

- 69.5% Gasoline,
- 18.6% Electricity,
- 4.30% Heat from oil,
- 5.39% heat from natural gas,
- 2.19% Phenols.

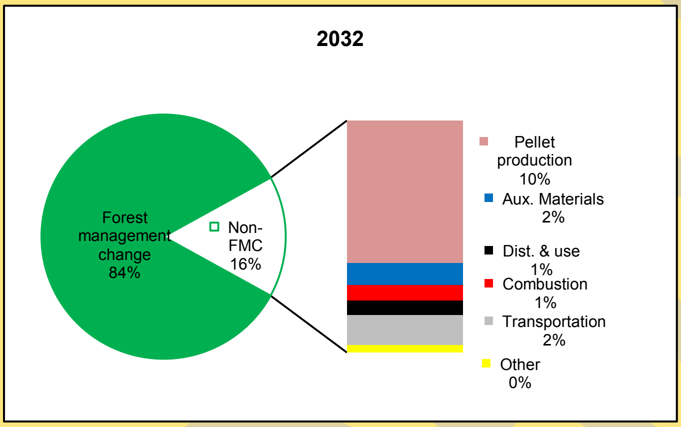

Figure 5: Contributions to total GHG emissions of the biorefinery system.

Sensitivity analysis

Allocation

The sensitivity of the results to the allocation method are shown in Table 2. Results of these biomass derived products and services can be compared with those derived from oil refinery. For instance, driving a car fuelled with bio-ethanol (118 g CO_2-eq./km, energy allocation) instead of conventional gasoline (198 g CO_2-eq./km), saves approximately 41% of CO_2-eq. emissions; savings will be up to 48% if the new allocation method is used.

All the allocation methods lead to relatively similar results for bioethanol and phenols, while for other products differences are larger. Allocation based on energy and exergy content of products show similar results for almost all the products. Allocation based on economic values increases the share of the transportation biofuel, while decreasing the environmental burdens assigned to electricity, heat and biomethane.

The new allocation method assigns higher emissions to electricity and heat, because these energy carriers are assumed to replace natural gas derived electricity and oil derived heat, which have a relevant contribution to the total GHG emissions of the fossil reference system. This new method is particularly important when GHG savings are the main task of the study, because it assigns more importance to those products which save more GHG emissions.

Forest management change

In this study, the parameter with the largest influence on the final results is forest management change (see Figure 5). To investigate the sensitivity of the results of the assumptions made for the assessment of forest management change we derived six different CO_2FIX models (Table 3).

Table 2: GHG emissions to 2032 of the biorefinery products according to different allocation methods.

		New method	Energy	Exergy	Economic	Substitution method
Bioethanol	g CO_2-eq./km	161	184	184	207	95
Electricity from CHP	g CO_2-eq./kWh	591	271	251	229	-1,139
Heat from CHP	g CO_2-eq./kWh	345	271	151	48.7	-663
Heat from biomethane	g CO_2-eq./kWh	64.9	75.8	105	14.5	-125
Phenols	g CO_2-eq./MJ	2.82	2.40	2.31	1.17	-5.43

Table 3: Model descriptions for sensitivity analysis of land use change

Model No.	Yield class	Location	Elevation (masl)	Annual precipitation (mm)	Average annual temperature (°C)
1	8	Bruck an der Mur	482	795.2	8.1
2	10	Bruck an der Mur	482	795.2	8.1
2a	10	Afflenz	780	885.8	6.3
2b	10	Mariazell	875	1081.3	6.1
2c	10	Mürzzuschlag	700	1035.2	6.2
3	12	Bruck an der Mur	482	795.2	8.1

Yield class

The number of hectares from which the residues must be collected varies in response to the yield class (models 1, 2, and 3). However, the emissions per tonne of biomass are insensitive to yield class. This can be expected because the same amount of biomass is extracted in all cases and the emissions depend on the decay rate of the biomass if it had been left on site. Since the area required is sensitive to yield class but the emissions are not, the loss of biomass over a cycle on a per hectare basis is also sensitive to yield class.

Climate

The variation in results by climate is investigated using models 2, 2a, 2b, 2c. The net emissions during a period of time from using biomass, that would have decayed, are a function of the decay rate of the biomass. In generality, the faster the decay rate, the less are the emissions. In the extreme, if 100% of the material decays in less than one year, then there are no net annual emissions caused by combusting the material. At the other extreme, combusting biomass than never decays causes 100% emissions. Using equations for decomposition rate as a function of climatic parameters (temperature and annual precipitation) from Moore et al (1999), we find for woody material that the annual decomposition is greatest for Mariazell and lowest for Afflenz. However the variability is quite small. The standard error of the mean total emissions is about 1.5% of the mean total emissions.

Rotation period

Two assumptions on forest management were made to create the previous models: These assumptions are:

1. Final felling rotation period; and
2. No collection of thinning residues for bioenergy.

If the stands had a final felling every 80 years instead of every 90 years then there is 8.5% less biomass to harvest at final felling. Hence more area of forest is required. The stands with no harvesting of forest residues also have less biomass with the 80-year rather than the 90-year rotation and hence there are fewer emissions when the biomass is used for energy. However the difference is small. The emission intensity decreases by approximately 1%. It is important to note that this result does not mean the forest should be converted to an 80-year rotation.

There is also variation caused by the assumption on the fate of thinning residues. When these are used fewer hectares of forest are required to produce the required amount of biomass since they are in addition to the residues from final felling. The thinning residues are 33% of the total residues removed from the forest per year. However the emission intensity does not vary if the thinning residues are used since the emissions are dependent on the amount of biomass removed per year and not whether they come from the final felling or not.

Conclusions

The use of forest softwood residues in biorefinery has the potential to co-produce bioenergy and chemicals which are currently produced by oil refinery. The biorefinery system depicted in this work produces ethanol, electricity, heat and phenols from lignocellulosic biomass and is compared with a reference system producing the same amounts of products from fossils.

The GHG balance reveals that the biorefinery system has lower total emissions than the fossil reference system after 13 years. Before this time, the biorefinery system produces more emissions because the land is in transition from a dynamic equilibrium with residues on site, to one with residues removed. The change in forest management cause a loss of carbon stocks in dead wood, litter and soil organic carbon and this is the major source of GHG (approximately 70-90% of total emissions depending on year). However, after 13 years, the biorefinery system produces less GHGs that the fossil reference system, and the difference between the two systems continues to increase with time so that after 50 years the biorefinery system has 55% of the emissions of the fossil reference system.

The biorefinery requires more total energy than the fossil reference system, but it is mainly from renewable energy (the energy content of the feedstock) and non-renewable energy sources are saved (84%).

In order to share the total GHG emissions of the biorefinery among the different co-products, several allocation procedures were applied. An attempt to avoid allocation through substitution method was developed and then allocations based on energy content, exergy content and economic value of outputs were compared with a new allocation method based on the shares of the total GHG emissions of the fossil reference system. All allocation methods are finally compared and the specific GHG emission factors (g CO_2-eq./unit) of each product are calculated.

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Protokoll zum Round Table: Energetische Nutzung der forstlichen Biomasse und zeitliche Betrachtung der Kohlenstoffneutralität

Veranstaltet im Rahmen der österreichischen Teilnahme an
Task 38 von IEA Bioenergy
in Form dreier Gesprächsrunden in Wien
am 25. November 2010, am 31. Jänner 2011 und am 8. April 2011

Präambel

Der aktuelle anthropogen bedingte Klimawandel zeigt bereits jetzt erste Folgewirkungen und wird mit noch deutlicheren Auswirkungen verbunden sein. Einige Regionen und Wirtschaftssektoren werden profitieren, in anderen werden die negativen Folgen des Klimawandels überwiegen. Es sind daher geeignete politische Strategien für Klimaschutz und die nötigen Anpassungsschritte auf allen Ebenen erforderlich; zukunftsweisende Entscheidungen sind rasch zu treffen. Dafür sind wissenschaftlich fundierte Entscheidungsgrundlagen dringend nötig. Dies betrifft auch die Diskussion über die Bewertung der Rolle der forstlichen Biomasse als Ersatz fossiler Energieträger.

Aufgrund der Überlagerung von Fragen der Reporting-Modalitäten im Rahmen der UN-Klimarahmenkonvention (UNFCCC) mit tatsächlichen oder geplanten Formen der Waldnutzung ergeben sich mehrere voneinander abweichende Interpretationsmöglichkeiten. Ein Aspekt dabei ist die zeitliche Betrachtung der tatsächlichen physikalischen Klimawirksamkeit des Einsatzes der forstlichen Biomasse als Energieträger. Diese zeigt bei kleinräumigen Systembetrachtungen (z. B. für einzelne Waldbestände) eine Verzögerung der Emissionsreduktionswirkung in Abhängigkeit von den jeweiligen Bestandeswachstums- und den Zerfallsraten der für unterschiedliche Verwendungszwecke eingesetzten Biomasse.

Die Energieerzeugung aus forstlicher Biomasse wird wegen der Substitution von fossilen Energieträgern in der Regel sehr positiv dargestellt, es gibt aber auch wissenschaftliche Veröffentlichungen, in denen die Treibhausgasreduktion durch die energetische Nutzung von forstlicher Biomasse bei Berücksichtigung einer relativ kurzfristigen zeitlichen Komponente (kürzer als die Lebensspanne/der Produktionszyklus eines Bestandes) kritisch bewertet wird.

Um die Bandbreite der Ergebnisse der angewandten modellhaften Betrachtungen transparent zu machen, wurde im Rahmen der österreichischen Beteiligung am Bioenergie-Netzwerk der Internationalen Energieagentur (IEA Bioenergy) ein „Round Table“ gegründet um eine Bewertung des Einsatzes von biogenen Rohstoffen aus dem Wald im Hinblick auf die Auswirkungen auf den Kohlenstoffkreislauf abzugeben.

Ausgangslage

Die politische Definition des Artikel 2 der UNFCCC legt als Ziel den Grundsatz fest, die globale Erwärmung auf weniger als zwei Grad gegenüber dem Niveau vor Beginn der Industrialisierung zu begrenzen. Der Nutzung von forstlicher Biomasse und dem Ersatz fossiler Brennstoffe wird dabei eine zentrale Bedeutung beigemessen.

Der Kohlenstoffkreislauf ist in einem nachhaltigen Waldökosystem langfristig immer im **Gleichgewicht**. In Wäldern wird durch Sonnenenergie getrieben – im Zuge der Photosynthese – CO_2 gebunden und in organische C-Verbindungen eingebaut. Diese haben unterschiedliche Verweilzeiten im Ökosystem und werden durch biologischen Abbau oder durch Nutzung (stofflich oder für Zwecke der energetischen Nutzung) am Ende des Produktzyklus wieder zu CO_2 umgewandelt.

Großflächige, vom Menschen **unbeeinflusste Waldökosysteme** z. B. in Tropenländern befinden sich im Durchschnitt in einem Gleichgewichtszustand, in dem sie fortwährend in etwa jene Menge an Kohlenstoff aus der Atmosphäre absorbieren, welche durch Abbauprozesse an diese wieder freigesetzt wird (Null Netto-Emission). Wenn diese Wälder exploitativ, auf nicht nachhaltige Weise genutzt werden, entstehen zusätzliche CO_2-Anreicherungen in der Atmosphäre.

Diskutiert man dagegen die Kohlenstoffspeicherung bzw. Abgabe für einen bestimmten Waldbestand, so ist zu beachten, dass Wälder verschiedene Lebens- bzw. Sukzessionsphasen durchlaufen (Verjüngung/Initialphase, Wachstum/Aufbauphase, Zerfallsphase) und diese die Kohlenstoffspeicherung bzw. Freisetzung sehr wesentlich beeinflussen. Die zu einem bestimmten Zeitpunkt gebundene Menge Kohlenstoff in einem Waldbestand hängt vom Alter des Waldes, der Baumartenmischung, dem Wachstumspotential des Standortes (= Bonität) und vom jeweiligen Bewirtschaftungskonzept ab.

Mit Erreichen der physiologischen Altersgrenze von Waldbäumen erhöht sich in einem unbewirtschafteten Waldbestand der Totholzanteil. Der Wald geht in die Zerfallsphase über. Durch den erhöhten Totholzanteil und den damit verbundenen biotischen Holzabbau (durch Insekten, Pilze, etc.) kommt es zur Netto-Kohlenstofffreisetzung, da weniger CO_2 gebunden als freigesetzt wird. Ein Waldbestand wird in dieser Phase zur Kohlenstoffquelle.

Die in Österreich praktizierte nachhaltige Waldwirtschaft nutzt Bäume vor dem Erreichen der physiologischen Altersgrenze. Vergleicht man die Kohlenstoffkreisläufe eines bewirtschafteten mit einem unbewirtschafteten Wald, so wird deutlich, dass im **bewirtschafteten Wald** die Zerfallsphase und damit die erhöhte Biomassemortalität fehlt. Daraus kann man schließen, dass durch eine auf die Optimierung der Holzproduktion ausgerichtete Waldwirtschaft das Ökosystem zumeist in den produktiveren Phasen des Sukzessionszyklus verbleibt, weil die Bäume vor ihrem natürlichen Tod und Zerfall genutzt werden. Die in Urwäldern übliche Zerfallsphase (mit entsprechender CO_2-Freisetzung) wird im Wirtschaftswald durch die Holznutzung teilweise ersetzt bzw. fällt aus. An die Stelle des natürlichen Biomasse-

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kreislaufs mit langsamer CO_2-Freisetzung (während des Zerfalls) tritt bei Verbrennung (z. B. für Zwecke der energetischen Nutzung) ein Kreislauf mit rascher CO_2 Freisetzung. In Wirtschaftswäldern ist die durchschnittliche Wachstumsrate bzw. Kohlenstoffbindungsrate durch das Vermeiden der Zerfallsphase höher als in nicht bewirtschafteten Wäldern.

Zusätzlich zu diesem höheren Bindungspotenzial ist auch der **Substitutionseffekt** zu beachten, der durch den Einsatz des geernteten Holzes entsteht, wenn dieses für den Ersatz von fossilen Rohstoffen oder anderer unter höherem energetischen Aufwand produzierte Waren verwendet wird.

Wenn fossile Energieträger verbrannt werden, gelangen enorme Mengen CO_2 in die Atmosphäre. Diese stammen zwar ebenfalls aus Photosyntheseprozessen, wurden aber in Form von Öl, Kohle und Gas während Jahrmillionen meist unterirdisch gebunden. Hingegen ist bei der Kohlenstofffreisetzung aus der Verbrennung von Holz aus heutigen Waldbeständen ein vergleichsweise viel kurzfristiger ablaufender Kohlenstoffkreislauf relevant.

Darüber hinaus haben Waldbewirtschaftungsmaßnahmen im Rahmen nachhaltiger Managementkonzepte positive Auswirkungen auf die **Stabilität, Vitalität und Resilienz** der Waldökosysteme und deren Kohlenstoffbindungsvermögen. Dieses ist insbesondere auch unter dem Aspekt durch die im Klimawandel intensivierten Störungen (z. B. Sturm, Insektenkalamitäten) zu bewerten.

Bei der Analyse der Kohlenstoffbilanz nachhaltiger Waldbewirtschaftungssysteme ist unter anderem zu berücksichtigen, dass in Fällen des Verbrennens von Teilen der geernteten Biomasse für energetische Zwecke eine frühere Abgabe der gespeicherten CO_2-Mengen an die Atmosphäre stattfindet, als wenn diese Biomasse stofflichen Nutzungen zugeführt worden wäre. Bei stofflicher Nutzung erfolgt die Kohlenstofffreisetzung zeitverzögert erst am Ende des jeweiligen Lebenszyklus. Bei energetischer Nutzung erfolgt sie hingegen sofort.

Im Rahmen nachhaltiger Waldbewirtschaftungssysteme ist die räumliche Betrachtungsebene für die Sicherstellung der ökologischen, ökonomischen und sozialen Komponenten der Nachhaltigkeit nicht der Bestand, sondern eine räumlich weit höher aggregierte Betrachtungsebene, wo in der Regel gleichzeitig die Effekte verschieden alter Bestände summiert werden. Auch nehmen beispielsweise in Österreich die Waldflächen immer noch zu und die jährliche Nutzungsrate liegt derzeit rund ein Fünftel unter der jährlichen Zuwachsrate.

Empfehlungen

In Hinblick auf den UNFCCC Grundsatz der Begrenzung der globalen Erwärmung auf weniger als zwei Grad hat die umweltverträgliche Nutzung forstlicher Biomasse als Ersatz fossiler Brennstoffe zentrale Bedeutung. Da während der Übergangsphase sowohl CO_2-Minderungs- als auch Steigerungseffekte auftreten, sollten Maßnahmen möglichst rasch gesetzt werden.

- Im Hinblick auf den drohenden Klimawandel ist es dringend geboten, alle Maßnahmen rasch umzusetzen, die geeignet sind, den Energieverbrauch und die damit verbundenen Emissionen von Treibhausgasen deutlich zu reduzieren.

- Nicht erneuerbare fossile Rohstoffe und Energieträger resultieren aus Kohlenstoffspeicherungen während erdgeschichtlicher Zeitspannen. Generell gilt es, die Freisetzung aus fossilen Quellen zu unterbinden und den aktuellen Bedarf an Rohstoffen und Energieträgern aus erneuerbaren Quellen bestmöglich abzudecken. Der Ersatz von fossilen Brennstoffen durch Waldbiomasse ist im Sinne der langfristigen Reduzierung der CO_2 Emissionen sinnvoll und weiter voranzutreiben. Auch wenn bestimmte Klimaschutzeffekte nur schrittweise voll wirksam werden, überwiegt der langfristige Nutzen des Waldbiomasseeinsatzes und macht einen sofortigen Umstieg sinnvoll.

- Eine Bewertung von Klimaschutzmassnahmen durch Waldmanagement bedarf einer objektiven Darstellung möglicher Vor- und Nachteile, die Berücksichtigung zusätzlicher im Rahmen von Nachhaltigkeitsaspekten wichtiger Aspekte: u.a. (i) Substitutionseffekte durch Verwendung von Holzprodukten, (ii) Substitutionseffekte durch Verwendung von forstlicher Biomasse aus nachhaltiger Waldbewirtschaftung, (iii) Kohlenstoffspeicherung in Holzprodukten, (iv) die erhöhte Stabilität von Waldbeständen und damit der in-situ C-Speicherung in Bezug auf Störungen, (v) verbesserte Resilienz von Waldökosystemen durch Anpassung an den Klimawandel, (vi) Effekte im Rahmen ländlicher Entwicklung. Dafür sind die Untersuchungseinheiten in geeigneter Weise räumlich abzugrenzen und geeignete Betrachtungszeiträume für forstliche Produktionszyklen festzulegen.

Teilnehmer des Round Table

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THE TIMING OF GREENHOUSE GAS EMISSIONS FROM BIOENERGY SYSTEMS USING FINANCIAL TYPE INDICATORS AND TERMINOLOGY TO DISCUSS EMISSION PROFILES FROM BIOENERGY

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ABSTRACT: Bioenergy systems in the long-term reduce greenhouse gas emissions when compared to fossil energy systems. This is one of the reasons that there is such interest currently in bioenergy. However, as has been pointed out by many authors, in the short-term the introduction of a bioenergy system can cause more emissions that its comparable fossil energy system and that these emissions are recovered over time by the bioenergy system. The combined profiles typically display an initial period with net positive emissions followed by period of net negative emissions. These profiles share the same characteristics as a typical investment cases. First there are initial costs associated with investments, which are followed by income and profit. In fact, authors have used the term “carbon pay-back time” to describe this feature.

In this short paper, the authors raise the question if adaption of terms and methods from financial theory may be of use to understanding the dynamic GHG characteristics of bioenergy systems. A short introduction to key financial theory concepts is provided. The potential adaption of the theory to bioenergy GHG metrics is explored and discussed.

Keywords: agriculture, biofuels, decision making, emissions, greenhouse gas (GHG)

1 INTRODUCTION

Bioenergy systems in the long-term reduce greenhouse gas emissions when compared to fossil energy systems. This is one of the reasons that there is such interest currently in bioenergy. However, as has been pointed out by many authors, in the short-term the introduction of a bioenergy system can cause more emissions that its comparable fossil energy system and that these emissions are recovered over time by the bioenergy system. The combined profiles typically display an initial period with net positive emissions followed by period of net negative emissions. These profiles share the same characteristics as a typical investment. Initially there are “costs” associated with investments, then “income” and finally “profit”. In fact, authors have used the term “carbon pay-back time” to describe this feature [1, 2, 3]

2 BASIC FINANCIAL METHODS

In finance, *net present value* (NPV) or net present worth (NPW) is a standard method for using the time value of money to appraise long-term projects. Used for capital budgeting, and widely throughout economics, finance, and accounting, it measures the excess or shortfall of cash flows, in present value terms, once financing charges are met.

The NPV is given by the equation,

$$NPV_t = -I_0 + \sum_{i=0}^{t} \frac{R_i}{(1+r)^i}$$

Where I_o = the initial investment, R_i = the net cash flow (the amount of cash, inflow minus outflow) at time i and r = the discount rate. This is chosen based on a firm's weighted average cost of capital but may be higher to adjust for risk or other factors. The discount rate can also be selected to reflect the rate of return if invested elsewhere (for example, a bank account).

While the NPV is a frequently used metric in itself, it is often useful to assess NPV relative to the initial investment made. That is, the performance of the economic activity, relative to the initial investment. This is often referred to as the *profitability index* (PI):

$$PI_t = -\frac{NPV_t}{I_0}$$

If PI > 0 then usually a project is accepted because a PI = 1 means that the project breaks-even.

The minimum amount of annual positive cash flow required to ensure that the investment breaks even, another key indicator of interest. This is referred to as *break even cash flow* (R_{BE}), and can be found as follows.

$$NPV_t = 0 \xrightarrow{yields} R_{BE} = \frac{I_0}{\sum_{i=0}^{t} \frac{1}{(1+r)^i}}$$

Firms often explore how long time it takes to recover the investments made. This is done through calculating the *pay back time* (PBT).

$$PBT = \frac{I_0 \left[\frac{1 - \frac{1}{(1+r)^t}}{r} \right]}{R_i}$$

Another financial indicator that could be used is the *internal rate of return* (IRR). It is used in capital budgeting to measure and compare the profitability of investments and is the effective interest rate of an investment or loan.

In general, an investment is considered acceptable if its IRR is greater than an established minimum acceptable rate of return or cost of capital. This ensures that the investment is supported by equity holders since, in general, an investment whose IRR exceeds its cost of capital adds value for the company (i.e., it is economically profitable).

The IRR of an investment or project is the discount rate that makes the net present value (NPV) of all cash flows (both positive and negative) from a particular investment equal to zero. Therefore:

$$NPV_t = -I_0 + \sum_{i=0}^{t} \frac{R_i}{(1+irr)^i} = 0$$

3. ADAPTING FINANCIAL TERMINOLOGY AND INDICATORS TO EMISSION PROFILES FROM BIOENERGY

Having established the a set of key indicators an associated terminology the question that we aim to address is to what extent these concepts may be relevant for assessing emissions profiles from bioenergy.

Evidently, by putting a price on emissions, one can easily convert emission flows to monetary flows and the methods are straight forward to apply, as so are the interpretations.

However if we don't want to monetize carbon then a equivalent set of indicators could be recommended. For example:

- Net present emissions (NPE) ↔ NPV
- Emission profitability (EI) ↔ PI
- Break even emission flow (EBE) ↔ RBE
- Emission pay-back time (EPBT) ↔ PBT; and
- Internal rate of emission return (IRER) ↔ IRR

In the previous equations one could replace I_o with IE_o the initial emissions invested and R_i with E_i, the net emissions at time *i*.

It is clear that many of these indicators would have similar uses as in financial analysis. The time period over which to do the calculation could be set to coincide with policy (for example, 2050).

4. DO EMISSIONS HAVE A TIME VALUE?

Important and justifiable concerns with respect to the application of discounting of emissions have, and still are, being raised. However, assessing the impacts of systems with dynamic emission profiles, e.g bioenergy systems, are becoming of increasing importance and we are currently facing constrains with current methods. Without arguing for the introduction of discounting to emissions, we aim to explore what may be offered by the adoption of approaches form financial theory. We do this by raising a set of questions for discussion.

First of all, discounting: Should this concept only be applied to calculations in monetary units? Although the concept of discounting originates from financial theory, it is generally accepted that it reflects preference for time. A discount rate of zero indicates indifference to time. All emissions, present or future, are all of equal value. The higher discount rate, the stronger is the preference for the present situation versos the future situation. Analogously, a negative discount rate technically represents higher preference for the future than for the present situation.

Methods for weighing the importance for the present versus the future should be of general importance in many situations. Discounting provides a model for this.

We already recognize that different greenhouse gases (GHGs) have different atmospheric residence times and different time-value when we sum emissions of three gases (CO_2, CH_4, and N_2O) weighted by their respective global warming potentials (GWP). GWP is the measure of the cumulative radiative forcing over a fixed time horizon (usually 100 years) of a pulse of some gas compared to the cumulative radiative forcing of an equal mass of CO_2 over the same period.

The idea that emissions and emission reductions have a different value now than in the future has already been investigated [4] but it is being revisited by a few authors [5, 6, 7, 8].

5. WHAT COULD BE A USEFUL DISCOUNT RATE?

Ignoring atmospheric discussions can we recommend a useful discount rate? IEA predicts that the amount of energy from biofuels will grow at 8.3% per annum from its present amount, 1.88 EJ in 2008 to 11.10 EJ in 2030 [9]. If emissions from biofuel production have the form shown in figure 1, then due to the increasing biofuel, net greenhouse gas emissions from the switch to biofuels will increase with time (figure 2).

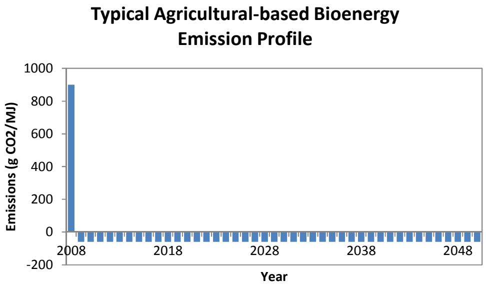

Figure 1: A typical agricultural-based bioenergy profile. There is a large emission due to the change in land management (CLM) to produce biomass for bioenergy followed by unlimited years of emissions savings. The

emission savings are given by the difference between the LCA emissions for the reference fossil system and the LCA emissions for the bioenergy system (excluding the CLM component). In this example, we assumed that emissions saved are 60 g CO2/MJ, and that the system takes 15 years to recover the initial CLM emissions (payback period).

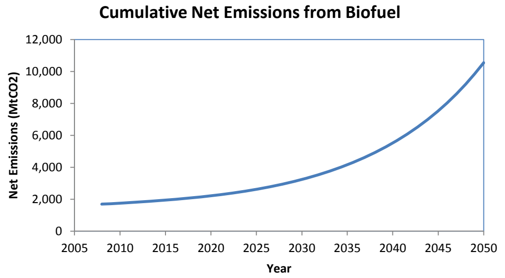

Figure 2: The cumulative net emissions from biofuel adoption assuming that all biofuel comes from land with a 15-year greenhouse gas payback period.

The reason for this is the rate of biofuel increase is more than the rate of greenhouse gas emission payback. The result is something akin to "deficit spending" that many western governments.

This suggests that we should emphasize the value of future emissions and emissions saved as compared to present emissions. This is the inverse of discounting, discounting with a negative discount rate, or in German – "aufzinsen". We recommend calculating the net present emissions using a discount rate equal to the negative of the predicted growth in biofuel (i.e. -8.3%).

Another way the predicted biofuel growth could influence policy is to use the growth rate as a hurdle for evaluating IRER at a certain date, say 2030 or 2050. For example, if a project has an IRER greater than 8.3% then it is acceptable. Figure 3 shows the IRER as a function of payback period for a typical agricultural-based bioenergy project. It shows that projects with a pay-back period of greater than 10 years have IRERs<8.3% and should not be considered.

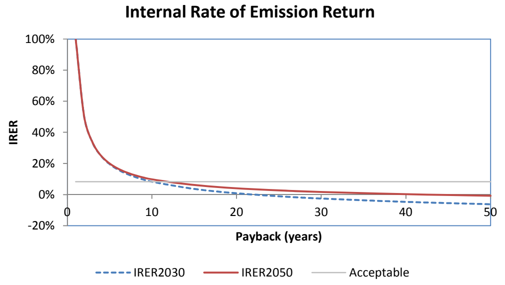

Figure 3: The internal rate of emission return versus pay-back period for a typical agricultural-based bioenergy project.

With this in mind, one could consider that an acceptable IRER would be higher than 8.3%. For example, a policy may be that only projects with an IRER > 10% are eligible. This would require a little quicker payback time to account for the risk of project failure.

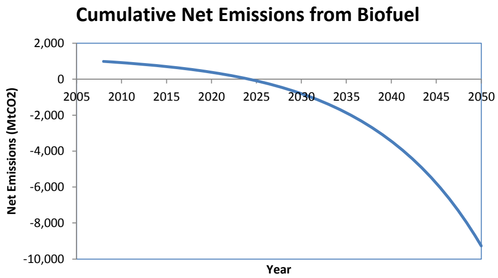

Figure 4: The cumulative net emissions from biofuel adoption assuming that all biofuel comes from land with an 8.75-year greenhouse gas payback period.

Figure 4 shows the cumulative net emission from biofuel assuming that all biofuel comes from land with an 8.75 greenhouse gas payback period. As one can see, with this condition, by 2030 biofuels are significantly reducing greenhouse gas emissions as compared to fossil energy.

6 CONCLUSIONS

Bioenergy emission profiles are often similar to financial cash flows. There is an initial emission or investment that is followed by years of emission savings or return of investment. Due to this similarity financial indicators may have a role in the evaluation of bioenergy projects. Financial indicators are also quite commonly used.

We have suggested a list of potential indicators for bioenergy systems that have their equivalent financial indicator. However, it remains difficult to decide on one crucial factor, discount rate.

Finally we investigate the use of some financial indicators in the evaluation of a typical emission profile from an agricultural-based bioenergy system. Given that the growth of biofuels is predicted to be 8.3% per annum, we suggest that this value can be used to set benchmarks for biofuel projects. For example, projects with an IRER of less than 8.3% should not be considered since the net emissions from biofuels will increase over time. In our simple emission profile example, this means that projects with EPBT > 10 years should not be considered by policy makers.

7 ACKNOWLEDGEMENTS

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The primary goal of Task 38 is to investigate all processes involved in the use of bioenergy and carbon sequestration systems, with the aim of assessing overall greenhouse gas balances and supporting decision makers in selection of mitigation strategies. Participating countries in 2011 are Australia, Austria, Belgium, Brazil, Finland, Germany, the Netherlands, Norway, Sweden, and the USA. For more detailed information on the Task see: http://www.ieabioenergy-task38.org/

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The objective of the project is to contribute to sustainable bioenergy development that benefits local people in developing countries, minimizes negative impacts on local environments and rural livelihoods, and contributes to global climate change mitigation. The project will achieve this by producing and communicating policy relevant analyses that can inform government, corporate and civil society decision-making related to bioenergy development and its effects on forests and livelihoods. The project is managed by CIFOR and implemented in collaboration with the Council on Scientific and Industrial Research (South Africa), Joanneum Research (Austria), the Universidad Autónoma de México and the Stockholm Environment Institute.

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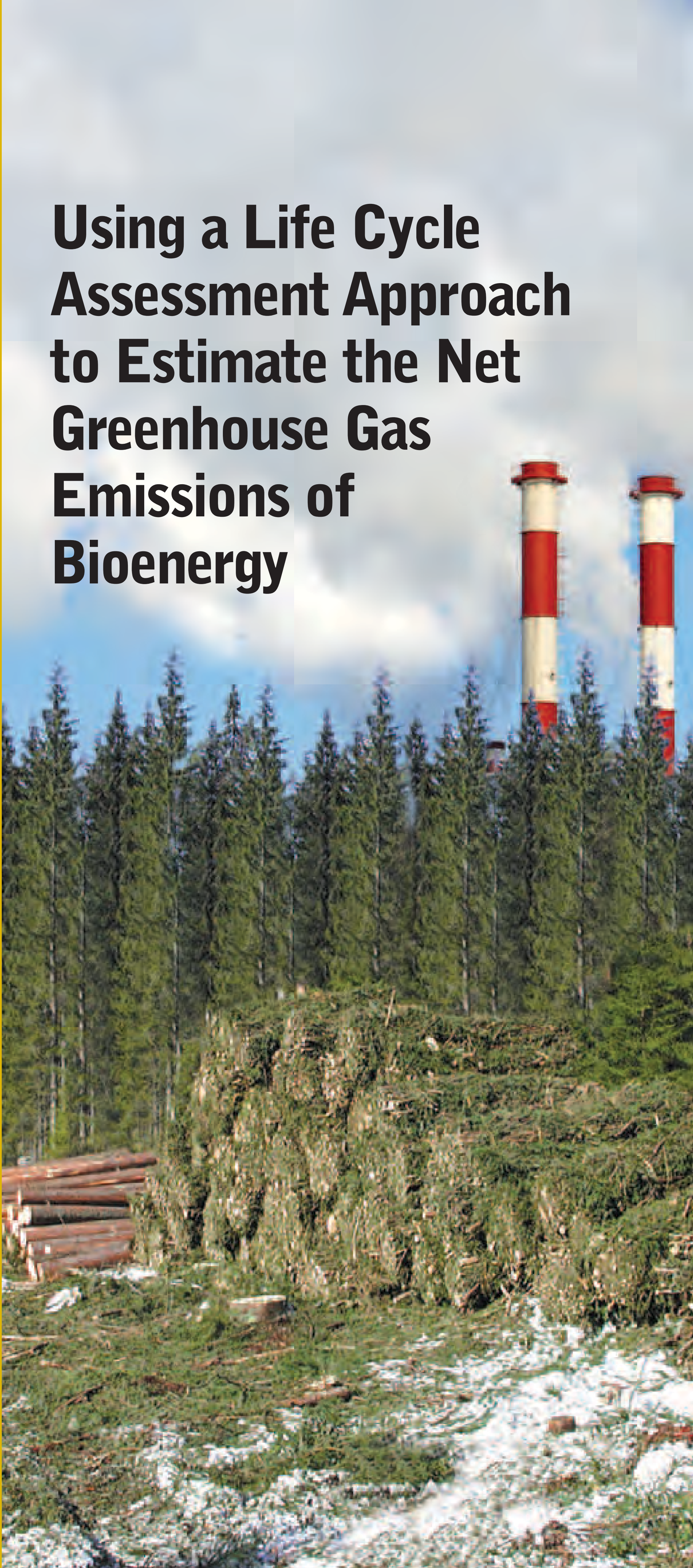

Using a Life Cycle Assessment Approach to Estimate the Net Greenhouse Gas Emissions of Bioenergy

This strategic report was prepared by Mr Neil Bird, Joanneum Research, Austria; Professor Annette Cowie, The National Centre for Rural Greenhouse Gas Research, Australia; Dr Francesco Cherubini, Norwegian University of Science and Technology, Norway; and Dr Gerfried Jungmeier; Joanneum Research, Austria. The report addresses the key methodological aspects of life cycle assessment (LCA) with respect to greenhouse gas (GHG) balances of bioenergy systems. It includes results via case studies, for some important bioenergy supply chains in comparison to fossil energy systems. The purpose of the report is to produce an unbiased, authoritative statement aimed especially at practitioners, policy advisors, and policy makers.

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USING A LIFE CYCLE ASSESSMENT APPROACH TO ESTIMATE THE NET GREENHOUSE GAS EMISSIONS OF BIOENERGY

Authors: Mr Neil Bird (Joanneum Research, Austria), Professor Annette Cowie (The National Centre for Rural Greenhouse Gas Research, Australia), Dr Francesco Cherubini (Norwegian University of Science and Technology, Norway) and Dr Gerfried Jungmeier (Joanneum Research, Austria).

KEY MESSAGES

1. Life Cycle Assessment (LCA) is used to quantify the environmental impacts of products or services. It includes all processes, from cradle-to-grave, along the supply chain of the product or service. When analysing the global warming impact of energy systems, greenhouse gas (GHG) emissions (particularly CO_2, CH_4, and N_2O) are of primary concern.

2. To determine the comparative GHG impacts of bioenergy, the bioenergy system being analysed should be compared with a reference energy system, e.g. a fossil energy system.

3. A reference energy system should be chosen that is realistically likely to be displaced by the bioenergy system. If this reference system is not certain, then one option is to use as the reference energy system the average fossil energy for that region. Another option is to make a conservative evaluation by comparing the bioenergy system with the best available fossil energy technology. Alternatively, a non-fossil option may be selected as the relevant reference energy system. Depending on the context of the study, this might be another renewable option or nuclear power.

4. The scope of the analysis (system boundary) should include all processes along the value chain with significant GHG emissions, including, where relevant, upstream processes of extraction or biomass production, and end-of-life processes.

5. The system boundary should be defined so that the bioenergy and reference fossil systems provide equivalent products and services. If it is not possible to achieve this through expansion of the system boundary then the GHGs can be allocated amongst energy and non-energy co-products of the bioenergy system (such as biodiesel and rapeseed cake, from processing of rapeseed oil), based on their share of physical (for example energy) or financial contributions.

6. Changes in carbon stocks in biomass, soil, and landfill can cause GHG emissions (or removals). These can be very important and should be included in the analysis.

7. In general, LCA is not concerned with the time at which the environmental impacts occur. However, in some cases bioenergy systems cause short-term GHG emissions due to the accelerated oxidation of carbon stocks through combustion as compared to natural decay. While this can affect short-term GHG targets, over a long-term perspective sustainable bioenergy causes less GHG emissions than comparable fossil energy systems.

8. Use of agricultural residues may affect GHG emissions through either changes in soil organic carbon (SOC) or land use changes that occur indirectly, in order to provide the equivalent services that the residues were providing. Exploitation leading to soil productivity losses may require compensating fertilisation (causing GHG emissions) to maintain yield levels and can also cause cropland expansion elsewhere to compensate for yield losses if these occur.

9. The type of technology, scale of plant, and co-products in both the bioenergy and reference energy system can influence the GHG mitigation benefits of the bioenergy system. Since small changes in methodological assumptions and input parameters can have large effects on the estimated environmental impacts, the bioenergy and reference systems should be described and assumptions listed in a transparent manner.

Cover Picture: *Harvesting sawlogs and forest residues in Finland. Thermal power station in background.*

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Life cycle assessment (LCA) is a powerful tool that may be used to quantify the environmental impacts of products and services. It includes all processes, from cradle-to-grave, along the supply chain of the product. When analysing energy systems, greenhouse gas (GHG) emissions (primarily CO_2, CH_4 and N_2O) are the impact of primary concern. In using LCA to determine the climate change mitigation benefits of bioenergy, the life cycle emissions of the bioenergy system are compared with the emissions for a reference energy system. The selection of reference energy system can strongly affect the outcome.

When reviewing the literature one finds large ranges of GHG emissions per unit of energy from LCA studies of similar bioenergy systems. The differences occur for a multitude of reasons including differences in technologies, system boundaries, and reference systems. Some studies may be incomplete in that the bioenergy system and reference system provide different services. Others may omit some sources of emissions (e.g. land use change).

This paper discusses key criteria for comprehensive LCAs based on IEA Bioenergy Task 38 case studies. LCAs of the GHG balance of four different bioenergy systems and their counterpart reference system are highlighted using the case study examples.

The first example investigates heat production from woody biomass and grasses. This study shows that the emissions saved for the same type of service can vary due to the source of the biomass. The bioenergy systems studied reduce GHG emissions by 75-85% as compared to the counterpart reference systems.

In the second example, electricity is produced from woody biomass using two different technologies with different efficiencies. Depending on the technology, the biomass must be transported different distances. The example illustrates the importance of the efficiency of the system and the small impact of soil organic carbon (SOC) decline in comparison with emissions saved. Since the bioenergy systems include carbon sequestration, they reduce GHG emissions by 108-128% as compared to the counterpart reference systems.

A biogas plant providing combined heat and power is analysed in the third example, which illustrates the importance of finding a beneficial use for the heat produced, and of controlling fugitive emissions. In the optimal configuration of closed storage and maximised use of heat, the biogas system reduces emissions by 71% as compared to the counterpart reference system. This reduction decreases to 44% when the heat is not fully used and to only 27% if fugitive emissions are not controlled.

In the final example the bioenergy system provides biodiesel for transport. This example demonstrates the importance of the use of co-products, as the same bioenergy chain produces very different emissions savings per kilometre depending on whether the co-product is used as a material or combusted for energy. Compared to the reference system, the bioenergy systems reduce GHG emissions by 18% and 42% when the co-products are used for energy or materials respectively.

Similar to the case studies presented here, published studies find that GHG mitigation is greater where biomass is used for heat and electricity applications rather than for liquid transport fuels. Overall, the emissions savings from bioenergy systems tend to be similar to that of other renewable energy sources.

1. WHY COMPREHENSIVE LIFE CYCLE ASSESSMENTS ARE IMPORTANT

In the 21st century, climate change mitigation and energy security are important aspects of energy policy. The potential to reduce GHG emissions by replacing fossil fuels such as oil, gas and coal with fuels derived from renewable biomass sources is a significant driver for the promotion of bioenergy. The GHG balances of bioenergy systems should be compared with those of fossil and other renewable energy sources such as wind and solar to underpin decisions on energy policy, land use and utilisation of biomass resources.

LCA, which includes all processes from manufacture through to disposal, is used to quantify environmental impacts of products or processes. Prompted perhaps by the variety of processes for converting biomass resources to bioenergy for heat, electricity or transportation services, and the vigorous discussion of the 'net benefit' of bioenergy, many studies have been undertaken worldwide using LCA methodology to analyse the GHG and energy balance of various bioenergy systems. LCA studies have also been published for other renewable energy options such as wind and solar, and for fossil fuel (oil, gas, and coal) systems providing various energy services. It should be noted that energy systems modelling can also contribute important complementary information to LCA comparisons by evaluating bioenergy options in a broader context to depict development of the total energy system.

The GHG balances of bioenergy and other energy systems depend on a large number of factors, components and assumptions. There are numerous sources of biomass, with different yields and production practices. As well, the same biomass may be used in a myriad of conversion technologies, transportation and distribution processes and end-use technologies. For these reasons, it is very important that the LCA comparison clearly describes both the system being studied (hereafter referred to as the study system); and the system that the study system is being compared with (hereafter referred to as the reference system). Both systems should provide the same level of services and the analysis should include all relevant, significant sources of GHG emissions (and removals) and energy uses. Otherwise, the LCA may be comparing 'apples and oranges' and result in misleading conclusions.

The aim of this technical paper is to summarise and outline the key methodological aspects of LCA with respect to GHG balances of bioenergy systems and include results for some important bioenergy supply chains, in comparison to fossil energy systems. These methodological aspects will be highlighted using case studies conducted by Task 38.

2. METHODOLOGY OF LIFE CYCLE ASSESSMENT

2.1 Introduction

A LCA involves the investigation and evaluation of the environmental impacts of a given product or service, based on the identification of energy and materials inputs and emissions released to the environment. In LCA, the environmental impacts are calculated over the entire lifetime of the product 'from cradle-to-grave' – hence the name 'life cycle'.

Figure 1 shows, for the case of biofuel, the main stages in the life cycle of a product from resource extraction, processing and transport through use and disposal.

A more detailed diagram of the life cycle stages in energy systems is shown in Figure 2. In this diagram, the resource extraction phase is composed of two stages – land use change or facility construction and cultivation or collection or resource extraction. In addition, processes for the transportation of raw biomass or fossil resource to a conversion facility and the distribution of the processed energy carrier to the end user are included. The diagram is more complicated than Figure 1 because it includes co-products. Co-products are goods or services that are provided by the system, in addition to the main service or product. For example, straw used for silage or bedding is a co-product from a grain crop; dried distillers grains with solubles (DDGS), used as animal feed, is a co-product of ethanol production. Disposal of waste products from the conversion process (for example, sludge from biodigesters) is also included in LCA. Some wastes are used beneficially thereby displacing other products (for example, ash from a thermal process applied as fertiliser reduces the need for commercial fertilisers) illustrating that 'one man's trash is another man's treasure'.

The International Standards Organisation (ISO) has published a series of standards for LCA (ISO 14040, 14044). As defined in ISO 14040, a typical LCA study has the following structure:

1. ***Goal and scope definition:*** This phase is used to define and describe the object of the analysis, establish the context in which the assessment is developed, discuss assumptions and data quality, and identify system boundaries and the environmental effects to be assessed. While LCAs of goods and services may consider a range of environmental impacts, including for example, abiotic resource depletion*, acidification and eutrophication potential, and human toxicity potential, it is common for LCAs of energy products to consider solely the global warming impact and energy balance.

2. ***Life cycle inventory (LCI):*** This phase involves compilation of data on energy, material flows, and emissions to the environment in all phases of the life cycle. The result of this phase is an inventory of all inputs and outputs in the form of elementary flows to and from the environment for all the processes involved in the study (for example, inputs of fertiliser, pesticide, fossil fuels, and outputs of products, wastes, and emissions to air such as particulates and the GHGs; CO_2, CH_4, and N_2O).

3. ***Life cycle impact assessment (LCIA):*** Here the impacts associated with the service under study are evaluated in terms of impact categories. For example, the global warming impact is determined by summing the emissions of all GHGs, each expressed in carbon dioxide equivalents (CO_2-eq) calculated from their relative global warming

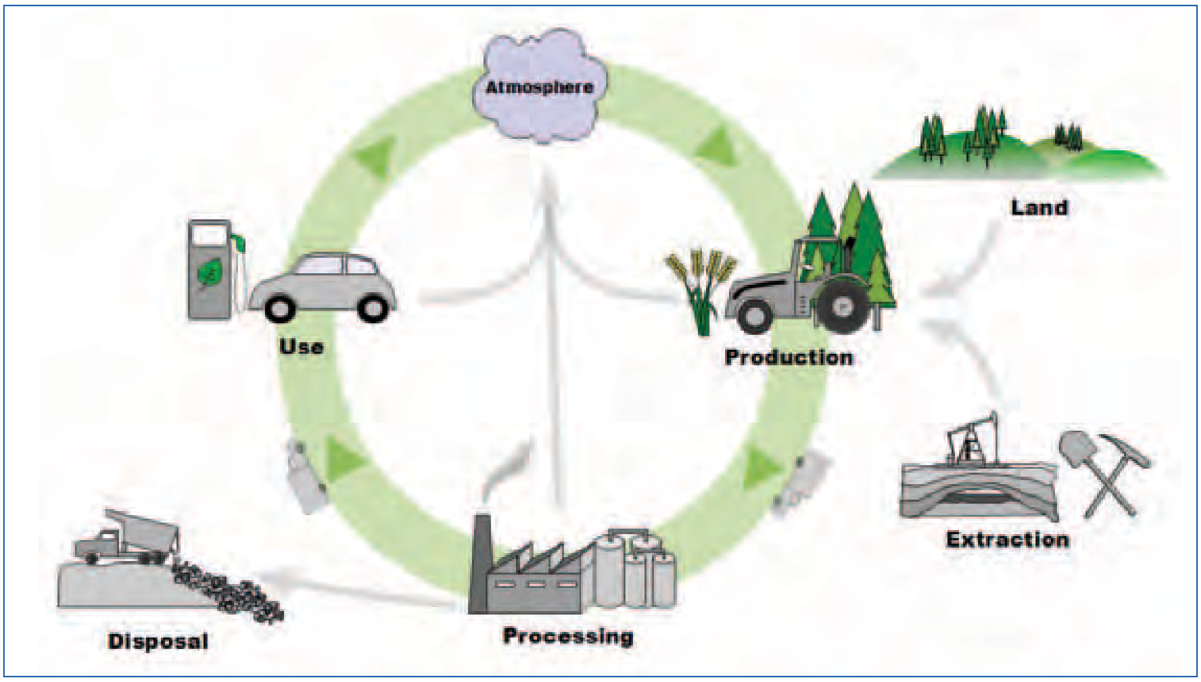

Figure 1. A simplified illustration of the main life cycle stages for a bioenergy system. The green circle represents the carbon cycle, the grey arrows show inputs and outputs from the bioenergy system. This simplified diagram does not attempt to show all carbon fluxes.

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*Abiotic depletion – Abiotic resources are natural resources such as iron ore and crude oil, which are regarded as non-living. Abiotic depletion is calculated based on estimates of reserves and rates of extraction of these resources to indicate the level of resource depletion.

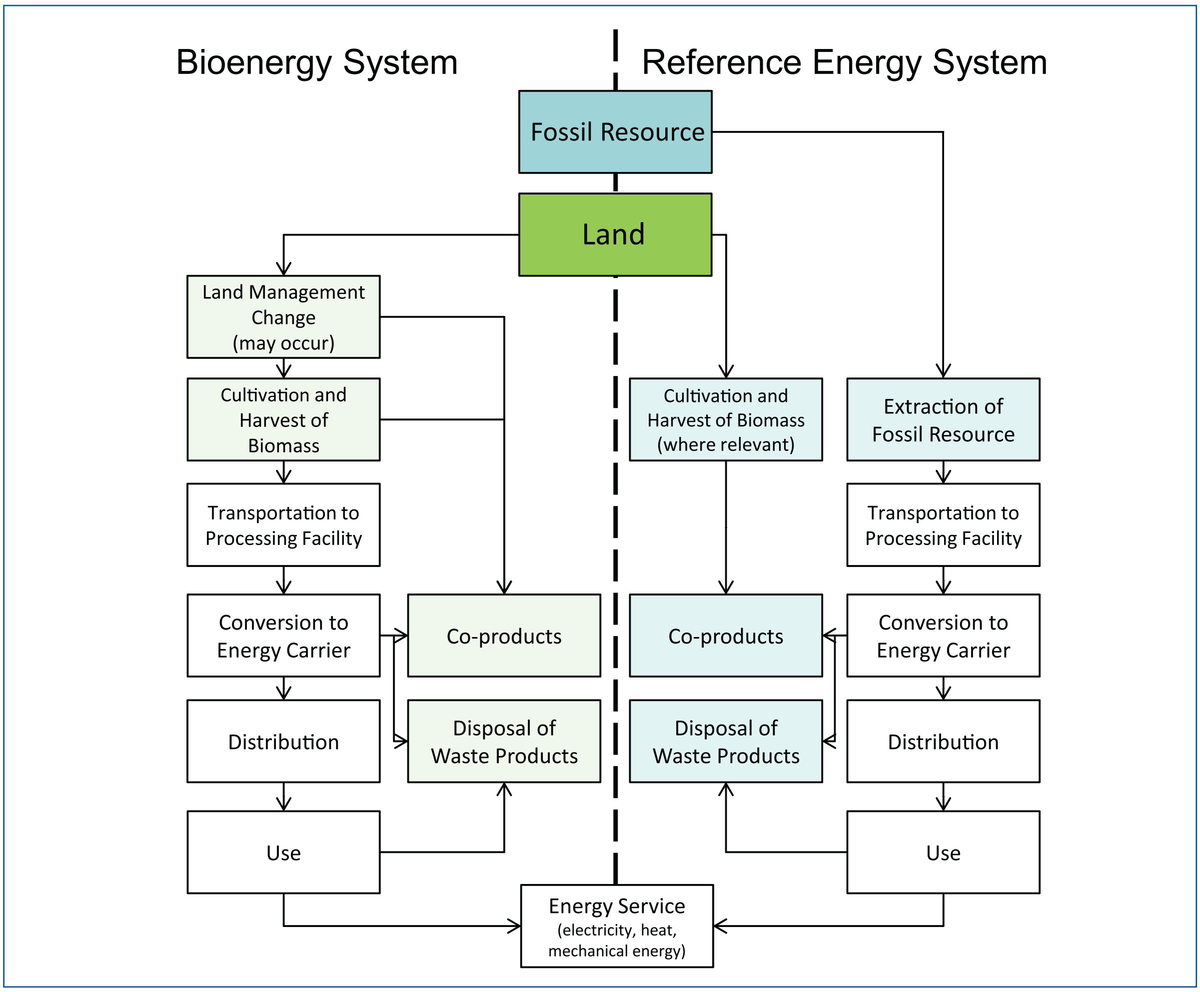

Figure 2. The life cycle stages of typical energy systems. The construction and dismantling of all facilities is not specifically shown in this diagram. However, the GHG emissions from these activities must be included.

potentials (GWP). Multiple impact categories can be combined using weighting to give an overall impact assessment (for example EcoIndicator 95, and ReCiPe). However, this is not considered further in this paper which focuses only on climate change impacts.

4. *Interpretation:* The final step is the interpretation of the results from the previous phases of the study in relation to the objectives of the study.

2.2 Comparing GHG emissions and energy usage of energy systems

Even though LCA can be used to analyse the environmental impacts of an individual product or service it is more commonly used to compare the impacts of two or more products or services. This is how LCA is used in Task 38 to compare bioenergy systems being studied to a reference fossil energy or bioenergy system. When comparing systems, one must take care that the comparison is valid. Otherwise, there is the risk that the comparison is between 'apples and oranges'.

2.2.1 Choice of reference system: The choice of the reference system to which the bioenergy system is compared is critical since the estimated benefits of bioenergy can differ widely depending on the assumed energy system replaced. For instance, fossil-derived electricity might be produced from oil, natural gas or coal, all of which have different GHG emissions per kWh of electricity generated. It would be misleading to calculate the GHG emissions caused by the bioenergy system and compare these to GHG emissions for an unrealistic fossil energy system. Ideally, in the most realistic evaluation, the bioenergy system should be evaluated against the energy system most likely to be displaced. However, in many real-life systems it is difficult to know which energy source will be replaced.

One option is to estimate the GHG emissions savings of the bioenergy system by comparing it to the average fossil energy system. Another option is to make a conservative evaluation by comparing the GHG emission of the bioenergy system with the GHG emissions for the best available fossil energy technology. For example, it could be assumed that electricity in the fossil fuel reference system is produced from natural gas (the lowest emission fossil technology), rather than coal. Since natural gas-generated electricity has a GHG emission factor of around 400 g CO_2-eq/kWh (110 g CO_2-eq/MJ) compared with 990 g CO_2-eq/kWh (240 g CO_2-eq/MJ) for coal-based electricity (see Figure 4, page 15, and *http://www.commodities-now.com/component/attachments/download/327.html*), assuming natural gas was being displaced would give a conservative estimate of emission reduction.

2.2.2 System boundary: In LCA, one must define the system boundary, outside which environmental impacts are ignored. The setting of the system boundary is very important and differences in system boundaries are often a major source of discrepancy between different analyses. The system boundary must include all life cycle stages, significant energy uses, material flows and GHG emissions in both the study and the reference system. In addition, for a valid comparison, the system boundaries should be set so that the same energy and product services are provided by both the bioenergy study and fossil energy reference systems.

As shown in Figure 2, both energy systems start with the same resources (land and fossil fuel) and both provide the same energy service. However, the paths from resource to service of the two systems are quite different.

The reference system includes the following process steps: construction of extraction facilities (optional); extraction of the resource; transportation of the resource to a conversion facility; conversion of the resource into an energy carrier that can be used by the user; distribution of the energy carrier; and use of the energy carrier to provide a service. If the fossil system is designed to provide a transportation service, then the fossil resource may be crude oil transported by pipeline or boat to a petroleum refinery that converts the crude oil to gasoline. The gasoline would then be distributed to gas stations for use in gasoline-powered vehicles to provide a transportation service.

The study system has process steps that are equivalent. Land use change should be included if the system requires a change in land management practices or a different biomass type than was originally on the land. This is equivalent to constructing the fossil extraction facility. The biomass that will be used as a feedstock must be cultivated and collected and transported to a conversion facility. Here it is converted into an energy carrier that is distributed to a user to be used to provide a service. Bioethanol derived from corn is an example of an energy carrier that is analogous to gasoline (the reference system). The land use change incurred could be pasture converted to cropland for the production of corn. Production of corn involves cultivation, using inputs such as diesel, fertilisers and pesticides. The corn is harvested and transported to the ethanol plant. At the plant, the corn is processed to ethanol, which is then distributed to gas stations and used in a vehicle.

Up to now, the paper has described two systems that provide the same energy service. In the bioenergy case, biomass is used to supply energy. To properly account for the differences between the study and reference systems one should consider what would have happened to that biomass in the reference case, when fossil fuel is the energy source. If the biomass for bioenergy is obtained from purpose-grown crops one should consider how that land would have been used in the reference system. This is why 'land' is included in both sides of Figure 2. For example in the reference system, the land may have originally been used as pasture for dairy cattle, producing dairy products. Thus dairy products are co-products of the reference system. In the bioenergy system, co-products should also be considered: the ethanol production process also produces dried distillers grains and solubles (DDGS), which can be used as feed for cattle. As such, the two systems are not strictly comparable.

In general, Task 38 (and ISO) considers it best practice to expand the system boundary of both the study and reference systems to include all significant sources of GHG emissions and energy uses, and assure equivalent services and co-products. This procedure is called system expansion. In the example above this would require consideration of an alternative source of feed for the dairy cattle. The DDGS could be a partial substitute

2.2.3 Comparing systems with different products:

If system expansion is not practical then the environmental impacts may be allocated between the main energy service and co-products in proportion to their functional or physical parameters (such as energy content of outputs) or to their economic value. For example, consider a bioenergy system producing 2 kg of rape cake with every 1 kg of biodiesel. If the energy content of rape cake is 52% of the total energy output then 52% of the GHG emissions associated with the system will be allocated to the rape cake and 48% to the biodiesel.

There are ongoing discussions about the 'best' allocation procedure and scientific publications show the benefits and disadvantages of alternative methods. The European Union's Renewable Energy Directive uses allocation by energy content to distribute emissions between co-products.

2.2.4 Units for comparison - functional units: Comparing the two systems requires some metric for the comparison. In LCA terminology, this is called the functional unit. It provides a reference to which the input and output process data are normalised. The results of the comparison are expressed in terms of the same functional unit, to ensure that the comparison of different systems is based on the delivery of the same service. There are two main types of functional units: input-related or output-related.

Input-related functional units: The question of relative land use efficiency for different biofuel pathways is often not addressed in LCAs. However, Task 38 recommends that the GHG emissions and energy balances of bioenergy systems are expressed on a per hectare basis, since the availability of land is the biggest bottleneck for the production of biofuels. Using input-related functional units answers the following questions:

- What amount of GHG emissions and fossil energy might be saved by using one biomass input unit (i.e. kg CO_2-eq saved/ kg biomass)?
- What amount of GHG emissions and fossil fuels can be saved per hectare by cultivating energy crops on agricultural land or harvesting forests for wood fuel (i.e. kg CO_2-eq saved/ha)?

Output-related functional units: Output-related functional units answer the question:

- What amount of GHG emissions and fossil energy might be saved by providing the same energy service from bioenergy?

Output-related functional units depend on the type of energy service provided by the bioenergy system. For example a typical functional unit for heat is g CO_2-eq saved / kWh_{heat}; for electricity it is g CO_2-eq saved/$kWh_{electricity}$; and for transportation g CO_2-eq saved / passenger-km.

The impact per unit of energy in the final energy carrier, e.g. per MJ of transportation biofuels, is not an adequate functional unit as it does not reflect the possible different efficiencies in the use of the energy carrier. For example, a car may travel further per MJ of gasoline than per MJ of ethanol because the internal combustion engine has been designed and calibrated for gasoline use; the fuel conversion efficiency may remain the same for lower ethanol blends such as E10 but may become lower for higher ethanol blends.

2.2.5 Changes in land management and use: Changes in land management and use can have significant impacts on GHG emissions associated with bioenergy supply chains. The new bioenergy land use may store a different amount of carbon than the original non-bioenergy land use. If there is a loss of carbon, in biomass or soil, then this is equivalent to a CO_2 emission. If instead there is a gain in biomass/soil organic carbon (SOC), then GHG savings are enhanced since CO_2 is removed from the atmosphere (sometimes designated 'negative emission'). A change in land use to produce biomass for bioenergy, for example, a shift from wheat to switchgrass cultivation, is a direct land use change (dLUC) and this is included within the system boundary of the LCA.

The term 'indirect land use change' (iLUC), refers to changes in land use that occur outside the system boundary due to the displacement of services (e.g. food production) that were previously provided on the land now used for bioenergy. Let's say Farmer A converts from growing wheat to growing switchgrass – an example of dLUC. This dLUC may result in iLUC since the reduced wheat availability drives up the wheat price, leading to somewhat reduced wheat demand and also increased wheat production elsewhere. If Farmer B converts his pasture to wheat cropping as a consequence of the action of Farmer A, CO_2 emissions may occur due to the ploughing of pasture land inducing SOC oxidation. This loss of SOC stock is referred to as an iLUC emission – it occurs at a site not directly affected by the biomass production, outside the control of Farmer A, and therefore outside the system boundary of the bioenergy system.

Most so-called attributional LCAs have up to now not considered iLUC and other indirect effects. As the dynamic effects of bioenergy expansion have become increasingly discussed, this omission has resulted in criticism of such bioenergy LCAs. In so-called consequential LCAs – that analyse bioenergy systems in the context of the economic interactions, chains of cause and effect in bioenergy production and use, and effects of policies/other initiatives that increase bioenergy production and use – attempts are made to consider indirect effects (primarily iLUC). However, quantifying emissions due to iLUC is very difficult because, as there is no direct link, it is not possible to identify which land use change is a result of a specific bioenergy system, nor which land use change is due to other causes, such as increased demand for food by the growing global population, or urban expansion. To determine emissions due to iLUC it is necessary to consider complex inter- and intra-sector interactions and trends, including regional and global deforestation, diets including responsiveness to food prices, cropland expansion and trade of food, feed, fibre and bioenergy, and so calculate iLUC on a regional or sectoral basis.

Measures can be taken to minimise iLUC associated with bioenergy, for example, by using biomass that is considered waste, or land that is not under agricultural production. Specific measures include:

a) lowering biomass demand through options such as stringent bioenergy efficiency requirements and efficient biomass-to-energy conversion;
b) using wastes/residues as biomass sources for bioenergy;
c) increasing biomass yield per hectare;
d) increasing intensity of production on other land remaining under agricultural use;
e) using co-products as animal feed;
f) using unproductive land (set-aside, fallow, degraded or otherwise marginal land) for energy production; and
g) integrating biomass production with agricultural land uses, such as through agroforestry.

Some of these measures are general requirements for optimising bioenergy systems but they may also mitigate food sector impacts resulting from the introduction of a bioenergy system. However, the consequences for land use change and the food sector will depend on the overall context, including existing policies. For instance, requirements for efficient biomass-to-energy conversion lower the biomass use per unit energy service provided, but also make biomass more valuable as bioenergy feedstock and this might instead increase the land pressure (and land price, and therefore food price) as biomass demand increases. If targets are set for specific bioenergy contributions then bioenergy efficiency requirements lower the volume of biomass needed to reach the target. If instead CO_2 targets or general renewable energy targets are used – and if more cost competitive bioenergy options become available – then more bioenergy will be used. In such a scenario, the GHG mitigation costs will be lower, but land use competition and pressures on valuable natural ecosystems may increase. In the absence of instruments discouraging conversion of carbon-rich land, the net effect may even be that land use change emissions increase.

It will be important that increased intensity of production (measures c and d above) do not result in unsustainable land use practices, or perverse outcomes such as increased net GHG emissions due to higher nitrous oxide emissions from additional nitrogen fertiliser inputs intended to increase biomass yields.

This paper has focused on iLUC in agriculture, but it can also be an issue with forestry. For example, the diversion of forest biomass from household heating to electricity production may cause iLUC to supply biomass for household heating, as the household will need to replace their fuel wood with another source. It is important to note that iLUC can also be an issue for other renewables. For example, the flooding of a river valley for a hydro-electricity project will cause iLUC to replace all services that the valley originally produced (agriculture, wood products).

For a more complete discussion of dLUC and iLUC, see the IEA Bioenergy publication (Berndes *et al.*, 2010) listed in Section 6 'Recommended Reading'.

2.2.6 Timing of emissions and removals: LCA is usually concerned with total environmental impacts over the entire lifetime of a process or service. Therefore, in conventional LCA it is commonly assumed that timing of emissions and removals is not important: the same weight is given to emissions that occur in the past, present and future. Thus, in LCA the total emissions from a process, including its establishment phase, are often amortised over the lifetime of the process. However, when operating a bioenergy system, there may be GHG emissions that occur primarily in the early stages (e.g. from combustion of living biomass, decay of soil organic matter, and accelerated oxidation of carbon stocks through combustion as compared to natural decay due to utilisation of harvest and wood processing residues), even when the land is being sustainably managed in the long run. Compensation for these emissions through carbon removals from the atmosphere may take some time; a new dynamic equilibrium will be reached, governed by dynamic ecosystem processes associated with the next rotation (e.g. forest growth and soil organic matter dynamics) and the energy and bio-based products that are harvested (i.e. the fate of products and wastes). During the transition to a new equilibrium carbon balance, there will either be a net emission of CO_2 if carbon stocks are lower in the new land use, or there will be a net removal of CO_2 from the atmosphere if carbon stocks increase to a higher level under the new land use.

There is agreement that over the long-term, bioenergy reduces GHG emissions when compared to fossil energy. However, the points made above regarding the timing of emissions and removals indicate that it may take several decades for atmospheric carbon removal by slow-growing forests to compensate for emissions that occur early in the life of a newly installed bioenergy scheme that utilises biomass from existing forests and wood products. Nevertheless, it is important to consider long-term climate objectives and encourage the establishment of bioenergy systems that can be demonstrated to provide a low carbon, GHG-friendly energy supply in the future.

2.3 Data requirements

The key data requirements for the calculation of the GHG and energy balance in the bioenergy system are listed in Table 1. Many parameters are system specific although some parameters such as the GHG emissions and energy balance for fertiliser, herbicide and pesticide production can be obtained from LCA databases such as ECOINVENT*, ELCD†, GEMIS‡ or US LCI§. Of course, similar information is also required for the fossil reference system (Table 2).

2.4 Quantifying environmental impacts

In LCA, all environmental impacts may be assessed. However, the work of Task 38 has typically focussed on two key assessment variables: GHG emissions and the primary energy usage. This report places principal focus on GHG balances and will report energy usage data in less detail.

GHG emissions: The most important GHGs in energy systems are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Carbon dioxide (CO_2) is the main product of the combustion of fossil fuel and biomass. The amount of CO_2 emitted per energy unit depends – amongst other things – on the carbon content and heating value of the fuel. In the biosphere, CO_2 is removed from the atmosphere by growing plants, through photosynthetic production of carbon compounds and their subsequent accumulation in plant biomass. CO_2 is also produced by the aerobic degradation (decay) of biomass. Carbon stock changes that occur because of land use changes are converted to CO_2 by multiplying by the ratio of the molecular weights of CO_2 to C.

Table 1: Data requirements for the GHG and energy balance of bioenergy systems

Process step (see Figure 2)	Parameters to be collected or estimated	Variable calculated
Land management change	Carbon stocks in landfill, soil, and vegetation affected by the bioenergy system	Carbon stock change due to land use change
Cultivation and harvest of biomass	Biomass yield Residue amount and use Co-products amount and type Fertiliser amount and type Herbicides and pesticides use Fuel use by machines e.g. tractor operations, pumps GHG emissions for fertiliser, herbicide and pesticide production	GHG emissions and energy input from collection and cultivation
Transportation of feedstock	Transport distance and mode Fuel use per unit distance transported	GHG emissions and energy input from transportation
Conversion to energy carrier	Auxiliary materials input Co-products amount and type Energy and material efficiency of conversion process Energy demand of conversion facility GHG emissions for auxiliary materials production	GHG emissions and energy input from conversion
Distribution	Distribution distance and mode Distribution losses (e.g. electricity grid) Energy demand of distribution system (e.g. district heating system) Fugitive GHG emissions for the distribution system (e.g. natural gas grid)	GHG emissions and energy input from distribution
Use	Energy efficiency Auxiliary energy demand Auxiliary materials input	GHG emissions and energy input from use
Disposal	Quantity and type of waste	GHG emissions from end-of-life phase

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* *http://www.ecoinvent.org/database/* † *http://lct.jrc.ec.europa.eu/assessment/data* ‡ *http://www.oeko.de/service/gemis/en/index.htm* § *http://www.nrel.gov/lci/*

Table 2: Data requirements for the GHG and energy balance of reference systems

Process step (see Figure 2)	Parameters to be collected or estimated	Variable calculated
Cultivation and harvest of biomass (where relevant)	Biomass yield Residue amount and use Carbon stock of soil and vegetation Co-products amount and type Fertiliser amount and type Herbicides and pesticides use Water use Energy consumption by machines e.g. tractor operations GHG emissions and energy balance for fertiliser, herbicide and pesticide production	GHG emissions and energy input from reference land use
Extraction and transportation of fossil fuel	Energy requirement in fossil fuel extraction Transportation distance and mode Energy requirements by transportation	GHG emissions and energy input from extraction and transportation
Conversion to energy carrier	Energy and material efficiency of conversion process Energy demand of conversion facility GHG emissions and energy balance for auxiliary materials production	GHG emissions and energy input from conversion
Distribution	Distribution distance and mode Distribution losses (e.g. electricity grid) Energy demand of distribution system (e.g. district heating system) Fugitive GHG emissions from the distribution system (e.g. natural gas grid)	GHG emissions and energy input from distribution
Use	Energy efficiency Auxiliary energy demand Auxiliary materials input	GHG emissions and energy input from use
Disposal	Quantity and type of waste	GHG emissions from end-of-life phase

Methane (CH_4) is a flammable hydrocarbon-compound that is the main component of natural gas, but it is also a product of incomplete combustion processes. CH_4 is also emitted during coal mining and extraction of raw oil and natural gas. In the biosphere, the anaerobic degradation of biomass produces CH_4. This occurs mostly from the management of animal and human excrement, the landfilling of organic waste and rice production.

Nitrous oxide (N_2O) is formed in combustion processes under certain conditions. The amount of N_2O emitted depends on the nitrogen content of the fuel and the combustion temperature. N_2O is also emitted as a consequence of nitrification and de-nitrification processes controlling the fate of nitrogen applied as chemical fertiliser, manure or through fixation by legumes.

Other GHGs such as sulphur hexafluoride (SF_6) and chlorofluorocarbons (CFCs) are not so important for energy systems, though SF_6 is used to test oil and natural gas pipelines for leaks.

Global Warming Potential (GWP) is used to express the contribution of different GHGs to global warming. The impacts of the non-CO_2 GHGs are expressed in terms of the equivalent amount of CO_2 (CO_2-eq). The equivalency factors of the different gases are dependent on the time period over which the equivalency is calculated since different gases have different residence times in the atmosphere. Usually the 100-year GWP factors are used. For example, one gram of CH_4 has the equivalent global warming impact as 25 g of CO_2 when a 100-year time horizon is used. Using the same time horizon, one gram of N_2O has the equivalent global warming impact of 298 g of CO_2.

3. KEY FACTORS THAT INFLUENCE GREENHOUSE GAS EMISSIONS AND ENERGY USAGE

3.1 Feedstock procurement

Choice of biomass feedstock plays an important role in the GHG emissions of the bioenergy system. In general, the use of industrial and domestic residues for bioenergy has the lowest GHG emissions from the procurement stage. Energy crops grown specifically for bioenergy have the highest emissions, due to the energy and material input, e.g. tractor use, fertiliser. Bioenergy systems based on in-field crop and forestry residues generally have intermediate emissions. However, the use of the non-energy co-products of energy crops (such as soy meal for animal feed) and the reference use of the residues must be taken into account, as these factors can enhance or counteract the GHG savings from use of bioenergy.

3.1.1 Changes in biomass and soil carbon stocks: and use change may be the most important factor that affects the GHG balances of bioenergy systems. In extreme cases, the total emissions caused by land use change in order to create the bioenergy system may be more than a 100 times greater than the annual GHG savings obtained from displacing fossil fuel consumption. As previously discussed, both direct and indirect land use change are important and need to be considered when evaluating the GHG outcome of bioenergy implementation. Some LCA studies have included the direct emissions caused by the loss of above ground biomass. Seldom have LCA studies included the emissions from indirect land use change.

Soil organic carbon: A variable that many biofuel LCA studies neglect entirely is the change in soil organic carbon (SOC) due to change in land use or land management. The amount of SOC is very site-specific and highly dependent on former and current agronomic practices, climate, and soil characteristics. At any one time, the amount of SOC reflects the balance between the inputs from plant residues and other organic matter, and losses due to decomposition, erosion and leaching. Intensive cultivation leads to loss of SOC, partly through the physical disturbance caused by tillage, which can stimulate decomposition.

A key factor controlling the amount of SOC is the frequency and duration of pasture phases because these facilitate the build-up of organic matter in the soil. Pasture periods are a time of less physical disturbance by tillage. Similarly, converting from conventional tillage of an annual crop to production of a perennial energy crop like switchgrass could result in substantial build-up of SOC over time. On the other hand, if woodlands or grasslands are converted to croplands used for cultivation of annual bioenergy crops involving frequent ploughing and tilling, SOC is likely to decrease.

Measuring changes in SOC is difficult since SOC depletion and build-up are relatively slow processes and SOC stocks are spatially variable. The few available experimental data and modelling studies indicate that short rotation perennial bioenergy crops can increase SOC compared with intensive cropping. On the other hand, increasing intensity of harvest from existing agricultural and forest systems, and replacing pastures with short rotation energy crops may reduce SOC. Conversely, changed management to increase the biomass output from forests, such as forest fertilisation, can result in increased SOC. If a land use change from forest ecosystems to a bioenergy crop occurs, then the loss of SOC may be very large. In an extreme case, the conversion of tropical peatland rainforest to oil palm for biodiesel may release ~800 t C per hectare converted, equivalent to 2900 t CO_2-eq.

Landfill: Landfills also store carbon and, as for SOC, the loss of biomass in landfills as a result of the use of residues is often ignored in LCAs. By diverting biomass from landfill to energy use, carbon that would otherwise have been stored in landfill is released to the atmosphere, and this 'avoided storage' counts as a negative contribution to the mitigation value of bioenergy. However, a fraction of biomass deposited in landfills decomposes to produce methane, which has 25 times higher GWP than CO_2 (100 year time horizon). Methane emissions avoided by using biomass from landfill for bioenergy enhance the climate benefit. Estimating the impact of avoided landfill is further complicated by the introduction of methane capture systems. In some cases, the methane is flared without use. In other situations, the methane is captured and itself used for energy. In this situation, the bioenergy system may or may not be preferable to a methane capture system on a landfill; this depends on the fossil fuel displacement effect of the bioenergy system vs. the landfill methane capture system and the effectiveness of recovery of landfill gas.

3.1.2 Environmental impact of agricultural residue removal: There is an ongoing debate about the desirability of utilising crop harvest residues from agricultural cropping systems for bioenergy production. There are generally two current uses of these harvest residues: (i) removal for use as fodder or bedding for animals; or (ii) soil management where the harvest residues are either left on the surface providing a mulch, or ploughed into the soil. In the first case, the straw is a valuable co-product that needs to be replaced if the straw is used for bioenergy. For example, an alternative source of animal feed should be provided in the bioenergy system and included in the analysis. If the residue is instead used for soil management in the reference system, the removal of crop residues could increase soil erosion, and reduce SOC and nutrient content, potentially leading to soil productivity losses and lower crop yields. The effects are strongly influenced by local conditions (climate, soil type and crop management). Direct GHG effects of this removal are a decline in SOC, and possibly changes in N_2O and CH_4 emissions from soil. In addition, if the soil fertility decreases, countervailing measures – e.g. increased fertilisation to keep up the yield levels or cropland expansion to compensate for the yield losses – will likely result in additional GHG emissions. To consider such consequences the system boundaries of the bioenergy system can be expanded to include this additional crop production elsewhere. Alternatively, if the system boundary is not expanded, the additional GHG emissions may be quantified in the same way as when quantifying the effects of indirect land use change.

In conclusion, removing crop residues for bioenergy should occur only if the environmental, economic and social benefits of this use are larger than the direct and ancillary benefits of residue retention. The effects of harvest residue use on the final GHG balance should be addressed case by case using suitable models and assumptions, as they are highly variable and depend on specific local factors.

3.1.3 N_2O and CH_4 emissions from agriculture: An important variable in LCA studies is the contribution to net GHG emissions of N_2O, which is produced by microbial processes in soil, from nitrogen supplied by fertiliser application or organic matter decomposition. Emissions from fields vary depending on soil type, climate, crop, tillage method, and fertiliser and manure application rates. The actual emissions may be small. Typically only 1.0-1.5% of N in synthetic fertiliser is emitted as N_2O*. However, as noted above, one gram of N_2O has the equivalent global warming impact of 298 g of CO_2 (100 year time horizon).

The impacts of N_2O emissions are especially significant for annual biofuel crops, because fertiliser application rates are higher for these than for perennial energy crops. Crops grown in high rainfall environments or under flood irrigation have the highest N_2O emissions, as denitrification, the major process leading to N_2O production, is favoured under wet soil conditions where oxygen availability is low. For example, more than 6% of applied N can be released as N_2O from sugar cane fields, in warm, moist environments.

Most studies of CH_4 emissions from ecosystems have focused on wetlands, since these are the hotspots of CH_4 production. Until recently, biological CH_4 formation was assumed to arise exclusively from anoxic environments, but there is growing evidence that terrestrial plants can also emit small amounts of CH_4 under aerobic conditions. The drier upland ecosystems are, however, normally net sinks for atmospheric

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*In 2007, these factors were criticised as underestimating N_2O emissions 3-5 fold. However, since that time this claim has been refuted.

CH_4 since CH_4 consumption exceeds production. However, under water logged conditions, some forests may switch to become CH_4 sources. Pastures and cropland may also be net sources or sinks for CH_4. There are indications that higher temperatures and water stress enhance CH_4 emissions from commonly cultivated plants. Hence CH_4 emissions from plants may become higher due to the global climate change.

Conversion of land use from cropland or pasture to woody energy crops may reduce emissions of CH_4, while conversion of forests to annual energy crops is likely to increase net CH_4 emissions. Within a LCA study, soil CH_4 fluxes usually make a relatively small contribution to the total life cycle GHG emissions of the bioenergy chain.

As with quantification of the impacts of residue removal, these 'non-CO_2' GHG emissions should be estimated for each specific case, using suitable models and assumptions, as they are highly variable and depend on local factors.

3.2 Feedstock conversion

3.2.1 Energy service provided by bioenergy: The potential for bioenergy to reduce GHG emissions differs for the three different types of energy service – heat, electricity and transportation. It is mainly determined by the conversion efficiency from biomass to energy service. In general, the energy efficiency of converting biomass to heat (70% to 90%) is higher than to electricity (20% to 40%) and transportation fuel (about 20% to 50%), if there is no credit given for non-energy co-products. This means that for the same quantity of biomass, the GHG reduction is likely to be higher when producing heat than it is for electricity and transportation fuel.

3.2.2 Status of technology: Generally, new bioenergy technologies have higher energy efficiencies and lower GHG emissions. For example, new pellet boilers have efficiencies up to 90% and quite low CH_4 and N_2O emissions compared to a 10-year old pellet boiler. However, the state of technology of the substituted fossil energy system also strongly influences the possible GHG reduction by the bioenergy system. If a combination of old coal-fired heat generation and inefficient, coal-based condensing power generation is displaced by a high efficiency biomass-fired combined heat and power system, then the change in technology may have contributed as much to the environmental benefit as the change from fossil to bioenergy.

The reader should recognise that there are both mature and developing bioenergy systems. Mature systems are those that are currently commercially available (e.g. heating systems, combined heat and power production and so-called '1st generation' transportation biofuels). Developing bioenergy systems are generally not in commercial operation. These can include both developing technologies, for example synthetic biofuels, and new feedstocks, such as *Jatropha* or algae. The data – and hence the estimates of environmental impacts – are much more reliable for commercially available systems as compared to systems under development. Data are particularly limited for bioenergy systems based on new feedstocks, so only rough estimates of possible GHG savings can be made for these at present.

3.2.3 Fate of co-products: In general, when more co-products are created from the conversion process, fewer GHG emissions will be allocated to the energy service. The non-energy co-products linked to the bioenergy systems substitute for other products on the market. For example, rape cake from biodiesel production substitutes conventional animal feed. The GHG emissions associated with the substituted products are included in the system boundary for the reference system. These are an environmental benefit since in the study system these emissions are avoided.

4. CASE STUDIES OF GREENHOUSE GAS AND ENERGY BALANCES OF BIOENERGY SYSTEMS

Task 38 is a group of researchers from various countries that work on the specific theme: 'GHG Balances from Biomass and Bioenergy Systems'. In 1997, Task 38 published its standard methodology for GHG balances of bioenergy systems based on LCA. Since then members of the Task have used this methodology to analyse the GHG balances of more than 15 different bioenergy systems in participating countries. A few of these case studies are used in the next sections to illustrate the major factors affecting GHG savings from different bioenergy systems.

4.1 Heat

The energy balance and GHG emissions of a small-scale biomass heating system in the southwest of England have been studied (Task 38 UK Case Study: The Greenhouse Gas and Energy Benefits of a *Miscanthus* and a Wood-fuelled Heating System*). These examples show how the choice of biomass can affect the estimate of GHG emission benefits.

Example 1 - 150 kW wood versus oil-fired heating systems in Southern England
The first example investigates the GHG benefits of a wood heating system at Grascott Farm in southwest England.

Study system: The heating system was installed in January 2003 to heat a five bedroom farmhouse and a three bedroom holiday cottage. It was expanded to heat an additional cottage in 2008. The biomass comes from thinning the under-managed broadleaved woodland and fir plantation on the property (7.5 oven dry tonnes per year) and slab wood (22.5 oven dry tonnes per year) from a local sawmill 5 km away. All wood is air dried to 25% moisture (per unit dry biomass) before chipping.

Reference system: The heat is supplied by a single oil-fired boiler with storage tank. The woodland on the property is left unmanaged and the slab wood would be used in a board mill approximately 10 km further away from the sawmill.

Results: The results of the LCA for this example are shown in Table 3. It is assumed that the increased management intensity causes no loss of carbon stocks in the forest. However, the use of the slab wood for bioenergy means that the board mill needs to use wood from somewhere else. The analysis expanded the system boundary to include substitution of slab wood from a mill 10 km further away. The study did not consider the

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*Task 38 Case Study by Heaton, R and Matthews, R. *www.ieabioenergy-task38.org/projects/task38casestudies/index1.htm*

Table 3: GHG and energy balances of wood-fired heating assuming slab wood would have been incinerated without energy recovery in the reference case

Item	Units	Reference System	Study System
Fossil energy input	kWh/kWh$_{heat}$	1.20	0.12
Fossil energy saved	kWh/kWh$_{heat}$	1.08	
	kWh/t$_{dry}$	5,641	
Emissions			
Land management change	g CO_2-eq/kWh$_{heat}$	N/A	0
Cultivation and harvesting	g CO_2-eq/kWh$_{heat}$	N/A	6
All other emissions	gCO_2-eq/kWh$_{heat}$	379	46
Total	g CO_2-eq/kWh$_{heat}$	379	52
Emissions saved	g CO_2-eq/kWh$_{heat}$	327	
	t CO_2-eq/ t$_{dry}$	1.71	

use of this biomass in the reference system. If one assumes that the additional biomass would have been incinerated without energy recovery in the reference case, then its use for bioenergy has no impact on carbon stocks. However, if it is assumed that the slab wood would have gone to landfill, then the loss of biomass in the landfill is estimated as 447 t over the 25 years of the project. This is roughly 79% of the biomass consumed.

If the slab wood had gone to landfill then the emissions from the study system would be 261 g CO_2-eq/kW$_{heat}$, including 209 g CO_2-eq/kW$_{heat}$ from 'land management change' so the savings would be only 118 g CO_2-eq/kW$_{heat}$. The diversion of wood from the landfill for bioenergy use causes a decrease in the carbon stock in the landfill. The amount and rate of loss depends on the decay rate of the wood. This demonstrates the importance of accurate identification of the reference system.

Example 2: 70 kW Miscanthus versus oil-fired heating systems in West London
Study system: In the second example, a 70 kW *Miscanthus*-fired boiler was installed as a bioenergy demonstration project in a rural office complex in Hertfordshire, West London. The biomass is harvested annually from the 4.5 ha surrounding the complex. The emissions from cultivation and collection of the biomass are included in the estimate.

Reference system: The heat is supplied by a single oil-fired boiler with storage tank. The surrounding land would be left unused (set-aside[*]) but the grasses would be cut once annually and left on the ground.

Results: The results of the LCA for this example are shown in Table 4. This bioenergy causes little to no land use change since the biomass in grassland and in *Miscanthus* are roughly equal. The results are comparable to the earlier example. This system requires more energy specifically for cultivation and harvesting than the wood-based example.

Comparison with literature: Ranges for typical LCA studies for heat are given in Figure 3. The results from Example 1 are high when the loss of landfill biomass is considered, but compare reasonably otherwise. The values for Example 2 are somewhat higher than other studies but this can be expected given the large emissions from cultivation.

4.2 Electricity

This case study assessed the potential GHG emissions reduction from substituting electricity from coal with bioenergy based on *Eucalyptus* spp. plantation residues in northern New South Wales (Task 38 Case Study - GHG balance of bioenergy systems based on integrated plantation forestry in North East NSW, Australia[#]). The case study highlights the importance of the efficiency of the energy conversion process, and demonstrates the inclusion of SOC dynamics when there is a land use change.

Table 4: GHG and energy balances of *Miscanthus*-fired heating

Item	Units	Reference System	Study System
Fossil energy input	kWh/kWh$_{heat}$	1.22	0.52
Fossil energy saved	kWh/kWh$_{heat}$	0.70	
	kWh/t$_{dry}$	2,763	
Emissions			
Land management change	g CO_2-eq/kWh$_{heat}$	0	1
Cultivation and harvesting	g CO_2-eq/kWh$_{heat}$	16	56
All other emissions	gCO_2-eq/kWh$_{heat}$	380	45
Total	g CO_2-eq/kWh$_{heat}$	396	101
Emissions saved	g CO_2-eq/kWh$_{heat}$	295	
	t CO_2-eq/ t$_{dry}$	1.17	

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[*] Set-aside land is land that does not produce a crop because it is not economically attractive. The land may still be managed (i.e. mowed, or tilled) to control weeds.
[#] Task 38 case study by Cowie, A. *www.ieabioenergy-task38.org/projects/task38casestudies/index1.htm*

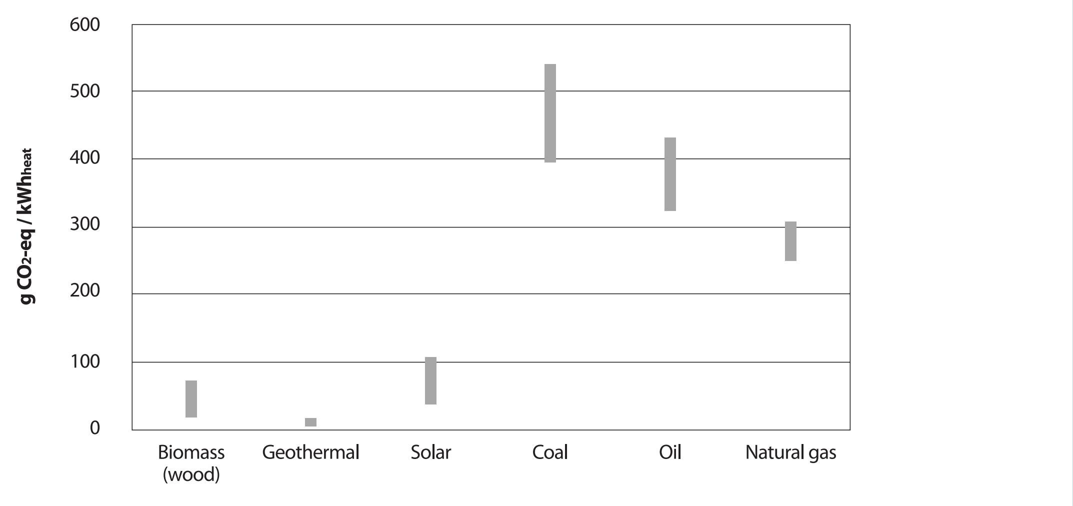

Figure 3. Ranges of GHG emissions for heat supply from different sources. Source: Cherubini *et al.* 2009. Energy- and GHG-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. *Resources, Conservation and Recycling. 53: 434-447.*

Example 1 – Firing of plantation residues in newly built 30 MW wood-fired generating stations in the plantation region

Study system: The study system is based on biomass production from conventional hardwood plantation forestry in northern New South Wales. Biomass is obtained from thinning, harvest and sawmill residues from 70,000 ha existing and 110,000 ha newly established hardwood plantations in the region. The biomass is fed into 30 MW wood-fired power stations newly constructed within the plantation region. There is no loss of timber production from the existing and newly planted plantations.

The 30 MW wood-fired generating stations use circulating fluidised bed boiler, steam turbine technology that has a 20% conversion efficiency. This value is low compared to most systems because it was assumed in the study that the biomass was not dried before combustion.

Reference system: The reference system to which the bioenergy system is compared represents current practice, in which electricity is generated from 500 MW black coal-fired power stations. In the reference system, thinning residues decay on the forest floor, harvest residues are windrowed and burned in the field, and sawmill residues that are not utilised in drying timber are burned to waste at the mill. Timber is obtained from 70,000 ha of existing plantations and 110,000 ha of newly established *Eucalyptus* spp. plantations.

The study and reference system boundaries include the power generation system, 70,000 ha of existing plantation, and 110,000 ha of grazing land newly converted to plantation. The same quantity of sawn timber is produced, and the same quantity of carbon is sequestered by the live trees. The carbon stock changes in the litter, deadwood, soil and landfill are estimated using a full carbon stock flow model (FullCAM). The calculation is made over 100 years to cover several plantation rotations.

Results: There is a decline in SOC predicted for the reference and bioenergy cases, for newly established forests (Table 5). Temporary loss of SOC commonly occurs where plantations replace pasture, because mineralisation exceeds input to the soil organic matter pool during the early stages of plantation growth, although large losses are limited to situations where high levels of fertilisation have built up a large pool of labile soil carbon in pasture. The rate of decline in soil C is greater under the study system than in the reference system. This is to be expected because biomass (thinning residues) is removed that would otherwise have entered the litter pool that interacts with the soil C pool. In addition, the combustion of the thinning material accelerates the return of carbon to the atmosphere as compared to the natural oxidisation. Nevertheless, changes in the soil C and litter pools are small compared with the accumulation of C in tree biomass over the first rotation, and the growing pools

Table 5: GHG balance and energy input of stand-alone 30 MW wood-fired electricity generation

Item	Units	Reference System	Study System
Fossil energy input	kWh/kWh_{elec}		0.25
Emissions			
Land management change	g CO_2-eq/kWh_{elec}	-313	-271
Cultivation and harvesting	g CO_2-eq/kWh_{elec}	40	59
All other emissions	gCO_2-eq/kWh_{elec}	981	12
Total	g CO_2-eq/kWh_{elec}	709	-201
Emissions saved	g CO_2-eq/kWh_{elec}	909	
	t CO_2-eq/ t_{dry}	0.949	

Table 6: GHG balance and energy input of 500 MW biomass co-fired electricity generation

Item	Units	Reference System	Study System
Fossil energy input	kWh/kWh$_{elec}$		0.45
Emissions			
Land management change	g CO_2-eq/kWh$_{elec}$	-235	-186
Cultivation and harvesting	g CO_2-eq/kWh$_{elec}$	28	40
All other emissions	gCO_2-eq/kWh$_{elec}$	981	88
Total	g CO_2-eq/kWh$_{elec}$	774	-59
Emissions saved	g CO_2-eq/kWh$_{elec}$	853	
	t CO_2-eq/ t$_{dry}$	1.30	

of products. Over several rotations, displaced fossil fuel carbon becomes the dominant pool.

The amount of biomass in tree growth, wood products, and hence 'products in landfill' do not differ between the bioenergy and reference cases.

Example 2 – Co-firing of plantation residues in existing 500 MW wood-fired generating station 360 km away from plantations.
Study system: In the second example, instead of going to newly built 30 MW facilities, the same amount of biomass is trucked 360 km and co-fired in an existing 500 MW generation station. The facility is a pulverised fuel black coal boiler, steam turbine in which biomass is co-fired 5% by weight. The efficiency of the system is 29%, which is lower than the efficiency of coal combustion due to the higher moisture content of the biomass

Reference system: The reference system is identical to Example 1.

Results: The results are shown in Table 6. Co-firing gives higher emissions reduction per unit of biomass than the stand-alone system due to the greater efficiency of energy conversion in the co-fired plant. (Note that the result for co-firing applies only to the electricity derived from biomass, not to the total electricity output of the plant). Due to the longer transportation distances, the emissions for co-fired bioelectricity are higher than those of the stand-alone system (Example 1, Table 5). In comparison, the emissions for electricity production from the reference coal power plant are 981 g CO_2-eq/kWh. The GHG emission savings per t of biomass for the co-firing option are higher than the stand-alone option, due to the higher efficiency of the co-firing system, even though there are higher transport emissions due to the longer transport distance to coal-fired power stations.

Comparison with literature: In Figure 4, the ranges of GHG emissions for electricity supply with different energy carriers are shown. The GHG emissions from hydro, solar and wind mainly arise from the construction and dismantling stage of the power plants. The bioenergy systems do not include direct changes in carbon stocks or indirect land use change. The GHG emissions from bioelectricity are 80% to 97% lower compared to fossil energy carriers, but similar to nuclear, hydro and wind power. Excluding land use change, the GHG emissions from Examples 1 and 2 are similar to those given in Figure 4.

4.3 Combined heat and power from biogas

This case study quantifies the GHG emissions savings of a biogas plant utilising dedicated energy crops, grass and manure as feedstock. In addition, the emissions of the bioenergy system were estimated with and without closed storage of the digested substrate (Task 38 Case Study - 'GHG benefits of a biogas plant in Austria', S. Woess-Gallasch, N. Bird, P. Enzinger, G. Jungmeier, N. Pena, R. Padinger and G. Zanchi).

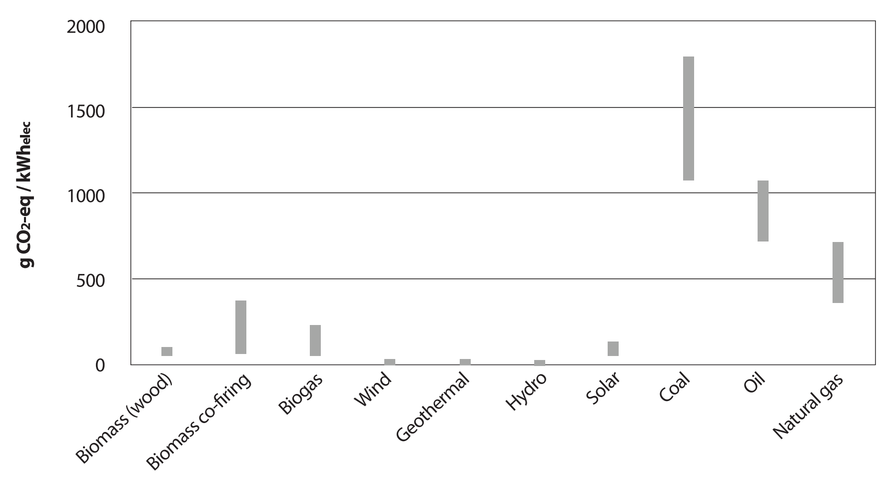

Figure 4. Ranges of GHG emissions for electricity and cogeneration from different sources. In biomass co-firing, biomass is assumed to provide between 5% and 15% of the energy. Source: Cherubini *et al.* 2009. Energy- and GHG-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. *Resources, Conservation and Recycling.* 53: 434-447.

The study shows the importance of finding a beneficial use for excess heat and preventing fugitive emissions from the biogas plant. In this example, land use change is not significant.

Study system: The biogas plant in Paldau, Austria, was analysed. The biomass used in the plant is derived from dedicated energy crops, animal manure and grass silage. The crops supply 3.12 kt per year of maize and 2.67 kt per year of maize silage. Animal manure (from pigs: 3040 m^3 per year; from cows: 300 m^3 per year) is supplied by five farmers situated close to the plant. In two cases, the manure is delivered by a pipeline (1,800 m^3 per year). The other three farmers deliver the manure by tractor in barrels (1,240 m^3 per year). Finally, the plant also consumes 740 t per year of grass silage.

The biomass goes through a two-stage digestion system, with a residence time of approximately 100 days. After digestion the digestate is stored in a closed storage tank for six months after which it is spread on pasture.

Approximately 270 m^3 per hour of biogas is collected from the digestion system (both stages) and from the storage tank. This is fed to two gas engines to produce electricity (4.03 GWh per year) and heat (7.2 GWh per year), but only 1.3 GWh per year heat is actually used. This results in an electricity conversion efficiency of 37% and an overall efficiency of 49%. If all the heat were used then the combined efficiency would reach 75%.

The maize used for biogas in the study system is, in the reference system, used for animal feed. Therefore, production of equivalent animal feed must be included in the study system. To supply this feed in the study system, additional fertiliser is applied to achieve increased yield of maize, and the remainder is supplied through imported soya feed.

Reference system: The reference system has two key differences to the study system. First, electricity is generated in a 500 MW natural gas closed cycle power plant and the heat is supplied by oil and wood boilers.

Secondly, in the reference system, the land used is set-aside land (20%) or used to produce maize for animal feed (80%). The set-aside land is mulched once per year to keep the soil properties suitable for future agricultural production. The maize crop residues are composted, and the animal manure is stored then used as fertiliser.

Results: The change in land use on 53 ha of set-aside land to cultivation of maize causes a small increase in SOC totalling 48 tonnes of CO_2 per year, reducing total GHG emissions by 3.4% (Table 7). The biogas plant reduced net GHG emissions by 44% compared with the reference system. Covering the stored digestate before spreading on pasture is important: emissions are 30% higher if the storage is not covered, and 1.9% less biogas is produced.

This study only reported the land use change emissions and the total emissions. To give the reader some idea of the relative contributions from the various stages, an estimate of emissions based on another study in Austria has been provided in Table 7. Typically, emissions from cultivation account for 64% of total emissions in the closed system.

In the case studied, only 17% of the heat generated was used. If the total available heat had been used, then emissions in the reference system would have increased to 930 g CO_2-eq per kWh_{total} and the emissions saved by the biogas plant with closed storage would be 664 grams per kWh_{total}. In this case the emissions from the biogas plant would be 70% less than the reference system. This demonstrates the importance of using as much of the produced heat as possible.

Comparison with literature: Figure 5 shows the typical emissions per total energy output for various energy sources. The results from this study are higher than typically found for biogas combined heat and power systems. The reasons for this difference may be two-fold:

a) in this study the majority of the heat produced is not used; and
b) in this study, most of the biomass comes from dedicated energy crops. This results in higher GHG emissions than biogas systems that use residues as the main feedstock.

This is an example where the timing problem referred to in Chapter 2.2.6 does not occur. Both the growth of dedicated crops (carbon uptake) and the decay of animal manure (avoided carbon emission) take place within roughly the same time span as the carbon emission from burning the 'biocarbon' in the biogas plant. Thus, the full credit of avoiding fossil carbon emission may be attributed to the bioenergy scheme.

4.4 Transportation biofuels

This study evaluated the GHG reduction potential of biodiesel use in Croatia (Task 38 Case Study: GHG Benefits of Biodiesel

Table 7: GHG balances of a biogas-fired combined heat and power system

Item	Units	Reference System	Study System Closed Storage	Study System Open Storage
Emissions				
Land management change	g CO_2-eq/kWh_{total}		-9	-9
Cultivation and harvesting	g CO_2-eq/kWh_{total}	Not calculated	*171*	*171*
All other emissions	g CO_2-eq/kWh_{total}	Not calculated	*105*	*182*
Total	**g CO_2-eq/kWh_{total}**	**473**	**266**	**344**
Emissions saved	**g CO_2-eq/kWh_{total}**		**207**	**129**
	t CO_2-eq/ t_{dry}		**0.29**	**0.18**

Note: values in italics are approximations based on other studies in Austria. They are given only for illustrative purposes.

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* *Task 38 case study by Fijan-Parlov, Liposcak, and Juric, Z. www.ieabioenergy-task38.org/projects/task38casestudies/index1.htm*

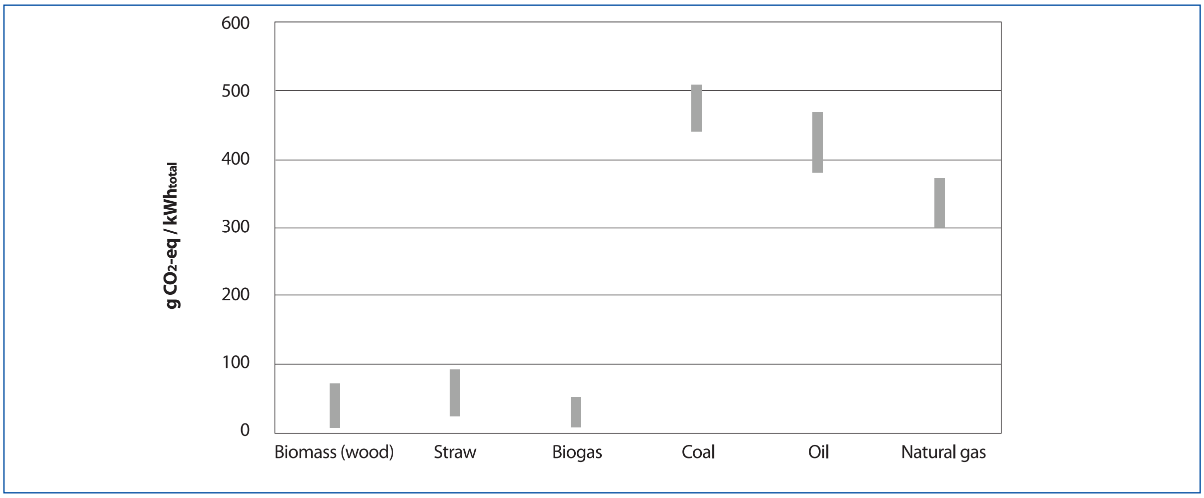

Figure 5. Ranges of GHG emissions for combined heat and power from different sources. Source: World Energy Council. 2004. Comparison of Energy Systems using Life Cycle Assessment, A Special Report of the World Energy Council, London and other sources.

Use in Croatia in the Context of Joint Implementation*). It illustrates that the use of co-products affects the environmental benefits.

Study system: The study system assumes that degraded and underutilised land that currently is set aside is converted to rape production for the production of biodiesel. The biodiesel will be used in public transportation (buses) or in private vehicles (cars) and displace fossil diesel use.

During the biodiesel production process co-products are created, such as rape cake in the process of pressing and glycerine in the process of esterification. The GHG emissions reduction depends strongly on how these co-products are used, and specifically whether they are used as material or energy sources. Two cases were analysed, where the bio-glycerine is used to substitute for either synthetically produced glycerine for material use (such as in the food or pharmaceutical sectors) or for fuel oil in a combined heat and power (CHP) facility.

Reference system: In the reference system, the land is left as set-aside and the buses are fuelled by fossil diesel.

Results: The GHG emission balances for the reference and study systems are shown in Table 8[‡]. No net change in carbon stock in soil is assumed to occur in the conversion of degraded set-aside land to rape production. In the study system, cultivation releases about 56 g CO_2-eq/km emissions from the use of machinery and fertilisers. Fossil fuel required to transport the rapeseed, process the rapeseed into biodiesel, create co-products (glycerine and rape cake), and distribute the biodiesel releases another 255 g CO_2-eq/km. The impact of co-product use is large. The glycerine can be used as an energy product, or as a material (for example, in the food or pharmaceutical sectors). In the former case, emissions saved from using the glycerine for energy amount to 154 g CO_2-eq/km whereas if the glycerine is used as a material there is a credit generated (-200 g CO_2-eq/km, Table 8).

Comparison with literature: Figure 6 shows the ranges of GHG emissions for transportation services for a passenger car fuelled with different energy carriers. The results from the study fit within these ranges. The analyses of bioenergy systems may or may not include direct changes in carbon stocks or indirect land use change. The estimates of GHG emissions from transportation biofuels vary substantially. This wide range is due to the variation in yields, inputs and emissions from agricultural systems in different locations, different feedstocks, and the different energy mixes used in biofuel production plants in different locations. The GHG emissions for 1st generation

Table 8: GHG balances of a rapeseed biodiesel-fuelled car system

Item	Units	Reference System	Study System Closed Storage	Study System Open Storage
Emissions				
Land management change	g CO_2-eq/km	Not applicable	0	0
Cultivation and harvesting	g CO_2-eq/km		56	
Co-products	g CO_2-eq/km		-154	-200
All other emissions	g CO_2-eq/km		255	255
Total	g CO_2-eq/km	**192**	**157**	**111**
Emissions saved	g CO_2-eq/km		**34**	**80**

[‡] *In the original Task 38 Case Study report (Fijan-Parlov et al.), the results are given for biodiesel used in buses only. The values shown in Table 8 have been converted using the relative fuel efficiency of buses and cars so that a comparison with Figure 6 can be made.*

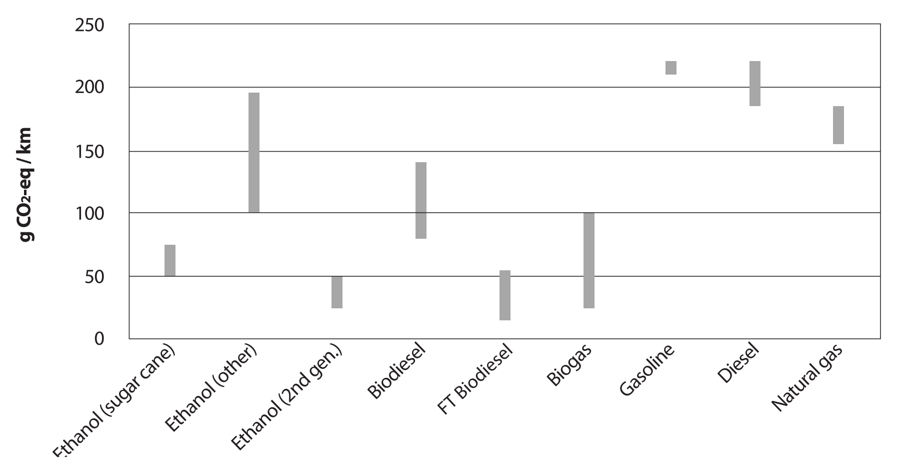

Figure 6. Ranges of GHG emissions for biofuels of different types from a variety of sources used in automobiles. FT = Fischer Tropsch. Values are for cars with average fuel efficiency. Source: Cherubini *et al*. 2009. Energy- and GHG-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. *Resources, Conservation and Recycling*. 53: 434-447.

transportation biofuels are, in general, lower than gasoline and diesel. As shown in Figure 6, 2nd generation transportation biofuels made from wood and straw might reduce GHG emissions by more than 90%.

The IEA Implementing Agreement on Advanced Motor Fuels has commissioned a study *'A Non-Technical Comparison of Life Cycle Analysis Tools for Transportation Fuels'*. This study aims to provide guidance to decision makers on the appropriate uses of LCA , specifically for transportation fuels. The study should be available in the second half of 2011.

5. CONCLUSIONS

LCA is a powerful tool used to quantify the environmental impacts of products and services. It includes all processes from cradle-to-grave along the supply chain of the product or service. LCA can be used to quantify the GHG emission savings of bioenergy, by comparing the bioenergy system with a reference fossil energy system.

However, when reviewing the literature one finds large ranges of GHG emissions per functional unit and emissions saved per functional unit from LCA studies of similar bioenergy systems. The differences occur for a multitude of reasons. For example, the studies may use different technologies, different system boundaries, different reference systems or different methods of allocation or system expansion. Furthermore, some studies are inconsistent in that the bioenergy system and reference system provide different services. Others may not include some sources of emissions (for example, land use change). Since small changes in methodological assumptions and input parameters can have large effects on the estimated environmental impacts, the bioenergy and reference systems should be described and assumptions listed in a transparent manner.

In this paper, the various components of LCA have been discussed with a particular focus on bioenergy systems. The conclusion is that LCA is the tool of choice for quantifying the GHG emissions from, and emissions saved by bioenergy systems. However, to ensure that reliable comparisons are drawn, LCA should be conducted following standard procedures. Generic guidance is given in ISO 14040 and 14044. In this paper more specific guidance is provided on the critical aspects, particularly related to impacts of biomass production and utilisation, that must be considered in undertaking any LCA of bioenergy systems. It is important that the following are considered:

1. LCA is used to quantify the environmental impacts of products or services. It includes all processes, from cradle-to-grave, along the supply chain of the product or service. When analysing the global warming impact of energy systems, GHG emissions (particularly CO_2, CH_4 and N_2O) are of primary concern.
2. To determine the comparative GHG impacts of bioenergy, the bioenergy system being analysed should be compared with a reference energy system, which is usually – but not always – a fossil energy system.
3. A reference energy system should be chosen that is realistically likely to be displaced by the bioenergy system. If this reference system is not certain, then one option is to use as the reference energy system the average fossil energy for that region. Another option is to make a conservative evaluation by comparing the bioenergy system with the best available fossil energy technology. Alternatively, a non-fossil option may be selected as the relevant reference energy system. Depending on the context of the study, this might be another renewable option or nuclear power.
4. The scope of the analysis (system boundary) should include all processes along the value chain with significant GHG emissions, including, where relevant, upstream processes of extraction or biomass production, and end-of-life processes.
5. The system boundary should be defined so that the bioenergy and reference fossil systems provide equivalent products and services. If it is not possible to achieve this through expansion of the system boundary then the GHGs can be shared amongst energy and non-energy co-products of the bioenergy system (such as biodiesel and rapeseed cake, from processing of rapeseed oil), based on their share of physical (for example energy) or financial contributions.
6. Changes in carbon stocks in biomass, soil and landfill, can cause GHG emissions (or removals). These can be very important and should be included in the analysis.
7. In general, LCA is not concerned with the time at which the environmental impacts occur. However, in some cases bioenergy systems cause short-term GHG emissions due

to the accelerated oxidation of carbon stocks through combustion as compared to natural decay. While this can affect short-term GHG targets, over a long-term perspective sustainable bioenergy causes less GHG emissions than comparable fossil energy systems.

8. Use of agricultural residues may affect GHG emissions through either changes in SOC or land use changes that occur indirectly, in order to provide the equivalent services that the residues were providing. Exploitation leading to soil productivity losses may require compensating fertilisation (causing GHG emissions) to maintain yield levels and can also cause cropland expansion elsewhere to compensate for yield losses if these occur.
9. The type of technology, scale of plant, and co-products in both the bioenergy and reference energy system can influence the GHG mitigation benefits of the bioenergy system. Since small changes in methodological assumptions and input parameters can have large effects on the estimated environmental impacts, the bioenergy and reference systems should be described and assumptions listed in a transparent manner.

In the cited case studies, bioenergy systems reduce GHG emissions by between 18% and 128% compared to their counterpart fossil reference systems. Since these studies consider a range of bioenergy technologies and reference systems that have different types of land management change and a variety of uses for co-products, it is difficult to generalise. However, the cited case studies and published LCA studies find that GHG mitigation is greater where biomass is used for heat and electricity applications rather than for liquid transport fuels. The emissions savings from bioenergy systems tend to be similar to those of other renewable energy sources.

6. RECOMMENDED READING

LCA Methodology

Cherubini, F., Bird, N., Cowie, A., Jungmeier, G., Schlamadinger, B. and Woess-Gallasch S. 2009. Energy- and GHG-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations. 2009. Resources, Conservation and Recycling 53: 434-447.

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Timing of Emissions from Land Use Change

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Soil Organic Carbon

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Crop Residues in Bioenergy

Blanco-Canqui, H. and Lal, R. 2007. Soil crop response to harvesting corn residues for biofuel production. Geoderma 355-362.

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CH_4 *and* N_2O *from Agriculture*

Stehfest, E. and Bouwman, L. 2006. N_2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data modelling of global annual emissions, Nutrient Cycling in Agroecosystems, 74: 207-228.

IEA BIOENERGY TASK 38

The primary goal of Task 38 'Greenhouse Gas Balances of Biomass and Bioenergy Systems' is to investigate all processes involved in the use of bioenergy and carbon sequestration systems, with the aim of assessing overall GHG balances and supporting decision makers in selection of mitigation strategies. Participating countries in 2011 are Australia, Austria, Belgium, Brazil, Finland, Germany, the Netherlands, Norway, Sweden, and the USA. For more detailed information on the Task see: http://www.ieabioenergy-task38.org/

Case Studies

Australia	GHG balance of a co-firing system of biomass and a wood fired conversion facility, both based on conventional hardwood plantation forestry.
	Does soil carbon loss in biomass production systems negate the GHG benefits of bioenergy?
Austria	Greenhouse gas benefits of a biogas plant in Austria
Canada	GHG impacts of pellet production from woody biomass in BC, Canada, and transporting them to Europe, USA and Canada substituting fossil fuels.
	GHG balance of a small pyrolysis plant using both sawmill residues and thinnings from a juvenile spacing program to produce bio-oil, used either in a pulp mill limekiln or for export of biofuel
Croatia	Assessment of the GHG emissions-reduction potential of biodiesel production in the context of Joint Implementation
Finland	GHG balances of bioenergy and carbon sequestration projects with links between increased use of construction wood and the use of biomass-fired cogeneration plants, replacing fossil fuels
Ireland	GHG benefits of using municipal solid waste as a fuel in a thermal treatment plant.
	GHG balance of peat use for energy.
New Zealand	Assessment of the GHG balance of a bioenergy cogeneration plant based on the use of sawmill residues
Sweden	GHG balances of bioenergy and carbon sequestration projects with links between increased use of construction wood and the use of biomass-fired cogeneration plants, replacing fossil fuels
Netherlands	Import of wood pellets from Canada and of palm kernel shells from Malaysia to Netherlands for green energy production
UK	GHG balances of *Miscanthus* fuelled biomass projects
USA	GHG emission reduction potential associated with anaerobic digestion plant of organic wastes, California

ACKNOWLEDGEMENTS

For some time the Executive Committee has recognised the need for an unbiased, authoritative statement, on life cycle assessment of the greenhouse gas balance of bioenergy. Accordingly, this strategic report began with a proposal commissioned from the late Dr Bernhard Schlamadinger. He was succeeded as principle author firstly by Dr Gerfried Jungmeier, and then by Mr Neil Bird. The original editorial committee consisted of Dr J. Peter Hall, Dr Josef Spitzer, and the late Mr Larry Russo. This committee subsequently evolved to Dr Josef Spitzer (Convenor), Dr Tat Smith, and Mr Paul Grabowski. Associate Professor Göran Berndes provided some insightful comments during final editing. More recently Tat Smith was appointed Consultant Editor and provided valuable input in finalising the manuscript. The Secretary, John Tustin, organised final editing and publication. In addition, many colleagues made valuable contributions to this report through its various stages. All these contributors are gratefully acknowledged.

IEA Bioenergy

IEA Bioenergy is an international collaboration set up in 1978 by the IEA to improve international co-operation and information exchange between national RD&D bioenergy programmes. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use. Currently IEA Bioenergy has 24 Members and is operating on the basis of 12 Tasks covering all aspects of the bioenergy chain, from resource to the supply of energy services to the consumer.

Further Information

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iea Energy Technology Network

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