

## Consumer perceptions of the environmental sustainability of liquid food packaging: a survey among Danish consumers

**Niero, Monia; Boesen, S.H.; Bey, Niki**

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# SETAC EUROPE 22<sup>nd</sup> LCA Case Study Symposium

Life Cycle Innovation for the Transition to a Sustainable Society

20 – 22 September 2016 | Montpellier, France



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International Reference Centre for the  
Life Cycle of Products, Processes and Services



This book is structured into three parts.

**The first part** provides general information on the SETAC Europe 22<sup>nd</sup> LCA Case Study Symposium, conducted from 20–22 September 2016 at the “Montpellier SupAgro” in Montpellier, France; **the second part** comprises the 3-day programme of the symposium, and **the third part** includes the abstracts of the presentations for the platform and poster sessions. The abstracts are reproduced as accepted by the Scientific Committee and appear in session order. In each abstract, the presenting author’s name is underlined. The author index cross-references the corresponding abstract numbers. Affiliation, session and keyword indices are also included.

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ISSN 2310-3191

# 22<sup>nd</sup> SETAC EUROPE LCA Case Study Symposium

*Life Cycle Innovation for the Transition to a Sustainable Society*

20 – 22 September 2016 | Montpellier, France

The symposium is co-organised by **SETAC Europe** and the two industrial chairs on LCA, the Industrial Chair for Environmental and Social Sustainability Assessment (**ELSA-PACT**) hosted by the French National Research Institute of Science and Technology for Environment and Agriculture – **Irstea**, and the International Life Cycle Chair of the **CIRAIG** hosted by Polytechnique Montréal in Canada.



We gratefully acknowledge the support of:

**Industrial partners:**



**Academic partners:**



**Financial support:**



**Scientific contributor:**



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# WELCOME FROM THE EXECUTIVE DIRECTOR

Dear Participant,



We are delighted to welcome you to the 22<sup>nd</sup> SETAC Europe LCA Case Study Symposium.

The Society of Environmental Toxicology and Chemistry (SETAC) is a not-for-profit, global professional organisation comprised of some 6,000 individual members and institutions from academia, business and government. Since 1979, the Society has provided a forum where scientists, managers and other professionals exchange information and ideas on the study, analysis and solution of environmental problems, the management and regulation of natural resources, research and development, and environmental education. SETAC's founding principles are multidisciplinary, science-based objectivity and tripartite balance among academia, business and government.

SETAC has a strong interest in Life Cycle Assessment and sustainability. The fostering of the LCA case study symposia over two decades, the many LCA and sustainability oriented sessions at the SETAC Annual meetings, the UNEP-SETAC Life Cycle Initiative and the recent Pellston workshop on Life Cycle Impact Assessment held in Valencia, are good indicators of the relevance of Life Cycle thinking for sustainable environmental quality and ecosystem integrity and the involvement of SETAC members in the development of this field.

The theme of this year's meeting is "Life Cycle Innovation for the Transition to a Sustainable Society" and the scientific programme was designed to provide every opportunity to share and learn about business practice, application experiences and challenges, as well as LCA's increasing role in governance, and the latest developments in methodology and teaching of LCA.

On behalf of SETAC I would like to thank the Steering Committee, chaired by Ralph Rosenbaum for drawing up an exciting programme covering a wide range of topics in LCA. Also my sincere acknowledgement to the co-organisers of this meeting, the Industrial Chair ELSA-PACT hosted by IRSTEA, the French National Institute of Science and Technology for Environment and Agriculture as well as the International Life Cycle Chair of the CIRAIG hosted by Polytechnique Montréal in Canada and to the other supporters of this meeting. Last but not least a big thank you to all the presenters at this meeting. By sharing your results and views we can work together on our mission «Environmental Quality Through Science®».

I wish you a fruitful and pleasant symposium. I hope that it will help you to establish new networks or build on existing ones and find new alleys to implement LCA towards a sustainable environment.

**Bart Bosveld, Executive Director**

SETAC Europe

# WELCOME FROM THE MEETING CHAR AND CO-CHAIR

A cordial welcome to Montpellier!

It is with great pleasure and anticipation that we welcome you to the gracefully Mediterranean city of Montpellier for the 22<sup>nd</sup> SETAC Europe LCA Case Study Symposium, which promises to be one of this year's essential events for the LCA community, gathering experts, practitioners, scientists, and policymakers from business, academia, government and NGOs. The SETAC Europe LCA Case Study Symposia are a classic series of annual meetings focusing on LCA application and development that were held since the early 1990s all over Europe. Following this tradition, the scientific programme of its 22<sup>nd</sup> edition was designed to provide plenty of opportunities to share and learn about business practice, application experiences and challenges, LCA's increasing role in governance and the latest developments in methodology and teaching of LCA.

This conference with the overarching theme of "Life Cycle Innovation for the Transition to a Sustainable Society" attracted over 170 abstracts from more than 20 countries on three continents, resulting in more than 130 oral presentations and 40 posters scheduled in 17 sessions with three parallel tracks. We would like to extend our gratitude to the members of the scientific committee for their availability to review abstracts and dedication in supporting the development of the scientific programme of the symposium. The sessions are covering subjects as diverse as emerging technologies, agriculture, buildings, water, transport, energy supply and storage, recycling, PEF, ecodesign, resource management, LCA of large-scale systems like cities or regions, life cycle management, policy evaluation, LCIA modelling, uncertainty, teaching LCA, or social LCA and life cycle sustainability assessment. The conference programme is complemented by two high-profile keynote speakers, Prof. Emer. Roland Clift from University of Surrey, UK and Dr. David Pennington from the European Commission. Conference-events include two evenings of social gathering and a water footprint workshop on ISO 14046 and the new AWARE method recommended by UNEP-SETAC and the PEF / ILCD guidelines.

The symposium is co-organised by SETAC Europe and the two industrial chairs on LCA, the Industrial Chair for Environmental and Social Sustainability Assessment (ELSA-PACT) hosted by the French National Research Institute of Science and Technology for Environment and Agriculture – Irstea, and the International Life Cycle Chair of the CIRAIIG hosted by Polytechnique Montréal in Canada.

Intending to walk the talk, special attention was paid to organising this conference with environmental and social sustainability principles in mind. To name a few examples: We chose a food supplier focusing on local and seasonal ingredients with a strong social commitment concerning employees, dedicated to limiting/avoiding food waste. The congress bags are reusable as apron and were produced by a local workshop employing persons with disabilities. The plastic glass included with the conference bag is reusable, avoiding disposable plastic cups during the event and thus reducing waste. Experts from Quantis evaluated the environmental footprint of the conference in a dedicated study and will present their results at the event.

On behalf of the organising committee we cordially welcome you to the 22<sup>nd</sup> SETAC Europe LCA Case Study Symposium 2016. We hope that you will be inspired and stimulated by these three conference days and the accompanying events, gaining new perspectives and ideas, meeting old friends and building new collaborations triggering Life Cycle Innovation for the Transition to a Sustainable Society.



**Ralph K. Rosenbaum**  
ELSA-PACT

French National Research Institute of Science and  
Technology for Environment and Agriculture – Irstea



**Manuele Margni**  
CIRAIIG

Polytechnique Montréal



# ORGANISING AND SCIENTIFIC COMMITTEE

The symposium is co-organised by **SETAC Europe** and the two industrial chairs on LCA, the Industrial Chair for Environmental and Social Sustainability Assessment (**ELSA-PACT**) hosted by the French National Research Institute of Science and Technology for Environment and Agriculture – **Irstea**, and the International Life Cycle Chair of the **CIRAIG** hosted by Polytechnique Montréal in Canada.

## Local Organising Committee

Ralph Rosenbaum, Lucie Lemagnen and Michele Egea from Irstea/ELSA-PACT.

## Scientific Committee

- Ralph Rosenbaum, Irstea, France (Chair)
- Manuele Margni, CIRAIG, Canada (Co-chair)
- Philippe Roux, Irstea, France
- Tomas Rydberg, IVL, Sweden
- Alessandra Zamagni, ENEA, Italia
- Alexis Laurent, DTU, Denmark
- Paolo Masoni, ENEA, Italia
- Guido Sonnemann, Université de Bordeaux, France
- Anne-Marie Boulay, CIRAIG, Canada
- Montse Nunez, Irstea, France
- Enrico Benetto, LIST, Luxemburg
- Annie Levasseur, CIRAIG, Canada
- Heinz Stichnothe, Thünen Institute, Germany
- Arnaud Helias, INRA, SupAgro, France
- Eleonore Loiseau, Irstea, France
- Gert Vanhoof, Procter & Gamble, Belgium
- Christian Bauer, SIG International Services GmbH, Germany
- Philippe Osset, SCORE LCA, France
- Urs Schenker, Nestlé, Switzerland
- Guy Castelan, Plastics Europe, Belgium
- Sebastian Zinck, Steelcase, France
- Stephane Morel, Renault, France
- Andreas Ciroth, GreenDeltaTC, Germany
- Peter Saling, BASF, Germany
- Serenella Sala, European Commission– JRC, Italia

## Process and general organisation

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B-1060 Brussels, Belgium  
+32 (0)2 772 72 81  
veerle.vandevreire@setac.org  
**setac.org**





## SETAC: Global and local

The Society of Environmental Toxicology and Chemistry (SETAC) is a not-for-profit, global professional organisation established in 1979 to provide a forum for individuals and institutions engaged in education, research and development, ecological risk assessment and life cycle assessment, chemical manufacture and distribution, management and regulation of natural resources, and the study, analysis and solution of environmental problems. SETAC is an open and democratic organisation that operates in a broad social context, reflecting the needs of the environment and people. Application of sound science plays a key role in this process. Membership worldwide comprises around almost 6,000 professionals in the field of chemistry, toxicology, biology and ecology; atmospheric, health and earth sciences; and environmental engineering.

## SETAC Europe

SETAC Europe is one of the five Geographic Units (GU) of the global Society, established to promote and undertake activities of SETAC in Europe and to support the activities of SETAC in the Middle East and Russia. As a GU, we share the mission of SETAC: To support the development of principles and practices for protection, enhancement and management of sustainable environmental quality and ecosystem integrity.

SETAC Europe is dedicated to the use of multidisciplinary approaches to examine the impacts of stressors, chemicals and technology on the environment. SETAC Europe is incorporated in Belgium as a not-for-profit organisation. The Society is governed according to its articles of association and bylaws. SETAC Europe maintains its administrative office in Brussels, Belgium. SETAC Europe is governed by a volunteer council, elected by the general membership at the Annual General Assembly. The General Assembly convenes every year during the SETAC Europe Annual Meeting. SETAC Europe organises congresses, symposia and workshops on a wide range of environmental topics, offers professional education and recently established a certification programme for environmental risk assessors.

For more information on SETAC and its activities, please visit [setac.org](http://setac.org).

## About Irstea



Irstea, the National Research Institute of Science and Technology for Environment and Agriculture, is a Public Scientific and Technical Research Establishment (EPST) falling within the purview of the ministries of research and agriculture. Its multidisciplinary, action-oriented approach to research and expertise in support of public policy involves strong partnerships with French and European universities and research organisations, economic entities and public authorities. The Institute is a founding member of AllEnvi, the National Alliance for Environmental Research, and the European PEER (Partnership for European Environmental Research) network. Irstea has the «Carnot Institute» label since 2006.

The Industrial Chair ELSA-PACT is hosted by Irstea, the French National Research Institute of Science and Technology for Environment and Agriculture, is a Public Scientific and Technical Research Establishment (EPST). Since more than 30 years, Irstea (formerly Cemagref) works on major issues of responsible agriculture and territories sustainable planning, water management and related risks, like drought, floods, inundations, biodiversity and complex ecosystems study in their interrelation with human activities.

Multidisciplinary research, appraisal and support to “agri-environmental” public policies, partnership with territorial authorities and actors of the economic world, such are the characteristics of Irstea, qualified “Carnot Institute”. In the continuity of the research model of Cemagref, every day our researchers and engineers put a lot of themselves into their mission: to take up the challenge of global change comprehension for a sustainable and environmentally friendly development.

For more information, visit: [irstea.fr](http://irstea.fr)





# Tools designed for you to evaluate the environmental and social impacts of your company

## OUR UNIQUENESS

ELSA-PAC's singularity lies in its close collaboration between the academic sector and its industrial partners in the field of Life-cycle assessment (LCA) whose objectives are to conduct research on the actual needs and constraints which the industrial sector encounters.



## 5 Activities

- Diffusion of methods and results
- Training
- Research: Access to leading-edge research
- International bodies: Access to the latest advances
- Applications: new software application developed at partners request

www.acv4e.irstea.fr  
ADEME2015  
Trophy laureate



## Our Methods & Results

- Collective definition of research framework
- Skills development
- Turn your company into a case for study and applicability

## Our objectives

Increase corporate environmental and social performance on the basis of the Life-cycle assessment (LCA) method, in an effort towards a sustainable society.

## Join the chair, an asset for your company


To be competitive, adapt, stand out in a competitive world whilst providing the assurance of sustainable products and services.


Benefit from environmental and social tools recognised socially.

Gain strategic advantages and reap the benefits from an international scientific environment.


Satisfy your training needs.

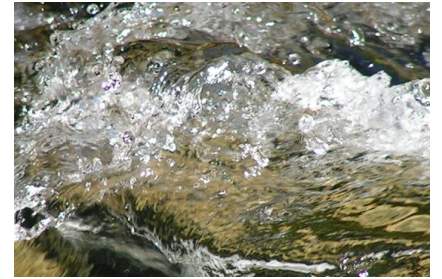
## Our partners testify

"SCP strives to participate in the development of knowledge on the ecological impact of water supply." 

"LCA is an essential and relevant tool which enables us to develop innovative technologies suitable for our professions, and to best manage our activities and our facilities, as they are integrated in their own territories." 

"LCA opens the way to new perspectives: to improve our tools and, on a wider scale, studies on environmental effects as well as the valuation of the impact of water resources" according to the wide range of its uses. Our group aims to continually offer top-performance tools and support public policies on territorial planning." 

"With a view to evaluate the different possible strategic scenarios, according to such criteria as the environment, social equity, economic efficacy, we do need tools to be reliable, extensive and scientifically proven, such as LCA". 



## Industrial Chair programme

Launched by the ANR Agency for National Research, this program promotes collaboration between research bodies and the industry so that research is closely linked to the needs and real constraints of the industry.

<b>COORDINATOR</b> Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture	<b>ACADEMIC PARTNERS</b> 	<b>CO-LABELING</b> 
<b>INDUSTRIAL PARTNERS</b> 	<b>FINANCIAL PARTNERS</b> 	<b>OUR CONTACT INFO</b> Chaire industrielle ELSA PACT IRSTEA 361 rue JF Breton BP 5085 34196 Montpellier - FRANCE Contact : lucie.lemagnen@irstea.fr Tél. 00 33 4 99 61 24 89

## FOLLOW US !



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Chaire ElsaPact

[www.elsa-pact.fr/language/en/](http://www.elsa-pact.fr/language/en/)



# CIRAIG<sup>MC/TM</sup>

The CIRAIG, a reference in  
life cycle sustainability assessment

[www.ciraig.org](http://www.ciraig.org)

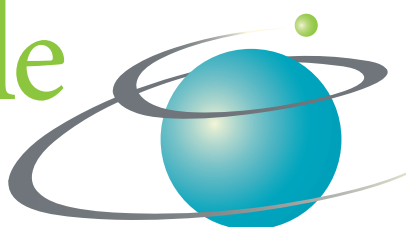
Do we still have time to make  
bad decisions?

Embracing complexity • Creating opportunity  
Together towards sustainability

Come join us in Montreal this October for CYCLE 2016!

5<sup>th</sup> INTERNATIONAL FORUM ON THE LIFE CYCLE MANAGEMENT OF PRODUCTS AND SERVICES

2016  
Cycle



Polytechnique Montréal  
Montréal, Canada  
October 13-14, 2016  
[www.ciraig.org/en/cycle2016.php](http://www.ciraig.org/en/cycle2016.php)

## Young Scientist Award Life Cycle Assessment



Anders Bjørn is the winner of the 2016 SETAC Europe Young Scientist LCA Award, sponsored by AG and Springer Nature. The SETAC Europe LCA Steering Committee recognises Anders for his comprehensive work on introducing absolute sustainability perspective into LCA and his efforts to broaden the adoption of life cycle thinking outside of the scientific community. Anders Bjørn has received the award at the 26<sup>th</sup> SETAC Europe Annual Meeting last May in Nantes, France.

Anders finished his PhD in 2015 at the Technical University of Denmark. His research focused on the development of indicators for absolute environmental sustainability in a life cycle perspective. He made original and important scientific contributions during his PhD, with many peer reviewed publications and his work led to a new research field in LCA. Much of his research has been presented in the latest four SETAC conferences.

Anders is also known as an excellent communicator both within and outside the LCA community. He engaged with different stakeholders in Denmark to increase the understanding of sustainability and life cycle thinking and as such has been acting as an ambassador for the LCA community. We congratulate Anders with this award and wish him a fruitful continuation of his activities.

## SETAC Europe EDANA Award for Life-Time Achievements in Life Cycle Assessment



Angeline de Beaufort is selected as the sixth recipient of the SETAC Europe / EDANA «Award for Life-time Achievement in Life Cycle Assessment».

Angeline has been very active in the past 20 years at the European Corrugated Board industry. Under her leadership, FEFCO and CEPI were among the pioneers to provide regular updates on LCI datasets for corrugated board materials. FEFCO was also one of the first associations to develop a software tool which simplifies and standardises the complex process of data collection. Angeline is very well recognised for her experience with LCA databases, as recently demonstrated with her position in the Ecoinvent 3 editorial board as expert for the manufacture of paper & paper products.

Angeline took also a very active role in SETAC. She was member of the SETAC LCA screening and streamlining working group and one of the driving forces behind the SETAC working group on Life Cycle Inventory. The work of this latter group was published in 2003 in a SETAC Code of Life Cycle Inventory Practice. Initiatives like this were key to the development of new LCI databases, such as Ecoinvent. Angeline chaired the SETAC Europe LCA Steering Committee between 2004 and 2006.

At the international level, Angeline was also active within the UNEP SETAC Life Cycle Initiative to provide input from her rich experience with LCA databases. She was one of the authors of the Global Guidance Principles for Life Cycle Assessment Databases, published in 2011. In summary, Angeline has a strong legacy of promoting the adoption of LCA into daily practice both within her industry work as well as through her collaboration at the international level in SETAC and UNEP. We congratulate her with this well-deserved award.

## SETAC Europe Life Cycle Assessment Advisory Group

The SETAC Europe LCA Advisory Group is aimed at advancing the science, practice, and application of LCAs to reduce the resource consumption and environmental burdens associated with products, packaging, processes, or activities. It serves as the focal point of a broad-based forum for the identification, resolution, and communication of issues regarding LCAs. Moreover, it facilitates, coordinates, and provides guidance for the development and implementation of LCAs, in collaboration with the LCA North America and, more recently, also with other societies that address the life cycle concepts in an interdisciplinary way. This is achieved by means of a series of initiatives that includes, among others, the planning and organization of LCA session at the annual meeting and conferences, such as the LCA Case Study Symposium.

Since 2011, the SETAC Europe LCA Advisory Group has been joining the Global Coordinating Group (GCG), established as a mechanism for communication between the regional Advisory Groups in Europe and North America and to allow the other Geographic Units to have representation in global SETAC LCA affairs. The mission of the LCA Global Coordinating Group within SETAC is to encourage and coordinate regional Advisory Group efforts to advance the science, practice, and application of LCAs and ensure that a global perspective is maintained toward the achievement of LCA Advisory Group objectives.

## LCA Advisory Group Steering Committee

- Ralph Rosenbaum (LCA CSS chair 2014; Irstea ELSA-PACT, France)
- Thomas Rydberg (LCA SC chair; Ivl Swedish Environmental Research Institute, Belgium)
- David Cockburn (AB Tetra Pak, Sweden)
- Gert van Hoof (Procter & Gamble Services, Belgium)
- Paolo Masoni (ENEA, Italy)
- Igor Budak (LCA CSS chair 2015; University of Novi Sad, Serbia)
- Sara Palander (Secretary; CPM-Swedish Life Cycle Centre, Sweden)
- Serenella Sala (SETAC Council member; European Commission - Joint Research Centre, Italy)
- Jean-Florent Campion (L'Oréal Research and Innovation, France)
- Heinz Stichnothe (Vice Chair; Thünen Institute, Germany)
- Cécile Bessou (CIRAD, France)
- Joost Dewaele (Procter & Gamble, Belgium)
- Roland Hischier (EMPA, Switzerland)
- Nicole Unger (University of Natural Resources and Life Sciences Vienna, Austria)
- Michele de Rosa (Aarhus University, Student representative, Denmark)





# INTENDING TO WALK THE TALK

In order to render our event more sustainable, the organisers and Quantis have teamed up to conduct a Life Cycle Assessment (LCA) of the event. A LCA of the event will give us a better understanding of the real environmental impacts of the conference - both during the preparation phase and during the conference - by quantifying the environmental footprint of the event. The environmental assessment will also serve to raise awareness for this initiative to all of our stakeholders.

The scope of the study is as large as possible, including all activities linked to the SETAC CSS 2016: Transportation, accommodation, logistics, catering, waste, publications and printed material, security, procurement, HQ operations. During the conference, a special emphasis will be placed on food waste.

The results of the LCA will also help manage the preparation and the running of the event by identifying the major levels of improvements.

The results of the LCA will be presented during the conference.

Quantis' is a global reference for environmental assessment and sustainability strategy of events and has worked on the following major events :

- \* Rio 2016 Olympic and paralympic games carbon footprint & offsetting
- \* Sustainability reporting and LCA of the UEFA EURO EURO 2016 championship
- \* LCA of the new FIA world championship for electric cars (Formula-E), held in Paris in 2016, and sustainability consulting based on a life cycle approach
- \* Involvement into the sustainable management of mega events Expo Milano 2015
- \* Environmental assessment of the UEFA Champions League Final in 2013
- \* Carbon footprint and management of the theme « Environment and Meteorology » of the bid committee of Annecy 2018 Olympic games candidacy



The symposium will be held at:

**SupAgro**

**Montpellier SupAgro**  
**2 place Pierre Viala**  
**34060 Montpellier Cedex 02**

**Tel : +33 (0)4 99 61 22 00**

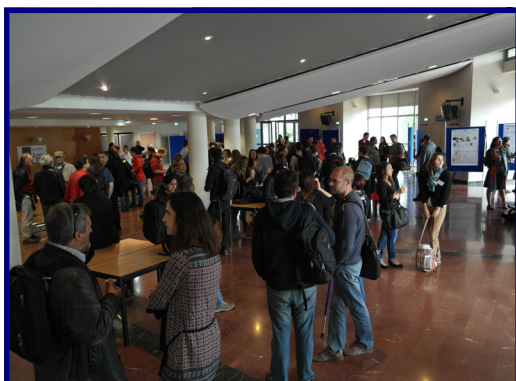
**Fax: +33 (0)4 99 61 29 00**



Montpellier SupAgro counts 1,669 students, 88 teacher-researchers and 321 staff members. It offers a full range of training courses from Bachelor (professional) degree to PhD, as well as several excellent engineer training curricula.

Its main purpose is initial and continuing training, research, international scientific and technical cooperation, and development represent the main missions. Agriculture, food, environment and rural territories are at the heart of its concerns.

It is located close to the centre of Montpellier.



# HOW TO GET TO SUPAGRO

## By road

Montpellier is linked to Paris by the A9 and A75 Motorways (around 700 km). It is also linked to Italy, Spain and Switzerland.

## Local Transportation

### Tramway & buses

You can buy tickets at the automatic distributors available at each tramway station. To buy passes, go to TaM office, next to railway station. Fares are:

One-way fare: 1.50€

1-day pass: 4€

7-day: 15.60€

10 ride pass: 10€

Tickets can be bought in the automatic distributors available at each tramway station.

There is a bus station in front of the entrance of SupAgro (Bus 6 - La Gaillarde).

The tramway "ligne 1", decorated in blue with white swallows, connects the northern part of the city with the odysseum terminal on the southeast side. The "ligne 2", decorated in a flower-power theme, goes from east to west. The colorful "ligne 3", designed by the famous fashion designer Christian Lacroix, goes from west to east, arriving near the seaside at Perols. From there, you can rent a bike or take a short walk (around 20 minutes) to get to the beach. The golden "ligne 4", also designed by Christian Lacroix, serves only downtown. Some 30 bus lines are connected to the tramway lines to offer a comprehensive network that will transport you around Montpellier.

### Véломagg' bicycle service

To take full advantage of our beautiful weather and gentle environment, stop by one of the city's numerous bike stations and pick up a bike to ride around. You'll feel truly free meandering through town and along 150 km of bicycle paths. The Véломagg' service offers bicycles just the way you want them: Available and inexpensive.

For your riding pleasure, 50 automatic bike stations with over 2,000 bicycles are available in Montpellier and Agglomération area. Service is open 24/24, 7/7.

All you need is personal identification and you can rent a bicycle to ride the streets of the city and outlying area. You can buy tickets at the Esplanade bike station (next to Montpellier Tourist Office).

A vélomag bicycle station is available in front of the entrance of SupAgro.

### Taxis

Tram Taxi: +33 4 67 58 10 10

Blue Taxi: +33 4 67 03 20 00

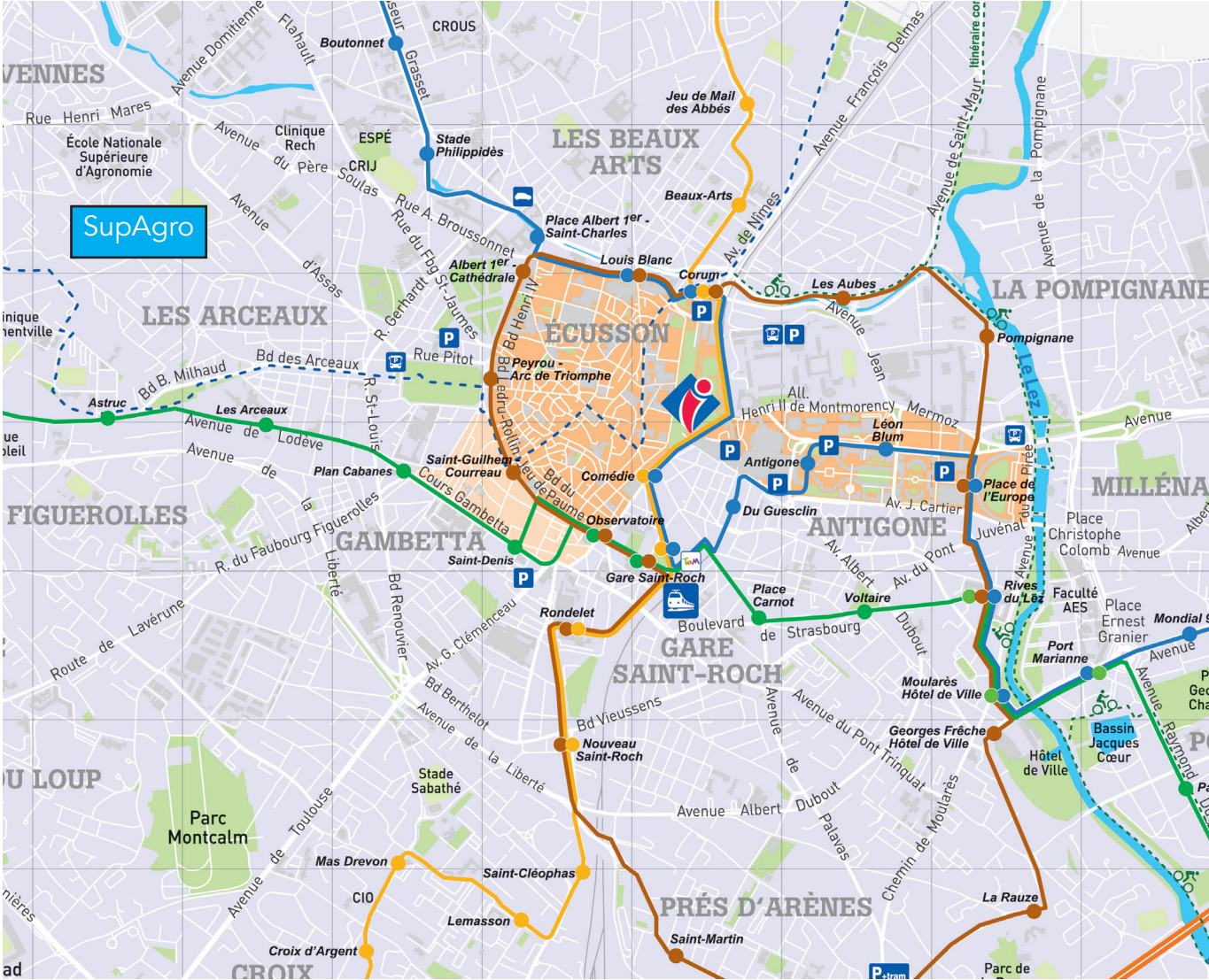
Radio du Midi Taxi: +33 4 67 10 00 00

Languedoc Taxi: +33 4 67 10 03 04

2000 Taxi: +33 4 67 04 00 60

Also available upon call, or at the railway station, or the Comedie station.

Location Map



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# PROGRAMME OVERVIEW

For day by day programme overview, see pages 38–46

## Monday 19 September, 18:30–22:00: WELCOME RECEPTION (Hall)

	Tuesday 20 September			Wednesday 21 September			Thursday 22 September		
	Amphi- théâtre Lamour	Salle du Conseil	Salle A	Amphi- théâtre Lamour	Salle du Conseil	Salle A	Amphi- théâtre Lamour	Salle du Conseil	Salle A
8:30	Opening session (Amphithéâtre Lamour)			Session 7	Session 9 (I)	Session 11	Session 14	Session 16 (I)	Session 17 (I)
8:50									
9:10									
9:30									
9:50									
10:10	Coffee Break (Hall)			Coffee Break (Hall)			Coffee Break (Hall)		
10:40	Session 1 (I)	Session 2 (I)	Session 4	Session 8 (I)	Session 9 (II)	Session 12	Session 15	Session 16 (II)	Session 17 (II)
11:00									
11:20									
11:40									
12:00									
12:20	Lunch Break + Poster Session (Hall)			Lunch Break + Poster Session (Hall)			Lunch Break + Poster Session (Hall)		
13:30	Session 1 (II)	Session 2 (II)	Session 5	Session 8 (II)	Session 9 (III)	Session 13 (I)	Closing session (Amphithéâtre Lamour)		
13:50									
14:10									
14:30									
14:50									
15:10	Coffee Break (Hall)			Coffee Break (Hall)					
15:40	Session 1 (III)	Session 3	Session (can- celled)	Session 8 (III)	Session 10	Session 13 (II)			
16:00									
16:20									
16:40									
17:00									
17:20	Poster + Drinks (Hall)			Poster + Drinks (Hall)					
	Guided tour + Wine tasting 19:00 – 21:00			Banquet 19:00 – 23:00 (Conference dinner)					

## Friday 23 September, 8:50–12:20: SHORT COURSE WATER FOOTPRINT (Building 21, Salle Ferguson)

The poster session runs from 20 September (8:00) till 22 September (15:00) in the Exhibition Hall.

## Sessions

1. Closing the loop: A sustainable use of resources
2. LCIA modelling of resources and emissions - new developments and applications
3. Special session: UNEP-SETAC Flagship project on global LCIA harmonisation and recommendation: Case studies and application results from the Pellston Workshop in January 2016
4. Environmental Footprint of Products and Organizations: first insights from PEF and OEF applications
5. Special session: LCA for policy evaluation and policy-making
6. Special session: Application of Social LCA in industry - from methodology to practice (*cancelled*)
7. Implementation of the land use framework into LCA practice
8. LCA for agriculture: Food, bio-material, bio-energy, including aspects of water use, land use, handling of pesticides, carbon accounting, end-of-life modelling
9. LCA of urban water systems from resources to users: water withdrawal, water treatment & distribution, water use, wastewater sanitation and reuse
10. LCA and uncertainties: How to deal with uncertainties in LCA studies and their interpretation?
11. Passenger and freight transport: On the road to a more sustainable mobility system?
12. Teaching LCA in high level education systems (universities and continuous education)
13. Energy: Conversion, supply and storage systems
14. LCA and LCM in industrial sectors, including public disclosure and reporting of sustainability metrics
15. Innovation through design of more sustainable systems: Eco innovations arising from LCA
16. Life Cycle Sustainability Assessment of Emerging Technologies
17. LCA of large-scale systems - from urban to national scale including territorial LCA, urban metabolism and their nexus with circular economy



## Professor Roland Clift CBE FREng from University of Surrey, UK



Emeritus Professor of Environmental Technology and founding Director of the Centre for Environmental Strategy at the University of Surrey; previously Head of the Department of Chemical and Process Engineering at the University of Surrey and past Executive Director and President of the International Society for Industrial Ecology. He is Visiting Professor in Environmental System Analysis at Chalmers University (Sweden), Adjunct Professor in Chemical and Biological Engineering at the University of British Columbia (Canada) and Visiting Professor in Industrial Ecology at the University of Coimbra (Portugal).

Roland is a past member of the UK Eco-labelling Board, of the Royal Commission on Environmental Pollution (RCEP), the Science Advisory Council of Defra, the Royal Society/Royal Academy Working Group on nanotechnology, the Working Group which drafted and updated the BSI/Defra/Carbon Trust standard on carbon labelling (PAS 2050), and of Rolls-Royce' Environmental Advisory Board. In 2004-5, he acted as Expert Adviser to a House of Lords Select Committee enquiry into energy efficiency. He was a contributing author and Review Editor for the 5<sup>th</sup> Assessment Report of IPCC (2014). His research is concerned with system approaches to environmental management and industrial ecology, including life cycle assessment and energy systems.

## Dr. David Pennington from the JRC/European Commission



Dr. David Pennington is a Principle Scientist of the European Commission. He is Project Leader for Raw Materials in the Directorate General Joint Research Centre (JRC), in the Land Resources Unit of the Sustainable Resources Directorate. Key activities include supporting the development of the European Knowledge Base on Raw Materials, in particular the Raw Materials Information System (RMIS), as well as the EU Raw Materials Scoreboard, Critical Raw Materials assessment, and supply chain assessment of raw materials. Dr Pennington has a PhD from the Hong Kong University of Science and Technology in

Chemical Engineering and a B.ENG from the University of Surrey. He worked in the United States Environmental Protection Agency and the Ecole Polytechnique Fédérale de Lausanne (EPFL). He's been on the Editorial Board of the International Journal of Life Cycle Assessment as well as of the Journal of Industrial Ecology.

## Short Course: Introduction to Water Footprint, ISO 14046 and AWARE Method

**Instructor:** Anne-Marie Boulay, CIRAI - Ecole Polytechnique de Montréal, Canada

**Description:** The course will cover the basic of the water footprint concepts, the evolution in time, the content of the ISO standard 14046 as well as several case studies examples. In terms of impact assessment methods, focus will be given to the new consensus-based methodology, AWARE, from the WULCA (water use in LCA) group of the Life Cycle Initiative for water scarcity footprint. Application and interpretation will be covered.

**Public:** Anyone interested in learning the basics principles of water footprint, the content and interpretation of the ISO standard 14046, as well as discover the new consensus based method for water scarcity footprint recommended by the Life Cycle Initiative as well as the JRC for the PEF upcoming update.

**When and where:** Friday 23 September | 8:50 –12:20 | Building 21, Salle Ferguson



## Opening session

Tuesday 20 September | 8h30 – 10h10 | Amphithéâtre Lamour

### Welcome by:

- Bart Bosveld (SETAC Europe Executive Director)
- Ralph Rosenbaum (Chair) and Manuele Margni (Co-chair)

### Presentation of:

- Local organisers ELSA (Arnaud Hélias), ELSA-PACT (Ralph Rosenbaum), Irstea (Véronique Bellon-Maurel)
- SETAC LCA Steering Committee (Tomas Rydberg)

**Environmental footprint** of the symposium by Quantis (Marcial Vargas-Gonzalez)

**Keynote** Prof. Emer. Roland Clift: “From incremental improvement to ecological limits: How might the Planetary Boundaries approach be applied in Life Cycle Assessment?”

## Closing session

Thursday 22 September | 13h30 – 15h10 | Amphithéâtre Lamour

**Keynote** Dr. David Pennington: “Meeting the knowledge needs of business and policy: The case of raw materials”

Final results for the **environmental footprint** of the symposium (Quantis)

### Closing remarks by:

- Ralph Rosenbaum (Chair) & Manuele Margni (Co-chair)
- Bart Bosveld (SETAC Europe Executive Director)



## **Session 1: Closing the loop: A sustainable use of resources**

*Co-chairs: Lucia Rigamonti, Monia Niero, Tomas Rydberg*

Tuesday 20 September, 10:40 - 17:20

Many initiatives have developed in order to address the issue of scarce resource management both at national and international level with the aim to cause a shift towards a resource-efficient economy. As reported in the recent communication by the European Commission "Closing the loop - An EU action plan for the Circular Economy", the overall objective of resource efficiency can be achieved only through the implementation of circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized. According to the waste management hierarchy adopted at the European Union level in accordance with the Directive 2008/98 on waste, disposal is the least preferable option. Waste prevention is at the top of the waste hierarchy, followed by preparing for re-use. Recycling and other recovery (e.g. energy recovery) are the following steps. The idea under this hierarchy is that waste should be treated as a resource. A sustainable waste management should thus consider waste as a source of material and energy that may contribute towards alleviating pressure on scarce natural resources. As such, waste presents opportunities for development of green and circular economy- inspired solutions.

In this session we look for contributions that deal with the application of Life Cycle Assessment (LCA) to solid waste technologies, treatments and systems, to solid waste prevention, to product/technology innovations which use waste as resource for producing products, and to the use of resources in continuous loops. All the different kinds of solid waste (e.g. municipal solid waste, construction and demolition waste, plastic fractions, packaging waste, waste of electrical and electronic equipment, and food waste) are of interest. As sustainability integrates economic, social and environmental aspects, studies that take into account all the three pillars of sustainability by applying different tools and modelling approaches are very welcome. Cases of industrial symbiosis analyzed based on the life cycle thinking concept may also be considered. Moreover, besides case studies, papers that address the methodological issues associated with the modelling of e.g. re-use and recycling activities and waste prevention actions are really appreciated, as well as on the quantification of the benefits from recycling and circularity of resources.

The objective of the session is to share information regarding: approaches for conducting life cycle sustainability assessment of waste prevention activities, waste treatments and management, and innovations which use waste as material resource, recommendations for different regions and situations, and consensus on approaches for modeling the different treatment units and activities and for measuring the efficiency of end-of-life options.

## **Session 2: LCIA modelling of resources and emissions - new developments and applications**

*Co-chairs: Montse Núñez, Manuele Margni*

Tuesday 20 September, 10:40 - 15:10

Life cycle impact assessment (LCIA) methods have evolved a lot in the last few years. State-of-the-art LCIA methods are more environmentally relevant than their predecessors in terms of impact pathway coverage, spatial and temporal differentiation, and application of modelling approaches (e.g., non-linear responses), among other improvements.

One of the pitfalls of the gain in methods robustness usually is the difficulty in everyday life operationalization with which LCA practitioners are confronted. This session welcomes abstracts on new LCIA characterization frameworks and methods of resources and emissions as well as case studies showing applicability of these recent LCIA methods.

The goal of the session is to create a platform of exchange between method developers from academia and LCA practitioners from industry and environmental consulting in order to allow for mutual learning of the latest available LCA characterization methods and identify challenges to face in operationalization.

The studies presented in this session can include: impact assessment methods ready-to-use or still under (advanced) development, strategies to cope with increased inventory data intensiveness, development of simplification schemes of applicability of complex LCIA methods, experiences of application and interpretation of results of new LCIA methods in complete LCA studies.

### **Session 3: Special session: UNEP-SETAC Flagship project on global LCIA harmonisation and recommendation: case studies and application results from the Pellston Workshop in January 2016**

*Chair: Anne-Marie Boulay*

Tuesday 20 September, 15:40 - 17:20

In late January 2016 a Pellston Workshop™ on “Global Guidance for Life Cycle Impact Assessment Indicators and Methods” was held in Valencia, Spain. The goal of the workshop was to reach consensus on recommended environmental indicators and characterisation factors for Life Cycle Impact Assessment (LCIA) in the areas of global warming, particulate matter emissions, water use impacts (both scarcity and human health impacts), land use impacts on biodiversity as well as overall LCIA framework and crosscutting issues.

Several practical recommendations on environmental indicators, including substantial innovations, were formulated (available at [www.lifecycleinitiative.org](http://www.lifecycleinitiative.org)). This session shows case studies applying these recommended methods.

### **Session 4: Environmental Footprint of Products and Organizations: First insights from PEF and OEF applications**

*Co-chairs: Gert Van Hoof, Serenella Sala, Guy Castelan*

Tuesday 20 September, 10:40 - 12:20

Life cycle thinking (LCT) adoption into EU policy development is established for a long time with LCAs supporting the selection of EU ecolabel criteria. New domains for LCT implementation into policy were explored in France a few years ago with the Grenelle decree and most recently the EU launched a pilot program to evaluate the feasibility of Product Environmental Footprints (PEF) and Organizational Environmental Footprints (OEF). These initiatives aim at communicating LCA information on products to help consumers make more informed decisions when they buy products, much like they may use nutritional information for food products. The EU PEF and OEF pilot projects started in 2013 and will finish end 2016. As such, there is a first basis of experience from the application of the PEF/OEF methodology and communication of results. We aim for case studies which share insights from actual pilot studies, but we also invite practitioners who applied the PEF guidance to their case studies.

## Session 5: Special session: LCA for policy evaluation and policy-making

Co-chairs: *Serenella Sala, Paolo Masoni*

Tuesday 20 September, 13:30 - 15:10

Life cycle thinking (LCT) and LCA have a high potential to be used more extensively in supporting policy making, from problem definition up to policy impact assessment and policy implementation.

However, when the object of the assessment is moving from products and services to systems and macro-scale, several improvements are needed in order to benefit the most from the LCA application. This requires to reflect upon current and future challenges for LCA within the policy domain.

The session on LCA and policy builds on this reasoning and provides an overview of the current level of adoption of Life Cycle Thinking and LCA in the European context. Then, the role of LCA in specific policies is highlighted, such as the circular economy package and the Ecodesign directive. Moreover, LCA could be useful for assessing the results of policy and interventions, e.g. in terms of resource efficiency and reduction of environmental burdens.

## Session 6: Special session: Application of Social LCA in industry - from methodology to practice *(cancelled)*

Co-chairs: *Alessandra Zamagni, Andreas Ciroth*

Tuesday 20 September, 15:40 - 17:20

The role of industry for fostering growth and competitiveness to sustain the economy recovery is largely recognized. And to mainstream competitiveness, it is also acknowledged that low prices and low quality are not the way forward: the competitive advantage of industry in the world economy has to be based on goods and services with high value added, and on an efficient management of the value chains, among others. A modern and sustainable industry is the key to an industrial renaissance for growth and employment.

To achieve these goals, scientifically robust and practical methods and tools are necessary to evaluate the performance of organisations and their improvement potential. While environmental and economic life cycle-based methods have already proven their ability to satisfy this need, from the social point of view, developments are necessary in the field of Social Life cycle Assessment (SLCA). SLCA is growing rapidly, and many new approaches have been proposed regarding i.e. development of impact pathways, performance reference points, inclusion of values in SLCA, how to address positive impacts, and frameworks for SLCA, to mention just a few. In addition, the development of databases on social indicators and risks is also providing an invaluable support for making SLCA practicable and meaningful, but the full operability of the method is not achieved yet. How to reconcile the urgencies of actions and interventions in the industrial context with ongoing methodological developments in SLCA? Several organisations have already dealt with this question, and proposed practical but robust approaches, as demonstrated by the initiative The Roundtable for Social Metrics.

This special session is open to contributions that discuss the application of SLCA in the industrial context, and investigate the approaches proposed for dealing with social issues in increasingly rich and complex value chains, engaging with stakeholders, the tools developed or used to support the social assessment, the data management and quality, and the assessment of both positive and negative aspects.

## **Session 7: Implementation of the land use framework into LCA practice**

*Co-chairs: Anthony Benoist, Cecile Bessou, Aurelie Tailleux, Vincent COLOMB*

Wednesday 21 September, 08:30 - 10:10

Since the end of the 1990s, taking into account the environmental effects of land use and land use changes has been identified as a key issue for the environmental assessment of agricultural and forestry systems. For 20 years, LCA researchers have worked on defining a conceptual framework to consider land use into LCA studies, mapping the related environmental mechanisms, and developing some characterisation models. Currently, LCIA methods such as ReCiPe endpoint or ILCD midpoint include models to assess the land use impacts on Biodiversity Damage Potential (BDP) and Biotic Production Potential (BPP). Nevertheless, the implementation of the land use framework into LCA practice is still work in progress. The ILCD handbook from 2011 rated the characterisation model for BPP as «recommended but to be applied with caution» and the one for BDP as «too immature to be recommended». Furthermore, LCA practitioners generally faced issues with a low availability of characterisation factors adapted to the initial goal and scope of their LCA studies.

This proposed session is dedicated to LCA practitioners and users who experienced understanding or practiced gaps, when assessing land use impacts. Presentations for this session should include LCA case studies dealing with land use impact assessment and research studies aiming at improving the implementation of the land use framework into LCA practice. Presentations investigating links with land use impact and other impact categories should be also fostered in order to seek for harmonisation with other research fields, e.g. on soil quality, salinization. These presentations and the following discussions will allow for gathering feedback from practitioners and policymakers on the difficulties and the solutions to collect the data needed for land use impact assessment, to develop and implement site-specific characterisation factors, and to interpret the related LCA results. Note that studies dealing with quantification of land use occupations and transformation, as e.g. studies about indirect land use change, are out of the scope of this session.

## **Session 8: LCA for agriculture: food, bio-material, bio-energy, including aspects of water use, land use, handling of pesticides, carbon accounting, end-of-life modelling**

*Chair: Montse Núñez, Assumpció Anton, Cécile Bessou*

Wednesday 21 September, 10:40 - 17:20

Agriculture is not only a significant contributor to greenhouse gas emissions, but also to many other environmental impacts related to the consumption and pollution of water, pesticides and fertilizers use, and food waste reduction and management. Although LCA is increasingly adapted to evaluate agricultural systems, many methodological challenges still remain unresolved. Furthermore, new ways of food production and consumption are expanding in recent years as alternatives to global food chains, such as short food supply chains and collaborative networks. The potential advantages of innovative agricultural systems are still not well documented, neither environmentally, nor socially and economically.

This session welcomes abstracts that: propose guidelines and methodological improvements dealing with LCA and agricultural systems; case studies that re-evaluate traditional farming systems by means of new LCA methodological advancements as well as evaluation of new agrifood systems and comparison to conventional systems. The abstracts presented may deal with: food, bio-materials, bio-energy, including aspects of water use, land use, handling of pesticides and fertilizers, carbon accounting, end-of-life modelling, organic vs traditional farming, multifunctionality of agriculture (i.e., combination of social, economic, environment, nutrition impacts).

## **Session 9: LCA of urban water systems from resources to users: Water withdrawal, water treatment & distribution, water use, wastewater sanitation and reuse**

*Co-chairs: Almudena Hospido, Lluís Corominas, Ywann Penru, Philippe Roux*  
Wednesday 21 September, 08:30 - 15:10

In a context of awareness of global change and water scarcity, water management in cities faces many challenges, which are linked to water resources, water users and water technologies. Decision makers require tools to assess the environmental impacts of urban water systems (UWS) and thereby compare different water resources (surface-water, groundwater, sea or rain water) and different technological solutions including infrastructure, operation and maintenance, for water and wastewater treatment. Holistic approaches are required to evaluate all components of the system in an integrated way and life cycle assessment (LCA) is more and more used for that purpose in the water community. The proposed session is dedicated to share case studies, experiences and new developments in the use of LCA for urban wastewater systems (UWS). It can include all applications related to water withdrawal, tap water treatment and distribution, water use phase (domestic, industry, agriculture...), wastewater treatment and water reuse, as well as guidelines and methodological improvements when applying LCA to water and wastewater systems.

The studies presented within the session can be: Water resource oriented Water technologies oriented:

- Application of recent developments in LCIA methods for water impacts assessment.
- LCA for the management of water resources and as a tool to support water public policy.
- Case studies using the newest consensual indicator AWARE from the Wulca working group.
- LCA studies as well as carbon and/or water footprints of urban water systems
- Eco-design of water technologies including solving the water-energy nexus using LCA.
- Comprehensive Life Cycle Inventory (LCI) including detailed construction and operation of water systems.
- Case studies focused on industrial applications.
- Uncertainty management in UWS LCAs Integrated approaches mixing both aspects (resources & technology) are also welcome

## **Session 10: LCA and uncertainties: How to deal with uncertainties in LCA studies and their interpretation?**

*Chair: Ralph Rosenbaum, Enrico Benetto, Lucia Rigamonti*

Wednesday 21 September, 15:40 - 17:20

Currently, the quantification and communication of uncertainty in Life Cycle Assessment (LCA), in both inventory and impact assessment, is usually omitted, firstly due to a lack of guidance in uncertainty modelling, and secondly because practitioners face hundreds of potentially relevant parameters that might change the result of a study, yet it is often unclear which aspects really matter and in what way. Addressing these issues, this session focuses on the integration of uncertainty management into daily LCA practice.

It explores approaches to estimate, communicate, visualise and interpret any kind of uncertainty information in LCA and its inclusion in decision-making. Identification and quantification of main sources of uncertainty in all stages of an LCA is a special point of interest; all with the ultimate goal of minimising resources needed to perform uncertainty analysis in LCA. Not the least, strategies for uncertainty reduction are certainly of interest in this context. LCA case studies, where uncertainty was consistently considered, are welcome to be presented focusing on the approaches and interpretations applied to uncertain aspects. Uncertainty information routinely reported for LCA results will improve trust and confidence in the method as users and decision makers will be provided with measures of confidence in the result, enabling for example to differentiate between compared options with scores that are essentially equal (revealed by overlapping uncertainty ranges) or well distinguishable. It will also provide a measure of confidence for impact indicators, as a smaller uncertainty range indicates a higher stability of the indicator, e.g. global warming potentials are likely to be considerably more certain than toxicity indicators. Communication and interpretation of uncertainty in LCA can improve its acceptance on the level of decision-making as it provides a measure of confidence in the decision suggested by an LCA result and might even seed continuous improvement of life cycle approaches as uncertainty information will point out weak (~uncertain) points in the methodology or single studies, and thus add to the transparency of LCA.

This session explicitly invites all stakeholders from developers to practitioners and decision-makers to present and discuss their views, experiences and ideas related to practical uncertainty management in LCA.



## **Session 11: Passenger and freight transport: On the road to a more sustainable mobility system?**

*Co-chairs: Christian Bauer, Andrea Del Duce*

Wednesday 21 September, 08:30 - 10:10

Today, passenger and freight transport are causing substantial environmental burdens contributing to global warming and negative impacts on human health due to emission of pollutants such as NO<sub>x</sub> and particulate matter. Inhabitants of large urban areas are suffering from bad air quality, partially due to exhaust emissions of vehicles. New energy carriers and technologies - battery and fuel cell electric vehicles, biofuels, autonomous driving, freight ships supported by wind energy, etc. - are in development and intend to reduce the environmental burdens of our current traditional transport system. At the same time, conventional vehicles are getting more energy-efficient and also cleaner. Innovations are not limited to new technologies: Also alternative ways of structuring our daily life (working at home, web-based collaboration, new ways of spatial planning, etc.) have potential to reduce mobility related burdens. Even if there is a considerable amount of LCA literature concerning conventional and alternative transport technologies, large uncertainties and gaps in knowledge still exist (Hawkins et al. 2012, Del Duce et al. 2014, Nordelöf et al. 2014, Bauer et al. 2015). This session aims at a comprehensive coverage of mobility related LCA, both in terms of assessment of individual technologies as well as mobility and transport systems.

Submissions addressing the following issues are encouraged:

- Environmental performance of conventional vs. innovative fuels and vehicles
- Environmental performance of potential future technologies including fuel chain related aspects
- Environmental consequences of autonomous driving
- Noise-related impacts
- Regionalization, both in inventory data and impact assessment
- Environmental consequences of re-thinking our mobility behavior
- Consequential studies addressing both short- and long-term aspects
- Effects of large-scale introduction of new technologies and new mobility patterns
- Consideration of behavioral aspects including rebound effects

Analyses of further aspects in the context of LCA of transport and mobility not listed here are also appreciated.

## **Session 12: Teaching LCA in high level education systems (universities and continuous education)**

*Co-chairs: Ralph K. Rosenbaum, Alexis Laurent*

Wednesday 21 September, 10:40 - 12:20

Sustainability and sustainable development are core issues in the centre of attention of our society and thus in our education systems. With an increasing number of quantitative and qualitative tools available, teaching sustainability and more specifically LCA and its principles in higher education is perceived as an important part of solutions towards a sustainable future and an important task of teachers and researchers active in this area. The complexity of related science and mechanisms, especially the broad and systemic approach required, poses numerous challenges which are rarely discussed among LCA (education) experts, but are essential to providing future engineers, scientists and leaders with a common understanding. Teaching LCA is an essential element to ensure its best use and usefulness, and also to enable future users to identify and avoid its misuse and pitfalls. Many aspects of sustainability have found their way into teaching at universities and continuous professional education, and many scientists are actively engaged in this process. This session aims to provide a platform for exchange of experiences, methods, and inspiration regarding the teaching of LCA and sustainability in a broader sense on the university level, and continuous professional education.

## **Session 13: Energy: Conversion, supply and storage systems**

*Co-chairs: Christian Bauer, Karin Treyer*

Wednesday 21 September, 13:30 - 17:20

Energy conversion and supply are often decisive factors in life cycles of products and services determining their environmental profiles. Moreover, the energy sector as such is one of the most important contributors to environmental burdens on local, regional, and global scales. The current trend towards renewable energy supply, often relying on intermittent generation technologies such as wind turbines and photovoltaic modules, will lead to a partial mismatch between actual supply and demand and can destabilize the electricity network. Energy storage can be a viable solution to counterbalance supply and demand and to guarantee stability of supply. Furthermore, some energy storage technologies allow for a transformation of energy carriers. Despite of the long tradition in LCA of energy conversion and supply, several challenges and opportunities exist. LCA literature on energy storage - especially for stationary applications - is scarce. Only batteries for battery electric vehicles have been decently addressed, with large uncertainties remaining.

This session shall cover the complete spectrum of energy related LCA (conversion, supply and storage) including both the technology and the energy system levels. We are encouraging (but are not limiting the session to) submissions dealing with the following issues:

- Data sources for creation of inventories related to energy technologies: What are the challenges of finding accurate, representative and consistent data and their use for energy related LCI?
- New/upcoming technologies: Case studies addressing important technology-specific gaps in the literature.
- Methodological aspects concerning LCA of energy storage: reference flows, functional units, system boundaries, application scenarios.
- Environmental benefits and potential drawbacks of energy storage as part of energy supply systems: local, regional, national and international application scenarios.
- Regionalization of LCA: What are the difficulties, benefits and potential drawbacks in the energy sector?
- Complexity vs. simplification: Which benefits and drawbacks come along with increasing differentiation of electricity sector LCI data?
- Integrated environmental and economic assessments of energy conversion, supply and storage, combining LCA and LCC.
- Attributional and consequential LCA modeling: What are challenges and benefits of these two approaches in the energy sector?
- Use of energy system LCA in energy and environmental policies: How can LCA be integrated into energy system models and other tools (or vice versa) in order to provide policy recommendations?

## **Session 14: LCA and LCM in industrial sectors, including public disclosure and reporting of sustainability metrics**

*Co-chairs: Gert Van Hoof, Guido Sonnemann*

Thursday 22 September, 08:30 - 10:10

Life cycle assessment (LCA) and life cycle management (LCM) are key tools to drive industry and business towards more sustainable business practices. They can be used for hotspot identification, internal decision making, benchmarking with competition, marketing and consumer communication, as well as to interact with stakeholders and shareholders. In this session, we welcome contributions that illustrate innovative applications of LCA and LCM in industry and business. In particular, we would like to see how these LCA and LCM have generated value for companies, and the society in which they operate. Contributions describing applications of LCA or LCM to communicate along the supply chain, including to consumers, as well as public reporting of sustainability metrics using LCA are encouraged.

## **Session 15: Innovation through design of more sustainable systems: Eco innovations arising from LCA**

*Co-chairs: Alessandra Zamagni, Paolo Masoni, Enrico Benetto, Wladimir Motta*

Thursday 22 September, 10:40 - 12:20

Starting from the principle that eco-innovation aims at reducing environmental impacts of a product or a service, LCA directly addresses this goal and can help pointing out where improvements are possible, bringing greater environmental benefits. This session aims to present case studies where such interrelation between LCA and eco-innovation occurs. Presenters are invited to share concrete examples of business success stories using LCA.

## **Session 16: Life Cycle Sustainability Assessment of Emerging Technologies**

*Co-chairs: Coen Van der Giesen, Valentina Prado, Jeroen Guinee*

Thursday 22 September, 08:30 - 12:20

For the development of new technologies it is important to have insights in the potential sustainability impacts as early as possible in the technology development cycle. For the assessment of these future impacts it is crucial to take a life cycle approach which introduces methodological challenges. As an example; the application of LCA to assess the environmental impacts of an emerging technology encounters the following issues:

First, conventional LCA assesses products, technologies and services on an industrial or commercial scale while emerging technologies are often not beyond lab or pilot plant scale. The challenge is to obtain data that is representative for the intended scale of use when data acquired from lab or pilot plant scales is unrepresentative for industrial or commercial scale systems.

Second, conventional LCA performs current and steady state assessments while emerging technologies are still under development and will be implemented in the future, sometimes even 20 -30 years from now. The challenge here is two-sided: how will a technology perform in 20-30 years' time when it will be implemented and in addition; how will the future system or context of the technology look like? It seems that using basic life cycle inventory data for the background system is not suitable to perform these assessments.

Third, the development of new technologies often also introduces new substances or materials (f.e. nanotechnology, GMO). Current impact assessment methods are not equipped to deal with these substances and new methods relying on risk assessments will take years to be develop before they can be used in LCA.



This session welcomes case studies in which a life cycle approach is applied to assess the sustainability (environmental, economic, social or combinations) impacts of emerging technologies and aims to share the experience on dealing with the methodological challenges that show up in doing so.

## **Session 17: LCA of large-scale systems - from urban to national scale including territorial LCA, urban metabolism and their nexus with circular economy**

*Co-chairs: Eleonore Loiseau, Serenella Sala, Alessandra Zamagni*

Thursday 22 September, 08:30 - 12:20

Although LCA has been traditionally product-oriented, recent proposals have been made to broaden its object of analysis by studying larger scale systems. There are increasing LCA case studies implementing at city, regional or even national scales. Introducing life cycle thinking and assessment is highly desirable for supporting decision making at different scales and ensuring a holistic approach in the transition of our societies towards sustainability. Decision makers need quantitative tools to pinpoint drivers of environmental impacts, linking them with sustainable production and consumption patterns occurring in specific local/regional contexts. Moreover, several eco-innovations (e.g. those related to the concept of circular economy) are to be planned considering the territorial dimension, and including their environmental performances. Hence, the proposed session is dedicated to share case studies and experiences in the use of LCA for large-scale systems. It can include all applications related to sustainable production and consumption at regional/national scales, LCAs of territory and city metabolism, prospective land planning scenario comparisons, or industrial ecology case studies. Guidelines and methodological developments on these new approaches are also highly encouraged

The studies presented within the session can include:

- LCA studies of large-scale systems (nations, regions, territories, cities).
- Use of input-output LCAs and hybrid LCAs to compute comprehensive inventories for consumption and production activities.
- Spatially explicit LCA and use of GIS tools for territorial LCAs.
- Consequential life cycle assessment of large scale, territorial-based policies.
- LCA as a tool to support land planning policies, including integration with other methodologies (e.g. risk assessment, environmental impact assessment of project and plans, etc.).
- Case studies focused on circular economy and industrial ecology.



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# PROGRAMME Monday 19 and Tuesday 20 September

**MONDAY 19 SEPTEMBER: WELCOME RECEPTION | 18:30–22:00 | HALL OF AMPHITHÉÂTRE LAMOUR**

**TUESDAY 20 SEPTEMBER: OPENING SESSION | 8:30–9:50 | AMPHITHÉÂTRE LAMOUR**

**TUESDAY 20 SEPTEMBER: ORAL PRESENTATIONS | 10:40–12:20**

Room	Amphithéâtre Lamour	Salle du Conseil	Salle A
Session	<b>Closing the loop: A sustainable use of resources (I)</b> Lucia Rigamonti, Monia Niero, Tomas Rydberg	<b>LCIA modelling of resources and emissions - new developments and applications (I)</b> Montserrat Pineda, Manuele Margni	<b>Environmental Footprint of Products and Organizations: first insights from PEF and OEF applications</b> Gert Van Hoof, Serenella Sala, Guy Castelan
10:40	1   Implications of synergetic indirect effects and increased flexibility for municipal solid waste management within future framework conditions. <u>Ciprian Cimpan</u> (University of Southern Denmark, Denmark)	6   Environmental Water Requirements (EWRs) indicator proposal to address local and temporal climate variability: development and testing on 72 USA rivers. <u>Andrea Loss</u> (University of Padua, Italy)	11   Learnings from a supporting study of New Zealand Dairy Product Environmental Footprinting. <u>Sandra Payen</u> (AgResearch, New Zealand)
11:00	2   Sustainability analysis through life cycle assessment: over the only environmental impacts. Application at the case study: Integrated waste management system in Baalbek (Lebanon). <u>Rosangela Spinelli</u> (Alma Mater Studiorum University of Bologna, Italy)	7   Challenges and opportunities in balancing water needs for humans and ecosystems through LCA. <u>Mattia Damiani</u> (IRSTEA Montpellier, France)	12   Made Green in Italy: a voluntary labelling scheme based on PEF. <u>Paolo Masoni</u> (ENEA, Italy)
11:20	3   LCA of inert construction and demolition waste management strategies in Lombardy region, Italy. <u>Lucia Rigamonti</u> (Politecnico di Milano, Italy)	8   Towards assessing impacts of water degradation on water resources. <u>Charlotte Pradinaud</u> (IRSTEA Montpellier, France)	13   Product Environmental Footprint (PEF): Communicating uncertainties related to data quality. <u>Omar Amara</u> (VITO NV, Belgium)
11:40	4   Comparing the impact of actual WEEE recycling practice with the legal minimum recycling and recovery rates at an Austria recycling company. <u>Nicole Unger</u> (BOKU University Vienna, Austria)	9   Including the hydrological cycle through a multimedia assessment of water flows in water consumption LCIA modelling. <u>Montserrat Pineda</u> (IRSTEA Montpellier, France)	14   Embedding Sustainable Strategy into Innovation: L'Oréal's Product Assessment Tool. <u>Francois Witte</u> (Quantis, France)
12:00	5   An assessment of resource conservation in WEEE management from a life cycle perspective: a case study of E-scrap recycling in Belgium. <u>Ha Tran</u> (Ghent University (UGent), Belgium)	10   LCIA of fisheries: a comparison of the available methods for resource use assessment. <u>Juliette Langlois</u> (Université Paul-Valéry Montpellier 3, France)	15   Combination of OLCA and EMS: OES2 - Organization Environmental Sustainability System. <u>Andrea Loss</u> (University of Padua, Italy)

! Check the addendum sheet for last updates

# PROGRAMME Tuesday 20 September

## TUESDAY 20 SEPTEMBER: ORAL PRESENTATIONS | 13:30–15:20

Room	Amphithéâtre Lamour	Salle du Conseil	Salle A
Session	<b>Closing the loop: A sustainable use of resources (II)</b> Lucia Rigamonti, Monia Niero, Tomas Rydberg	<b>LCIA modelling of resources and emissions - new developments and applications (II)</b> Montserrat Pineda, Manuele Margni	<b>Special session: LCA for policy evaluation and policy-making</b> Serenella Sala, Paolo Masoni
13:30	16   Challenges in LCA modelling of multiple loops for aluminium cans. <u>Monia Niero</u> (Technical University of Denmark, Denmark)	21   Assessing the environmental impacts of integrated weed management strategies in pasture systems using LCA. <u>Aaron Simmons</u> (NSW DPI, Australia)	26   Life cycle thinking and assessment supporting European policies: an overview. <u>Serenella Sala</u> (European Commission - Joint Research Centre, Italy)
13:50	17   Creating an LCA end-of-life approach taking into account all the benefits of material-loops. <u>Marcial Vargas Gonzalez</u> (Quantis, France)	22   Missing induced dinitrogen monoxide emissions in LCA. <u>Arnaud Helias</u> (Montpellier SupAgro, France, Metropolitan)	27   LCA in assessing the efficiency of Circular Economy Policies. <u>Tomas Rydberg</u> (IVL Swedish Environmental Research Institute, Sweden)
14:10	18   Closing the loop: feasibility of new approaches for assessing resources conservation in anthropogenic systems. <u>Luca Zampori</u> (European Commission - Joint Research Centre, Italy)	23   The zinc paradox - a problem for USEtox-based indicators of national chemical footprints? <u>Rickard Arvidsson</u> (Chalmers University of Technology, Sweden)	28   Effects of European regulation and eco-design analysis on environmental impacts from domestic appliances: The case of vacuum cleaners. <u>Alejandro Gallego Schmid</u> (The University of Manchester, United Kingdom)
14:30	19   Closing the loop: feasibility of new approaches for assessing resources conservation in anthropogenic systems. <u>Jachym Judl</u> (Finnish Environment Institute Finland)	24   Advancing the impact assessment of releases of nanomaterials: combining the USEtox and the SimpleBox4Nano models. <u>Beatrice Salieri</u> (EMPA, Switzerland)	29   Evaluation of Resource Efficiency in Research and Innovation Projects: Challenges and Recommendations of the MEASURE project for Industry. <u>Sophie Sfez</u> (Ghent University, Belgium)
14:50	20   When logistics is significant for closing loops: A sensitivity analysis of distance and transport alternatives for different types of livestock manure. <u>Marta Torrellas</u> (IRTA, Spain)	25   Towards a consideration of operating orbits of the outer space into a new LCIA resource framework. <u>Thibaut Maury</u> (University of Bordeaux, France)	30   Life cycle assessment for policy-making: Case of the human health impacts from national NMVOC emissions in the EU-27 between 2000 and 2010. <u>Alexis Laurent</u> (Technical University of Denmark, Denmark)





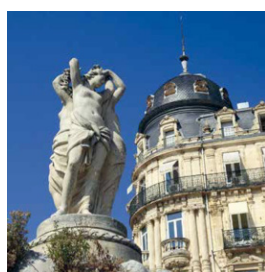
# PROGRAMME Tuesday 20 September

## ORAL PRESENTATIONS | 15:40–17:20

\* Alternative timings

Room	Amphithéâtre Lamour	Salle du Conseil	Salle A
Session	<b>Closing the loop: a sustainable use of resources (III)</b> Lucia Rigamonti, Monia Niero, Tomas Rydberg	<b>Special session: UNEP-SETAC Flagship project on global LCIA harmonisation and recommendation: Case studies and application results from the Pellston Workshop in January 2016</b> Anne-Marie Boulay*	<b>Special session: Application of Social LCA in industry - from methodology to practice</b> Alessandra Zamagni, Andreas Ciroth
15:40	31   Residues allocation and uncertainty analysis in carbon footprint estimation of cement production in Brazil. <u>Ana C B Passuello</u> (UFRGS - Federal University of Rio Grande do Sul, Brazil)	Short Introduction to AWARE. <u>Anne-Marie Boulay</u> (CIRAIG - Ecole Polytechnique de Montreal, Canada)  36   <b>15:50</b> Water footprint profile of virgin and waste cooking oils: assessing freshwater degradation and comparing the WSI and the AWARE methods to address scarcity impacts. <u>Carla Caldeira</u> (University of Coimbra, Portugal)	41   Cancelled
16:00	32   Estimating avoided environmental impacts of rare earth production through rare earth recycling from NdFeB magnet material. <u>Rita Schulze</u> (Öko-Institut e.V., Germany)	37   <b>16:07</b> Calculating the Water Scarcity Footprint using AWARE: The case of a Volkswagen car. <u>Yasmine Emara</u> (Technische Universität Berlin, Germany)	42   Cancelled
16:20	33   Identifying indirect effects of primary production of rare earth elements in consequential LCA. <u>Guido Sonnemann</u> (University of Bordeaux, France)	38   <b>16:24</b> Application of AWARE to bottled water and beverages. <u>Sébastien Humbert</u> (Quantis, Switzerland)	43   Cancelled
16:40	34   Renewable feedstocks - Fuels vs. Chemicals context. <u>Ananda Kumaran Sekar</u> (SABIC Research & Technology Private Ltd., India)	39   <b>16:41</b> Water scarcity footprint for green HDPE. <u>Yuki Hamilton Onda Kabe</u> (Braskem, Brazil)	44   Cancelled
17:00	35   Life cycle environmental impacts of carbon fibre recycling and reuse in automotive applications. <u>Fanran Meng</u> (The University of Nottingham, United Kingdom)	40   <b>16:58</b> Rate of climate change vs. long-term warming: Application of the revised climate change impact assessment method to a biogas power plant. <u>Carine Lausset</u> (NTNU University, Norway)	45   Cancelled

## GUIDED TOUR AND WINE TASTING | 19:00–21:00



## ORAL PRESENTATIONS | 8:30–10:20

Room	Amphithéâtre Lamour	Salle du Conseil	Salle A
Session	<b>Implementation of the land use framework into LCA practice</b> Anthony Benoist, Cecile Bessou, Aurelie Tailleux, Vincent Colomb	<b>LCA of urban water systems from resources to users: water withdrawal, water treatment &amp; distribution, water use, wastewater sanitation and reuse (I)</b> Almudena Hospido, Iluis corominas, Ywann Penru, Philippe Roux	<b>Passenger and freight transport: On the road to a more sustainable mobility system?</b> Christian Bauer, Andrea Del Duce
8:30	46   Global land demand in the future: Food, feed, energy and forestry. <u>Lorie Hamelin</u> (SDU, Denmark)	51   Integration of freshwater impact in lifecycle assessment of three water technologies. <u>Ryle Gejl</u> (DTU (Technical University of Denmark, Denmark)	56   Default transport model for products produced and consumed in Switzerland. <u>Tereza Levova</u> (ecoinvent Centre, Switzerland)
8:50	47   Characterization factors development at a land management practice level: Learnings from a forestry case study for land use impact assessment on climate change. <u>Anthony Benoist</u> (CIRAD, France)	52   Up to what point the impacts associated to the supply of 1m <sup>3</sup> of tap water are different in contrasted locations? <u>Susana Leão</u> (IRSTEA Montpellier, France)	57   Environmental assessment of the introduction of light-weight materials in the passenger-car fleet: feasibility and relevance of consequential LCA. <u>Mélanie Guiton</u> (CRP Henri Tudor, Luxembourg)
9:10	48   Spatial trends in soil erosion and runoff potential: Is it relevant to discriminate between crop-specific land use in a LCA context? <u>Manuele Margni</u> (CIRAIG - École Polytechnique de Montréal, Canada)	53   LCA of loss reduction scenarios in drinking water networks including uncertainty management. <u>Laureline Catel</u> (IRSTEA Montpellier, France)	58   Comparative LCA of traditional versus electric vehicles in urban area: does the car size influence the results? <u>Pierpaolo Girardi</u> (RSE SpA, Italy)
9:30	49   Capturing the benefits of responsible forestry practices in LCA: Focus on biodiversity. <u>Sebastien Humbert</u> (Quantis, Switzerland)	54   LCA of softening water with nanofiltration integrating the effects at the domestic users. <u>Philippe Loubet</u> (Bordeaux INP, France)	59   Social and economic indicators integration toward a holistic consequential Life Cycle Assessment : Application to a Bus Rapid Transit project in France. <u>Anne de Bortoli</u> (Ecole des Ponts ParisTech, France)
9:50	50   Using LCA to assess impacts of maintaining Natural Capital in agricultural systems: A case study of soil organic carbon as a metric in cropping systems of Central NSW, Australia. <u>Aaron Simmons</u> (NSW DPI, Australia)	55   LCA of softening water with nanofiltration integrating the effects at the domestic users. <u>Eva Risch</u> (IRSTEA Montpellier, France)	60   LCA of polyurethane aircraft seating cushion. <u>Bert Käbisch</u> (FraunhoferInstitut für Chemische Technologie ICT, Germany)



# PROGRAMME Wednesday 21 September

## ORAL PRESENTATIONS | 10:40–12:20

Room	Amphithéâtre Lamour	Salle du Conseil	Salle A
Session	<p><b>LCA for agriculture: food, bio-material, bio-energy, including aspects of water use, land use, handling of pesticides, carbon accounting, end-of-life modelling (I)</b> <u>Montserrat Pineda</u>, <u>Anton Assumpcio</u>, <u>Cecile Bessou</u></p>	<p><b>LCA of urban water systems from resources to users: water withdrawal, water treatment &amp; distribution, water use, wastewater sanitation and reuse (II)</b> <u>Almudena Hospido</u>, <u>Iluis corominas</u>, <u>Ywann Penru</u>, <u>Philippe Roux</u></p>	<p><b>Teaching LCA in high level education systems (universities and continuous education)</b> <u>Ralph Rosenbaum</u>, <u>Alexis Laurent</u></p>
10:40	<p>61   Soil Organic Carbon, climate change, and soil quality: a mapping of existing methods for LCA. <u>Anthony Benoist</u> (CIRAD, France)</p>	<p>66   Assessing wastewater treatment in Latin America and the Caribbean: Enhancing life cycle assessment interpretation by regionalization and impact assessment sensibility. <u>Manuele Margni</u> (CIRAIG - École Polytechnique de Montréal, Canada)</p>	<p>71   Life cycle assessment - practice and reporting (LCA-PR): experiences from developing, teaching and further developing an LCA course for Industrial Ecology master students. <u>Coen Van der Giesen</u> (Leiden University, Netherlands)</p>
11:00	<p>62   Life Cycle Assessment of energy crops: the importance of site -specific nitrogen emissions. <u>Heinz Stichnothe</u> (Thünen Institute, Germany)</p>	<p>67   Removing phosphorus from wastewater: Influence of treatment method. <u>Stefano Longo</u> (Universidad de Santiago de Compostela, Spain)</p>	<p>72   Experiences from the use of web-based audience engagement systems in an LCA classroom. <u>Bo Weidema</u> (International Life Cycle Academy, Spain)</p>
11:20	<p>63   Life cycle assessment of bioethanol from date waste in Tunisia. <u>Antoine Esnouf</u> (Institut National de Recherche Agronomique, Narbonne-France, France, Metropolitan)</p>	<p>68   Are wastewater treatment plant construction inventories from Ecoinvent up to date? <u>Iluis Corominas</u> (ICRA, Spain)</p>	<p>73   Making Life Cycle Assessment accessible for engineering students as well as professional occasional practitioners : what are the priorities? Example of urban planning in France. <u>Anne de Bortoli</u> (Ecole des Ponts ParisTech, France)</p>
11:40	<p>64   Sustainability Issues in the Food-Energy-Water Nexus in the UK dairy sector: Energy and Water Consumption. <u>Angelina Frankowski</u> (The University of Manchester, United Kingdom)</p>	<p>69   LCI model and tool for chemicals discharged down the drain. Case study on detergent formulations. <u>Ivan Muñoz</u> (2-0 LCA consultants, Denmark)</p>	<p>74   Teaching management of sustainable innovation in emerging technologies. <u>Stig Olsen</u> (Technical University of Denmark, Denmark)</p>
12:00	<p>65   An analysis on how switching to a more balanced and naturally improved milk would affect consumer health and the environment. <u>Almudena Hospido</u> (Universidad de Santiago de Compostela, Spain)</p>	<p>70   LCA of tertiary treatment sanitation designed for micropollutants and nitrogen removal: what environmental benefits for which impacts? <u>Ywann Penru</u> (Suez, France)</p>	<p>75   Digital Game Based Learning as an approach to increase LCA awareness and knowledge. <u>Rossella Luglietti</u> (Politecnico di Milano, Italy)</p>

## ORAL PRESENTATIONS | 13:30–15:10

Room	Amphithéâtre Lamour	Salle du Conseil	Salle A
Session	<p><b>LCA for agriculture: food, bio-material, bio-energy, including aspects of water use, land use, handling of pesticides, carbon accounting, end-of-life modelling (II)</b>                      Montserrat Pineda, Anton Assumpcio, Cecile Bessou</p>	<p><b>LCA of urban water systems from resources to users: water withdrawal, water treatment &amp; distribution, water use, wastewater sanitation and reuse (III)</b>                      Almudena Hospido, Iluis corominas, Ywann Penru, Philippe Roux</p>	<p><b>Energy: conversion, supply and storage systems (I)</b>                      Christian Bauer, Karin Treyer</p>
13:30	<p>76   Worldwide mapping of freshwater deprivation effects integrating cascade effects: application to 3 water stress indicators. <a href="#">Nabil Belakhil</a> (Montpellier SupAgro, France)</p>	<p>81   Life Cycle Assessment of Phosphorus Recycling Technologies from Sewage Sludge Ash: Primary vs. Ash-based Secondary Phosphate Fertilizers for German Agriculture. Yasmine Emara (Technische Universität Berlin, Germany)</p>	<p>86   LCA as a support for energy-policy-making: Multi-scale analysis of environmental impacts of electricity generation in the world from 1980 to 2010. <a href="#">Alexis Laurent</a> (Technical University of Denmark, Denmark)</p>
13:50	<p>77   Environmental impacts of agricultural practices and Water and Soil Conservation Works : The case of the Merguellil catchment. <a href="#">Meriem Jouini</a> (Montpellier SupAgro, France)</p>	<p>82   Cost-benefit analysis of implementing innovative source-separated urine treatment. <a href="#">Elorri Igos</a> (Luxembourg Institute of Science and Technology (LIST), Luxembourg)</p>	<p>87   Environmental pressures of global electricity generation: applying the inventory that matches regionalized impact assessment methods. <a href="#">Catherine Raptis</a> (ETH Zurich, Switzerland)</p>
14:10	<p>78   Comparison of agricultural pesticides emission models for LCIA: An apple case study. <a href="#">Miriam Colin Avila</a> (IRSTEA Montpellier, France)</p>	<p>83   Life cycle assessment of a combined EGSB-CANON process for swine manure management. <a href="#">Stefano Longo</a> (Universidad de Santiago de Compostela, Spain)</p>	<p>88   Regionalized Life Cycle Inventory of Power Producing Technologies and Power Grids in India. <a href="#">Muhammed Noor Hossain</a> (Chalmers University of Technology, Sweden)</p>
14:30	<p>79   Calculation of on-field pesticide emissions for maize production in Northern Italy: how much do different soil typologies affect the results of PestLCI 2.0 model? <a href="#">Valentina Fantin</a> (ENEA, Italy)</p>	<p>84   Environmental and Water-Saving Impacts of On-Site Water Reuse in Hotels. <a href="#">Mark Santana</a> (Catalan Institute for Water Research (ICRA), Spain)</p>	<p>89   Life cycle impacts of energy system infrastructure: comparing coal generating station retrofits for conventional and steam-treated wood pellets. <a href="#">Jon McKechnie</a> (University of Nottingham, United Kingdom)</p>
14:50	<p>80   Accounting for spatial variability and speciation in Copper terrestrial ecotoxicity: Case study of wine consumption in Quebec. <a href="#">Cecile Bulle</a> (CIRAIG - ESG - UQAM, Canada)</p>	<p>85   Comparative LCA of water reuse and other options for water supply in a coastal mediterranean village. <a href="#">Christian Remy</a> (Kompetenzzentrum Wasser Berlin gGmbH, Germany)</p>	<p>90   Poster spotlights: P03, P04, P05, P06</p>

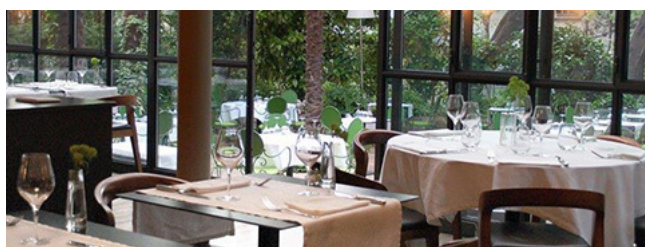


# PROGRAMME Wednesday 21 September

## ORAL PRESENTATIONS | 15:40–17:20

Room	Amphithéâtre Lamour	Salle du Conseil	Salle A
Session	<b>LCA for agriculture: food, bio-material, bio-energy, including aspects of water use, land use, handling of pesticides, carbon accounting, end-of-life modelling (III)</b> Montserrat Pineda, Anton Assumpcio, Cecile Bessou	<b>LCA and uncertainties: how to deal with uncertainties in LCA studies and their interpretation?</b> Ralph Rosenbaum, Enrico Benetto, Lucia Rigamonti	<b>Energy: conversion, supply and storage systems (II)</b> Christian Bauer, Karin Treyer
15:40	91   Assessing environmental performance of humidification technology used in supply of fresh fruit and vegetables. <a href="#">Mikolaj Owsianiak</a> (DTU Technical University of Denmark, Denmark)	96   An integrated method for identification, classification, and quantification of uncertainty in Life Cycle Assessment studies—case study application to a building. <a href="#">Deidre Wolff</a> (Dublin Energy Lab, Ireland)	101   LCA of varying electricity supply with relevant shares of intermittent renewable generation based on highly time-resolved electricity market data. <a href="#">Michael Baumann</a> (University of Stuttgart, Germany)
16:00	92   Environmental impacts of agro-municipal resource use in an Alpine municipality. <a href="#">Iris Kral</a> (AlpS GmbH, Austria)	97   Addressing high variability in LCA with Global Sensitivity Assessment: from a single parameterized model to multi-parameterized clustered models. <a href="#">Paula Perez-Lopez</a> (Mines ParisTech, France)	102   Life Cycle Assessment of Electricity Storage Technologies for Different Discharge Durations and Scales. <a href="#">Xiaojin Zhang</a> (Paul Scherrer Institut, Switzerland)
16:20	93   Understanding regional variability on impacts of cropping systems; a case study of wheat in Central NSW, Australia. <a href="#">Aaron Simmons</a> (NSW DPI, Australia)	98   Sensitivity analysis and uncertainty propagation to investigate the results' robustness of building life cycle assessment. <a href="#">Marie-Lise Pannier</a> (Mines ParisTech PSL - CES, France)	103   Including storage in local grids - the case of an island in the North Sea. <a href="#">Jutta Hildenbrand</a> (Swerea IVF AB, Sweden)
16:40	94   LCA of rapeseed and sunflower oils as the basis for guidelines on LCA in vegetable oil sector. <a href="#">Laureen Badey</a> (ITERG, France)	99   Uncertainty propagation in ABM/LCA coupled models. <a href="#">Paul Baustert</a> (Luxembourg Institute of Science and Technology, Luxembourg)	104   Prospective Life Cycle Assessment of Sodium-Ion Batteries. <a href="#">Gonzalo Rodriguez-Garcia</a> (Helmholtz Institute Ulm, Germany)
17:00	95   Integrated assessment of the pressures associated with raw food production on biodiversity in view of an absolute ecological sustainability assessment. <a href="#">Anastasia Wolff</a> (Mines Saint Etienne, France)	100   Discussion.	105   Discussion

Banquet | 19:00–23:00 | Le petit jardin | 20 rue Jean Jacques Rousseau, 34000 Montpellier



## ORAL PRESENTATIONS | 8:30–10:10

Room	Amphithéâtre Lamour	Salle du Conseil	Salle A
Session	<b>LCA and LCM in industrial sectors, including public disclosure and reporting of sustainability metrics</b> <u>Gert Van Hoof</u> , <u>Guido Sonnemann</u>	<b>Life Cycle Sustainability Assessment of Emerging Technologies (I)</b> <u>Coen Van der Giesen</u> , <u>Valentina Prado</u> , <u>Jeroen Guinee</u>	<b>LCA of large-scale systems - from urban to national scale including territorial LCA, urban metabolism and their nexus with circular economy (I)</b> <u>Eleonore Loiseau</u> , <u>Serenella Sala</u> , <u>Alessandra Zamagni</u>
8:30	<b>106</b>   Environmental impacts of alcoholic beverages. <u>Bo Weidema</u> (International Life Cycle Academy, Spain)	<b>111</b>   LCA for ex-ante environmental assessment of new technologies. <u>Coen Van der Giesen</u> (Leiden University, Netherlands)	<b>116</b>   Implementation of LCA within EIA procedure: an innovative methodology applied on two wastewater treatment plants case studies. <u>Pyrene Larrey-Lassalle</u> (IRSTEA Montpellier, France)
8:50	<b>107</b>   A benchmark for LCM in shoe companies - Environmental impacts in the Swedish market of six trade categories of footwear. <u>Yuqing Zhang</u> (IVL Swedish Environmental Research Institute, Sweden)	<b>112</b>   Scale-up in Life Cycle Assessment: a case study of a surfactant production based on seaweed. <u>Sylvain Martinez</u> (Institut National de Recherche Agronomique Narbonne France France, Metropolitan)	<b>117</b>   Application of the Solid Waste Infrastructure Management System (SWIMS) model to support regional and national decision making. <u>David Turner</u> (EMPA, Switzerland)
9:10	<b>108</b>   LCA supporting a wood-panels "Factory of the Future". <u>Emil Popovici</u> (Luxembourg Institute of Science and Technology (LIST), Luxembourg)	<b>113</b>   Life Cycle Sustainability Assessment of rare earth permanent magnets. <u>Christina Wulf</u> (Forschungszentrum Juelich GmbH, Germany)	<b>118</b>   LCA of time-differentiated electric vehicle deployment in Copenhagen between 2016 and 2030. <u>Florence Bohnes</u> (Technical University of Denmark, Denmark)
9:30	<b>109</b>   Environmental sustainability benefits from the use of a new multilayer structure in menstrual pads. <u>Gert Van Hoof</u> (Procter & Gamble Services, Belgium)	<b>114</b>   Prospective life cycle assessment of adipic acid production from forest residue. <u>Matty Janssen</u> (Chalmers University of Technology, Sweden)	<b>119</b>   Defining consequential LCA of mobility policies focusing on a specific demographic group: The case of cross border commuters. <u>Tomas Navarrete Gutierrez</u> (Luxembourg Institute of Science and Technology (LIST), Luxembourg)
9:50	<b>110</b>   Use of life cycle thinking to steer sustainability within innovation portfolio management. <u>Ananda Kumaran Sekar</u> (SABIC Research & Technology Private Ltd., India)	<b>115</b>   LCA of solvents for electrolytes of lithium-ion batteries. <u>Gonzalo Rodriguez Garcia</u> (Helmholtz Institute Ulm, Germany)	<b>120</b>   Large-scale hybrid LCA of passenger multimodal mobility policies and scenarios. <u>Thomas Gibon</u> (Luxembourg Institute of Science and Technology (LIST), Luxembourg)



# PROGRAMME Thursday 22 September

## ORAL PRESENTATIONS | 10:40-12:20

Room	Amphithéâtre Lamour	Salle du Conseil	Salle A
Session	<b>Innovation through design of more sustainable systems: Eco innovations arising from LCA</b> Alessandra Zamagni, Paolo Masoni, Enrico Benetto, Wladimir Motta	<b>Life Cycle Sustainability Assessment of Emerging Technologies (II)</b> Coen Van der Giesen, Valentina Prado, Jeroen Guinee	<b>LCA of large-scale systems - from urban to national scale including territorial LCA, urban metabolism and their nexus with circular economy (II)</b> Eleonore Loiseau, Serenella Sala, Alessandra Zamagni
10:40	<b>121</b>   LCA case study: comparison of different chemical pathways for the production of ethyl and n-butyl acetates. <u>Cecile Bories</u> (Laboratoire de Chimie Agro-industrielle Université de Toulouse INRA INPT, France)	<b>126</b>   Assessing the green credentials of continuous flow hydrothermal synthesis for the production of titania nanoparticles. <u>Pablo Caramazana Gonzalez</u> (The University of Nottingham, United Kingdom)	<b>131</b>   Integration of morphological analysis in early-stage LCA of the built environment at the neighborhood scale. <u>Marc Lotteau</u> (University of Bordeaux ISM UMR, France)
11:00	<b>122</b>   Eco-design of an innovative environmental biorefinery to produce added value chemicals from waste. <u>Amandine Foulet</u> (National Research Institute of Science and Technology for Environment and Agriculture - Irstea, France)	<b>127</b>   A life cycle assessment study of photocatalytic active nanomaterials in view of their potential for a more sustainable hydrogen production pathway. <u>Roland Hischier</u> (EMPA, Switzerland)	<b>132</b>   Carbon footprint of urban lawns. <u>Pernilla Tidåker</u> (JTI - the Swedish Institute of Agricultural and Environmental Engineering, Sweden)
11:20	<b>123</b>   Eco-design of a micro-algae fractionation process by coupling process simulation and environmental life cycle assessment <u>Remi Julio</u> (INP-ENSIA-CET, France)	<b>128</b>   Lessons from early assessments of production processes for the nanomaterial graphene. <u>Rickard Arvidsson</u> (Chalmers University of Technology, Sweden)	<b>133</b>   Determination of the Carbon Footprint of all Galician production and consumption activities based on the territorial LCA methodology. <u>Laura Roibás</u> (Universidade de Santiago de Compostela, Spain)
11:40	<b>124</b>   Ecoinnovation applied to an LCA framework of a small-scale gold mining in Colombia. <u>Elisabetta Zerazion</u> (University of Modena and Reggio Emilia, Italy)	<b>129</b>   Life Cycle Assessment of commercial-scale graphene production. <u>Jon McKechnie</u> (University of Nottingham, United Kingdom)	<b>134</b>   Comparison and complementarities between Eurostat and Territorial LCA methods for land planning based on a Mediterranean case study. <u>Guillaume Junqua</u> (Ecole des Mines d'Alès, France, Métropolitain)
12:00	<b>125</b>   Bringing the life cycle perspective into the Cradle-to-Cradle certification: the case study of aluminium cans. <u>Monia Niero</u> (Technical University of Denmark, Denmark)	<b>130</b>   Combining Prospective Modelling and Uncertainty Assessment to Evaluate our Capacity to Differentiate Future Development Scenarios Using the Example of Graphene Production. <u>Didier B St-Pierre</u> (EMPA, Switzerland)	<b>135</b>   Evaluation of alternatives for the calculation of the final demand carbon footprint of a region. <u>Laura Roibás</u> (Universidade de Santiago de Compostela, Spain)

## CLOSING SESSION | 13:30-14:50 | AMPHITHÉÂTRE LAMOUR

## FRIDAY 23 SEPTEMBER | SHORT COURSE ON WATER FOOTPRINT | 8:50-12:20 | BUILDING 21, SALLE FERGUSON

The poster session runs from 20 September (8:00) till 22 September (15:00) in the Exhibition Hall.

Poster titles and abstracts submitted as from 8 August are only available in the online programme.

## Life Cycle Innovation for the transition to a sustainable society

- P01 | Life Cycle Assessment of DMSO solvent, comparing an open manufacturing system with a closed one.** [Klara Szita Toth](#) (University of Miskolc, Hungary)
- P02 | Sustainability assessment of innovative photovoltaic panel treatment to convert waste into resources promoting circular economy. PV-MOREDE device.** [Laia Puigmal](#) (LEITAT Technological Centre, Spain)
- P03 | Life Cycle Assessment of power production by using low temperature waste heat from industrial processes.** [Doris Rixrath](#) (Forschung Burgenland GmbH, Austria)
- P04 | Renewable energies for Graciosa Island, Azores - Life cycle assessment of electricity generation.** [Christina Wulf](#) (Forschungszentrum Jülich, GmbH Germany)
- P05 | LCA and Cost Analysis of innovative Li-S batteries for electric vehicles.** [Gabriela Benveniste](#) (IREC, Spain)
- P06 | Comparative Life Cycle Exergy Assessment of on-grid hybrid and conventional Base Transceiver Stations.** [Igor Budak](#) (University of Novi Sad, Faculty of Technical Sciences, Serbia)
- P07 | ADEME SOCLE project, Soil Organic Carbon accounting to improve Life cycle Evaluations.** [Cecile Bessou](#) (CIRAD, France)
- P08 | A pragmatic approach for the Life Cycle Assessment of industrial systems as a basis for eco-innovation, the example of Fives' products.** [Marcial Vargas Gonzalez](#) (Quantis, France)
- P09 | More sustainable textiles and improved laundry processes for mitigating the microplastics impact in the marine environment. MERMAIDS project.** [Laia Puigmal](#) (LEITAT Technological Centre, Spain)
- P10 | LCA of different Kraft paper mill scenarios to integrate the manufacturing of new eco-designed supercapacitors based on black liquor.** [Philippe Loubet](#) (Bordeaux INP, France)
- P11 | Integrating LCA methods in companies' processes via hazardous substance declaration - creation of a tool.** [Axel Roy](#) (Bureau Veritas CODDE, France)
- P12 | Consumer perceptions of the environmental sustainability of liquid food packaging: a survey among Danish consumers.** [Monia Niero](#) (Technical University of Denmark, Denmark)
- P13 | Analysis of the variability and reliability of Environmental Product Declarations for the comparison of environmental performances of construction products.** [Mélanie Guiton](#) (CRP Henri Tudor, Luxembourg)
- P14 | Feedback from a collaborative LCA network: SCORE LCA's four first years.** [Jade Garcia](#) (SCORE LCA, France)
- P15 | Glucose production: influence of the datasets choice on LCA results.** [Saïcha Gerbinet](#) (Université de Liège, Belgium)
- P16 | Using LCA and integrate quality evaluation for a new eco-design approach in viticulture.** [Anthony Rouault](#) (Ecole Supérieure d'Agricultures, France)
- P17 | Energy returns on investment (EROI) of four agricultural biomasses for bioenergy generation.** [Leonidas Carrasco-Letelier](#) (National Institute of Agricultural Research (INIA), Uruguay)
- P18 | The best options for Eucalyptus energy crops according to EROI values.** [Leonidas Carrasco-Letelier](#) (National Institute of Agricultural Research (INIA), Uruguay)
- P19 | Carbon Footprint of Italian Natural Mineral Water: an empirical research.** [Olimpia Martucci](#) (Università degli Roma Tre, Italy)
- P20 | Carbon footprint in fertilizer production as a tool for reduction of GHG emissions.** [Anna Bojanowicz-Bablok](#) (Institute of Environmental Protection NRI, Poland)
- P21 | LCI of food products sectors: from field data collection to the big picture.** [Antoine Besnier](#) (ITERG, France)
- P22 | LCA of urban development projects: coupling LCA and transport simulation tools.** [Charlotte Roux](#) (Mines ParisTech, France, Metropolitan)
- P23 | LCA case study: Tertiary treatment process options for wastewater reuse.** [Erwan Carré](#) (Ecole des Mines d'Alès, France)
- P24 | How is carbon footprint of SIAM configuration affected by methane management?** [Carolina Alfonsín](#) (Universidad de Santiago de Compostela, Spain)
- P25 | Sustainability assessment of integrated innovative wastewater technologies in Mediterranean tourist facilities (demEAUmed project).** [Ariadna Claret](#) (Leitat Technological Center, Spain)





**P26 | Dynamic Life Cycle Assessment applied to a wastewater treatment plant construction and operation.** [Allan Hayato Shimako](#) (Université de Toulouse, France)

**P27 | LCA of energy systems - a comparison of methods.** [Doris Rixrath](#) (Forschung Burgenland GmbH, Austria)

**P28 | Water utilization of beef supply chain from the Brazilian savannah.** [Mirelly Costa](#) (Federal University of Grande Dourados, Brazil)

**P29 | A Consistent Framework for Modeling Inorganic Pesticides: Adaptation of Life Cycle Inventory Models to Metal-Base Pesticides.** [Nancy Peña](#) (IRTA, Spain)

**P30 | Environmental and economic assessment of an eco-innovative Continuous Flow Integrative Sampler (CFIS) for pharmaceutical compounds measurement in waters.** [Isabel Gutierrez-Prada](#) (CETAQUA, Spain)

**P31 | Life cycle assessment of steam-thermolysis to recycle carbon fibers from composite waste.** [Andrea Nunes](#) (École des Mines d'Albi-Carmaux, France)

**P32 | Reducing climate impact in steel industry - LCA of a new gasification technology.** [Kristin Fransson](#) (Swerea IVF AB, Sweden)

**P33 | Life Cycle Assessment as a tool to assess the sustainability of innovative materials: the case of second generation superconductors tapes.** [Carme Hidalgo](#) (Leitat Technological Center, Spain)

**P34 | Life cycle approach for comparing nano-based textile finishing processes versus conventional textile finishing. ECOTEXNANO project.** [Raquel Villalba González](#) (Leitat Technological Center, Spain)

**P35 | "End of life" treatment environmental impact analysis for a new car back seat.** [Rocio Pena](#) (AIMEN, Spain)

**P36 | Application of SLCA in energy generation.** [Lena Landström](#) (Vattenfall AB, Sweden)

**P37 | The work conditions in the Brazilian sugarcane industry: an application of Social Life Cycle Assessment (S-LCA).** [Mirelly Costa](#) (Federal University of Grande Dourados, Brazil)

**P38 | Life cycle sustainability analysis of municipal solid waste management systems in developing countries. A Brazilian case study.** [Valeria Ibáñez Forés](#) (Universitat Jaume I, Spain)

**P39 | Resource use assessment of a portable battery recycling system.** [Ha Tran](#) (Ghent University (UGent), Belgium)

**P40 | Life Cycle Assessment of storm water management systems for Nørrebro, Copenhagen.** [Sarah Brudler](#) (Technical University of Denmark, Denmark)

**P41 | A new method for allocating impacts to products from complex multifunctional processes: An illustration and application to an integrated biorefinery.** [Sylvestre Njakou Djomo](#) (Aarhus University, Denmark)

**P42 | The Economic and Environmental Assessment in the Design Process: A Decision Support Toolbox conceptualization.** [Rossella Luglietti](#) (Politecnico di Milano, Italy)

**P43 | Pragmatic Sustainability Evaluation Tools for Cross-Sector use in the EU Process Industries.** [Tomas Rydberg](#) (IVL Swedish Environmental Research Institute, Sweden)

**P44 | Tidal Renewable Energy Schemes as Building Blocks in a Low Carbon Society - A Life Cycle Assessment Case Study.** [Eva Fenrich](#) (Esslingen University of Applied Sciences, Germany)

**P45 | System analysis of biogas upgrading using enhanced membrane separation materials.** [Alexander Lamond](#) (The University of Nottingham, United Kingdom)

**P46 | Life Cycle Assessment and Net Energy Analysis of Ground-Mounted Photovoltaic Systems, based on the latest inventory data.** [Enrica Leccisi](#) (Parthenope University of Naples, Italy)

**P47 | Life Cycle Analysis of crystalline silicon photovoltaic (c-Si PV) panels at their end-of-life: energy savings and material recovery.** [Enrica Leccisi](#) (Parthenope University of Naples, Italy)

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## Keynote Speakers

### From incremental improvement to ecological limits: How might the Planetary Boundaries approach be applied in Life Cycle Assessment?

Roland Clift, Emeritus Professor, Centre for Environmental Strategy, University of Surrey, Guildford, Surrey GU2 7XH, UK.

Tuesday 20 September | 9:30 | Amphithéâtre Lamour

Environmental Life Cycle Assessment has generally slipped into assessing incremental improvement – whether a product or system represents a reduction in environmental impact, rather than whether it is compatible with keeping human activities within the ecological constraints needed for the planet not to be tipped out of its “Holocene” state. Arguably, LCA needs to be applied in a more rigorous and stringent way. The “Planetary Boundaries” (PB) approach, originally proposed by Rockström et al. and much discussed since, provides a conceptual framework for defining and potentially quantifying ecological constraints which human activities must observe to be sustainable. Life Cycle Impact Assessment could potentially use the PBs in a “distance to boundary” framework, analogous to the more familiar “distance to target approach”. However, applying the PB concept at the level of a company or a product system raises a number of conceptual and practical problems.

This keynote lecture will focus on two of the problems:

1. **Boundary definition:** How and at what geographical scale can each boundary be defined?
2. **Apportioning:** How can an equitable basis be found to share the “ecological space” between different activities?

These issues will be explored for specific Planetary Boundaries, selected to show a range of different operational questions and practical difficulties. Both boundary definition and apportioning entail scientific assessment but also political consensus. A specific example, to be discussed, is the boundary for atmospheric concentration of greenhouse gases: is it realistic or constructive to define the Planetary Boundary as a concentration which has already been exceeded? Does the “contract and converge” approach provide a sufficient basis for apportioning greenhouse gas emissions?



## Meeting the knowledge needs of business and policy: the case of raw materials

David Pennington, Gian Andrea Blengini, Tamas Hamor, Philip Nuss, Cynthia Latunussa, Beatriz Vidal, Viorel Nita, Lucia Mancini, Simone Manfredi, Fabrice Mathieux, Fulvio Ardente, Serenella Sala, Valentina Castellani, Rana Pant, Luca Zampori, Simone Fazio, Dominic Wittmer, Jo Dewulf

**Thursday 22 September | 13:30 | Amphithéâtre Lamour**

Ensuring the secure and sustainable supply of raw materials is essential to maintaining and strengthening industry in the European Union. Associated knowledge of supply chains and their role in our industry is crucial. But, can the scientific community meet the needs of business and governments?

The European economy requires a wide variety of raw materials. Not all of them can be provided domestically through mining or recycling. Trends suggest continued growth in demand, with an increasing diversity of the raw materials required for emerging new technologies and more sophisticated products. Reliance on international supply chains for raw materials and semi-finished products is increasing. This international nature, the complexity of global supply chains and the diversity of raw materials are challenges to providing a relevant knowledge base.

Governments and business must assess supply chains in relation to ethical, environmental, and economic considerations; considerations essential to sustainable and secure supply, which is fundamental to the competitiveness of industry in the EU. Reliance remains mainly on primary raw materials, biotic and abiotic. But, there is equally a growing focus on secondary raw materials from urban mining and recycling.

A variety of assessment methods are now available to support sustainability and security analyses of raw material supply chains. These include Material Flow Analysis, Life Cycle Assessment, criticality assessments, resource efficiency assessments, trade outcome and value chain diagnosis, and others. Such methods can provide insights at the macro scale of the economy, as well as for supply chains of specific materials and products. Similarly they are useful for insights into current situations, as well as for assessing future policy scenarios and business improvement opportunities.

In terms of coverage, information is often available only for bulk primary material supply chains, usually with a limited geographical and technological scope. Analyses tend to address resource quantities, world production distribution, trade flows of raw materials and products, flows in terms of quantity between the ecosphere to the technosphere, applications, final consumption, etc. Analyses remain, however, in their infancy in relation to social considerations associated with supply chains, including in relation to conflict minerals policy, and of economic considerations such as criticality, including the risk of supply chain disruptions.

The EU's Raw Materials Initiative, together with the European Innovation Partnership on Raw Materials and the European Institute of Innovation & Technology (EIT) on Raw Materials, bring together key stakeholders that all have a role in the provision of the European Knowledge Base on Raw Materials; governments, business, and academia. Activities include H2020 research projects, industry commitments, as well as developing investment funds to facilitate e.g. small and medium enterprises.

The EU's Raw Materials Information System (RMIS) is evolving at the heart of its Knowledge Base. Methods and data supporting the environmental and social assessment of supply chains are advancing, including in terms of data availability, coherence and quality assurance. Data on supply chains and activities for regions outside the EU remain a challenge, but one that is being addressed through international data networks, awareness raising, and tools such as crowdsourcing. Sustainability data on supply chains of high profile materials, such as critical raw materials and recycled materials, are increasing in availability; while a lot more remains to be done to fill gaps and to improve quality.

The scientific community has an important role to help meet these raw materials knowledge challenges, complementing business and government activities as well as helping to support meeting their needs. Opportunities exist to integrate methods across disciplines, as well as to better integrate considerations relevant to business and policy support into assessments to meet needs.



## Platform Abstracts

### Closing the loop: a sustainable use of resources (I)

1

#### **Implications of synergetic indirect effects and increased flexibility for municipal solid waste management within future framework conditions**

C. Cimpan, University of Southern Denmark / SDU Life Cycle Engineering; M. Rothmann, Rambøll; H. Wenzel, University of Southern Denmark

Life cycle assessments addressing municipal solid waste management systems (MSWMS) most often represent and evaluate these systems or compare isolated technological and management solutions in a much too simplistic interaction with their surroundings, accounting for a minimum of probable future system interactions/effects and using static representations of background systems (e.g. the use of simple marginals or average when modelling energy from waste integration in the energy system). The nature of the background systems is known to be especially decisive when comparing the global warming potential (GWP) of different waste management strategies. Within the study reported here, a number of alternative MSWMS were simulated and evaluated, comprising combinations of separate collection and different downstream treatment/handling approaches for remaining residual waste, including advanced mechanical treatment with additional material recovery as an alternative to direct thermal treatment. These systems represent strategies considered by a number of Danish regional authorities to meet targets, while maintaining or enhancing the benefits of energy recovery. The simulated systems were assessed and compared against a large variety of background system scenarios, consisting of the most probable future development of the Danish and surrounding countries energy systems towards 2050. Specific focus was placed on modelling of possible indirect effects on adjoining systems that would result as consequence of implementation of such alternative systems, including: 1) synergy between biowaste separate collection and animal manure utilization for biogas production; 2) liberated incineration capacity due to increased separate collection leading to combustible waste imports and possibly avoided landfilling; and 3) production of local refuse derived fuel (RDF) increasing flexibility with waste-derived energy integration. Results showed that in short-to-medium term, MSW management would see a decrease in GHG savings, consistent with the diminishing share of fossil fuels in the energy system being displaced by the energy recovered from the waste. The ability to maintain net waste-derived GHG savings from waste energy recovery in a longer-term perspective was found to be potentially dependent on the ability to integrate waste based energy production in the surrounding energy system. From a climate perspective, the benefits of recycling gain more prominence in the future.

2

#### **Sustainability analysis through life cycle assessment: over the only environmental impacts. Application at the case study: integrated waste management system in Baalbek (Lebanon)**

A. Bonoli, University of Bologna; R. Spinelli, Alma Mater Studiorum University of Bologna; P. Neri, A. Ferrari, University of Modena and Reggio Emilia; S. Bamonti, Alma Mater Studiorum - University of Bologna

Sustainable development has as primary aim to improve environmental, economic and social conditions, both at local territorial and global level. The sustainability represents a complex concept often confused with the environmental impact reduction. A complete sustainability investigation depends on the environmental impacts and also on its economic and social consequences, both in absolute and relative terms. The research shows as the method of life cycle assessment (LCA) can be used to do a complete sustainability analysis of a case study. Specifically the study has the objective to evaluate, through the LCA approach, the environmental impacts of an integrated waste management plant projected in Lebanon and also to estimate economic and social effects related to this plant. The plant was dimensioned to serve the population of Union of Commons of Baalbek. It consists of a sorting and composting plants, an anaerobic digester plant and a sanitary landfill located in the Caza of Baalbek. The environmental analysis was conducted using the SimaPro 8.2 software and the IMPACT 2002+ evaluation method. The inventory analysis has been conducted using primary and secondary data whenever available. The remaining data have been obtained from the Ecolnvent database v.2 - v.3. In the analysis have been included (i) the municipal solid waste collection, (ii) the waste separation (with different sorting process technologies to divide recyclable items, compostable material and not-differentiated inert waste) (iii) the pretreatment of recyclable material, (iv) anaerobic digestion of organic material, (v) composting of the remainder organic material and of the anaerobic digestion product, (vi) disposal in a landfill of not recyclable material, (vii) the use of anaerobic digestion biogas to produce electricity by cogeneration. An economic quantification, differentiating incoming, investments and

operation costs of the plant has been done. Finally, the social effects with an estimation of benefits deriving from the introduction of a new waste management system in a developing country have been considered. Three specific indicators to demonstrate (i) the occupation (jobs related to the waste management system), (ii) the function of the system (the management of municipal solid waste) and (iii) the management mode choice (that is representative of the combination introduced by the system of alternative waste treatment) have been used.

### 3

#### **LCA of inert construction and demolition waste management strategies in Lombardy region, Italy**

S. Pantini, L. Rigamonti, Politecnico di Milano / Department of Civil and Environmental Engineering  
The Construction and Demolition Waste (CDW) is one of the most abundant waste streams generated in European Union, representing approximately 20-30% of the total waste production. In Italy, roughly 49 Mt of CDW were originated from construction, renovation and demolition activities in 2013, almost all of which were non-hazardous. Among Italian regions, Lombardy was the largest producer of CDW likely due to the high economic activity of this region. CDW is a heterogeneous material; most of it is inert and has a considerable potential for being recycled and re-used as secondary material in civil and road construction, as a substitute of natural aggregates. Hence, a proper management of CDW is essential to ensure environmental protection and enhance waste valorisation towards a resource-efficient system. In this view, the main purpose of this study was to evaluate the environmental performances of the CDW management system currently implemented in Lombardy Region by applying the Life Cycle Assessment methodology (LCA). As first step, the CDW amount and composition have been quantified, and the mass balance of the whole CDW management system has been reconstituted, based on official regional data. Technical visits at some of the selected CDW recycling facilities have been carried out in order to improve the knowledge on the treatment processes actually applied to CDW and to collect primary operational data to create a LCA inventory dataset specific for the analysed geographical context. The quality of secondary products obtained from CDW recovery/ recycling facilities and their actual reuse will be investigated in order to evaluate the type and amount of "avoided materials" that can be replaced by recycled products. Results of the LCA analysis of the current situation, together with a literature review aimed at defining state-of-the-art treatment technologies will allow to identify possible alternative CDW management strategies, innovative production processes and/or alternative re-use solutions that can improve the environmental performances of the current management system. These alternative scenarios will be evaluated and compared from a life cycle perspective in order to quantify the benefits arising from the suggested improving actions. The results of the study will be used to support the regional authorities in the identification of the critical aspects of the current CDW management system and of the possible actions to improve it towards a circular economy.

### 4

#### **Comparing the impact of actual WEEE recycling practice with the legal minimum recycling and recovery rates at an Austria recycling company**

N. Unger, BOKU University Vienna / Institute of Waste Management; P. Beigl, S. Salhofer, BOKU University Vienna / Institute of Waste Management

The treatment, recycling and recovery of Waste Electrical and Electronic Equipment (WEEE) is highly regulated by European and national directives, e.g. by defining different minimum recycling and recovery rates by device category and depollution of electronic components. For operators running highly selective mechanical pre-treatment processes these minimum rates are significantly exceeded. The motivation for overachieving these rates is the need to have a sound economic business model where specialised technical infrastructure is efficiently utilised and high quality secondary materials are delivered. This case study focuses on an Austrian durable goods recycling company. The environmental impacts of its current practices in WEEE recycling (aiming at running a profitable business) are compared with the environmental impacts if the same company 'only' recycled and recovered to the legal minimum rates. For the latter, a realistic scenario regarding what process steps would be omitted is used. The system description is based on primary data for processing activities, and characterisation and analysis of both the input WEEE as well as all output streams. These output streams are further treated in five main destinations, i.e. aluminium, copper and ferrous metal smelters, a plastic recycling facility and an incineration facility. Special attention is put on the methodological challenges of accounting for the avoided burden due to recycling by applying a sensitivity analysis to the replacement ratios as well as the replacement products, producing a range of results. The outcomes of the study show the amount of currently recovered materials and the range of environmental benefits from these, compared to the legal minimum requirements. Moreover, the actual recycling rates for individual materials at this site are determined which – taken together – deliver both, environmental and economic benefits. This study also shows that the minimum recycling rate proves to be more relevant when deciding on processing than quotas for recovery.

5

## **An assessment of resource conservation in WEEE management from a life cycle perspective: a case study of E-scrap recycling in Belgium**

H.P. Tran, Ghent University (UGent) / Department of Sustainable Organic Chemistry and Technology; E. Van Eygen, Vienna University of Technology / Christian Doppler Laboratory for Anthropogenic Resources; S. De Meester, Ghent University - Campus Kotrijk / Department of Industrial Biological Sciences; J. Dewulf, Ghent University - Campus Coupure / Department of Sustainable Organic Chemistry and Technology

Transition towards circular economy has been defined as a strategic action plan to promote a sustainable and resource efficient economy, especially for economies depending on import of raw materials like Europe. Accordingly, waste is considered as resource and waste disposal should be minimized. The waste hierarchy also defines recycling as a preferred option next to waste prevention and reuse to manage waste fractions containing high valuable contents like electronic scrap (E-scrap). However, recycling is not for free. Therefore, comprehensive and systematic assessment of the performance of E-scrap recycling is crucial to ensure the sustainability of the system. In Belgium, after collecting the waste electrical and electronic equipment is separated into five fractions i.e., cooling and freezing appliances, big white goods, television screen and monitor, gas discharge lamp, and other appliance (so-called OVE), in which the OVE is the biggest fraction (39%). In this study, the performance of the recycling of the OVE fraction in 2013 was assessed. First, material flow analysis (MFA) was employed to assess the OVE recycling chain. Second, the Cumulative Exergy Extraction from the Natural Environment (CEENE) method was used to quantify the overall natural resource consumption of the recycling system in the life cycle perspective. The result is then compared with a benchmarking scenario, in which OVE fraction is incinerated and the same basket of product (BoP) is obtained from virgin materials. The results show that base metals such as ferrous, aluminum and copper are recycled at a large extent (more than 96%). Moreover, the recycling is mainly performed in Belgium (7%) and the rest of Europe (91%), and hence supporting the circulation of these materials within European economy. The exergetic life cycle assessment identified the secondary treatment (smelting, etc.) as the most resource demanding step of the whole recycling chain, representing over 96% of the total resource consumption. Nuclear energy and fossil fuels, caused by electricity consumption contributed most to the total resource footprint. Finally, in comparison with the landfill scenario, the natural resource consumption of the recycling scenario is 27% lower, indicating the higher sustainability from the resource perspective.

## **LCIA modelling of resources and emissions - new developments and applications (I)**

6

### **Environmental Water Requirements (EWRs) indicator proposal to address local and temporal climate variability: development and testing on 72 USA rivers**

A. Manzardo, CESQA University of Padua / Department of Industrial Engineering; A. Loss, University of Padua / Department of Industrial Engineering; A. Fedele, CESQA University of Padua / Industrial Engineering; A. Scipioni, CESQA University of Padua / Department of Industrial Engineering

Climate changes are putting a lot of stress on the availability of water in a growing number of regions worldwide. At the same time, water requirements for food production and industrial processes are growing so that water management has become central to international debate. Focusing on surface water, not all the water available in a watershed is for human uses because part of it is needed to sustain freshwater ecosystems. To account for this issue in Life Cycle Assessment studies, the concept of environmental water requirements (EWRs) was introduced. To determine EWRs, two methods have been widely applied in literature: the environmental flow method (EF) (Smakhtin, 2004) and the variable monthly flow method (VMF) (Pastor et al., 2014). These methods, with different time scale, are based on algorithms that estimate EWR starting either from the mean annual runoff (MAR), or from mean monthly runoff (MMR). The present research starting from the VMF method formulated by Pastor et al., 2014 proposes to modify the EWR calculation algorithm by the inclusion of monthly Climatic moisture index (CMI) (Willmott et al., 1992; Vorosmarty et al., 2005) parameters in order to highlight the potential increasing of EWR due to high local evapotranspiration ET. This parameter in fact is considered a key variable that influences hydrological and biological processes in most ecosystems and especially in water stressed regions (Hanson et al., 2004). The applicability of the proposed was tested in the USA context acquiring data from the USGS database and the web-based hydrology analysis tool (Lim et al., 2005). The assessment was performed classifying the different river basins into freshwater ecoregions (FEOW) (Abell, 2008) in order to investigate the link between EWR results and local climate conditions. EWRs have been estimated for the most important 72 USA rivers. The results show that the proposed EWRs method increase the protection of ecosystems especially in water-limited regions and during dry seasons where CMI values increase. On average, EWR increase from 5% to 60%.

7

**Challenges and opportunities in balancing water needs for humans and ecosystems through LCA**

M. Damiani, M.N. Pineda, P. Roux, R.K. Rosenbaum, IRSTEA Montpellier / UMR ITAP ELSA  
 With global population growth water demand is expected to rise by more than 55% by 2050 while climate change is increasingly altering local water balance worldwide. Urbanization, food and agricultural production, industrial activities and energy production may undermine water availability for rivers, lakes and wetland ecosystems. For this reasons, the development of operational tools for water resource management has become a pressing issue of concern. As a valuable support for decision-making, the interest of including methods assessing water consumption impact on ecosystem in LCA is well recognized and recently several approaches have been proposed. Given the high complexity of global and local water cycles and the ecological implications of their alteration, current models had to come to terms with the need of operationalization renouncing partially to scientific exhaustiveness and applicability at large scale. Consequently, performing an LCA using a combination of the present methods is recommended with some reservations, as recently highlighted by UNEP/SETAC Life Cycle Initiative's WULCA working group. In order to improve the consideration of water consumption impacts on ecosystems in LCA, this study wants to investigate alternative indicators supporting a better harmonization between the need for freshwater ecosystem protection and water use among stakeholders. An extended review has been carried out on the current practices for environmental flow management and ecohydrology. The analysis identified a number of hydrological, hydraulic rating, habitat simulation and holistic methods that can be of potential interest for decision support through LCA. In order to test the possibility for their inclusion in LCIA modelling, they have been ranked against a set of criteria including data availability and intensiveness, geographical and temporal relevance, suitability for mechanistic modelling and environmental significance. Based on the specific needs for improvement of the current LCIA methods, the study highlighted the opportunities deriving from a better inclusion of environmental flow management principles in LCA. Life cycle impact assessment of water consumption is still at its first steps and ecohydrological approaches will be an extremely valuable resource in order to provide LCA practitioners with reliable impact assessment methods.

8

**Towards assessing impacts of water degradation on water resources**

C. Pradinaud, M.N. Pineda, P. Roux, R.K. Rosenbaum, IRSTEA Montpellier / UMR ITAP ELSA  
 In water use impact assessment, the consideration of water quality aspects leads to different results than just considering the consumed quantity. A number of LCIA methods link water consumption to the Area of Protection (AoP) 'Resources', whereas no method links water degradation (pollution) to this AoP, essentially because the definition of water as a resource in function of its quality is not well established. Although the concern grows over the state of water resources available for future generations (in terms of quantity as well as quality) there is no consensus so far on how to consider long-term (>100 years) emissions and impacts of e.g. metals. The related impacts currently contribute to the toxicity impact categories, often to a very large extent resulting in a 'masking effect' regarding other toxic emissions. Given the underlying projection into a very far future they are also very uncertain and thus usually neglected. This study aims to answer 1) to which extent we have to consider the quality of the water withdrawn to assess impacts from water consumption, 2) how to handle overlaps and double counting between the assessments of impacts from degradative water use relative to emission impact categories like toxicity, and 3) finally, we propose a new LCIA characterization framework to handle long-term water pollution. To clarify the role of the water quality parameters, we first describe the environmental disturbances and consequences of water use through a mechanistic approach. At each step, we analyze if the water quality aspect is necessary or not. The definition of freshwater as part of the AoP Resources is discussed and thus which impact pathways are relevant for this AoP. The concept of water functionality is a key element in this debate. So far, the existing method which includes the water quality aspect sees water degradation as a loss of functionalities, which may result in water deprivation for humans. However, the link between loss of water functionalities and impacts of water deprivation on human health is not self-evident and may lead to double-counting with human toxicity impacts. Alternatively, we suggest to use this concept to link long-term water pollution impacts to the AoP Resources, considering functionality loss due to pollution as a damage to the water resource potentially affecting future generations, without requiring uncertain assumptions on how the resource will exactly be used in the far future.

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**Including the hydrological cycle through a multimedia assessment of water flows in water consumption LCIA modelling**

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A very recent analysis of life cycle impact assessment (LCIA) methods addressing impacts of water consumption on ecosystems showed that available methods cannot or only partially be compared and combined (Núñez et al., 2016). To overcome the lack of compatibility, the study recommended to develop a unified framework which will also serve as a basis for future harmonised LCIA method development for assessing water consumption impacts on ecosystems. The Water Use in LCA (WULCA) working group undertook this recommendation and is currently developing consensus-based guidelines. Some distinctive attributes of the framework include the following: i. A mechanistic model, meaning that the indicators are based on a sequence of interconnected sub-factors in the characterisation factor. These sub-factors link human activities (i.e., life cycle inventory, LCI) to potential midpoint and endpoint impacts on ecosystem quality. Water scarcity indices are not part of the equation, since they are not part of the cause effect chain addressing potential environmental damage (Boulay et al., 2014) ii. A multimedia model that represents the hydrological cycle based on two types of elements: water storage compartments (stocks) and connections between compartments (flows). This approach will allow one to differentiate impacts on ecosystems from consuming water from different sources. Moreover, it will render the assessment of land use-related impacts on the hydrological balance and water consumption impacts fully compatible. In other words, we will no longer need to distinguish between green water (soil water) and blue water (river and aquifer water) consumption and impacts, as both water flows are regarded in the multimedia model. This has largely been a subject of discussion in LCA and water footprinting, since there is no clear separation of green and blue water iii. A flexible structure organised in matrices that can be regarded by both midpoint and endpoint methods. This structure will facilitate, among others, comparison between intermediate results (i.e., for one specific sub-factor of the characterisation factor), easy update with e.g., new water compartments, and tracking exchanges between different compartments, which also avoids double counting of impacts. This talk will focus on explaining the main framework's properties and how its implementation will improve the environmental relevance of and compatibility between LCA water consumption indicators.

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### **LCIA of fisheries: a comparison of the available methods for resource use assessment**

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Context. Recent methodological developments occurred in the last years for Life Cycle Impact Assessment (LCIA) of fisheries, especially to assess their impacts on resource availability. Historically, a first method, noted (1), was developed by Papatryphon et al (2004) and currently used in LCA case-studies, based on the Net Primary Production used to produce biomass ( $NPP_{use}$ ), depending on trophic level of species. Two other methods, noted (2) and (3), were developed by Emanuelsson et al (2014) and Langlois et al (2014) based on the Maximum Sustainable Yield (MSY) of species. Purpose. The present paper proposes a statistical comparison of the Characterization Factors (CFs) calculated by species using these three different methods, to highlight which influences the methodological choices could have on LCA case studies results. Methods. CFs provided in the literature did not always focus on the same species, because authors did not use the same database for their methodological development. Thus, some CFs have been calculated to obtain a set of 74 CFs for each of the methods (1), (2) and (3). CFs have been normalized to be compared and then treated by R 3.3-data treatment software. The first test has been a ranking test, allowing comparing the order of impact severity for every species in the set, depending on the method used. The second test has been a multivariate analysis, allowing comparing the CFs distribution. When a value of CF was missing for one or another method, the statistical comparison could not be performed. Nonetheless, as a third result, the data obtained were used to calculate the percent of global landings that can be represented using each method. Results. We observed a good correlation between CFs from methods (2) and (3) from one hand and CFs based on method (1) using  $NPP_{use}$  from the other hand. Method (1) strongly depends on species trophic levels, and methods (2) and (3) strongly depend on the MSY by species, being indirectly correlated to trophic level, explaining the correlation. It also highlights that each method provides the same range of results, the main distinction being the percent of global landings represented. Conclusions. This paper is a support to discuss which recent methods could be chosen as reference for fisheries impact assessment from a resource point of view.

## Environmental Footprint of Products and Organizations: first insights from PEF and OEF applications

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### Learnings from a supporting study of New Zealand Dairy Product Environmental Footprinting

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**Objectives:** To provide feedback in terms of the guidelines applicability, relevance and limitations from a New Zealand supporting study of the Product Environmental Footprint Category Rules (PEFCR) — Dairy Products. **Methods:** The Life Cycle Assessment of 1 kg of raw milk at the farm gate was performed, in compliance with the PEFCR. This covered all stages of raw milk production, based on Taranaki (NZ) regional average data for farm inputs, and NZ-average fuel and electricity use. Sixteen environmental impact categories were assessed. **Results:** First, we identified the main contributing stages. Total feed production was the major contributor (>90%) for most impact categories. This shows that defining the amount of feed used is critical, and calls for an internationally-accepted model to determine feed requirements. Second, we examined the underlying methodology for water depletion, land use, freshwater ecotoxicity and freshwater eutrophication impact categories. For water depletion, the methodology is not up to date owing to recent international method developments, and is not consistent with current water databases. For freshwater ecotoxicity, the impact depends on the inventory flow models for the main contributing substances, but guidance on their partitioning between soil, air and water compartments is lacking. For freshwater eutrophication, the characterisation factors were developed for emissions in Europe, and their transferability to NZ is highly uncertain. For land use, the current methodology based on soil carbon changes is an indirect indicator of land use and there is large uncertainty in appropriateness of parameters for evaluating it: a sensitivity analysis for rate of change in soil carbon under long-term pasture showed a major effect on the result. **Recommendations:** Owing to the major contribution of feeds, an internationally-accepted model should be applied using primary farm data to determine animal feed requirements for farms with grazed pasture or crops. A stricter guidance on the inventory flow models is essential for a consistent application of some impact assessment methods across LCA studies, as illustrated here with freshwater ecotoxicity. Site-specific impact assessment methods should be further analysed for their relevance in a specific case study, as illustrated here with freshwater eutrophication. Some environmental impact indicators have high uncertainty and need to be revised, as illustrated here with water depletion and land use.

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### Made Green in Italy: a voluntary labelling scheme based on PEF

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In Italy has been recently approved a law for the "Promotion of the Green Economy" (L. 221/2015). Among others, relevant aspects are: Development of the National Action Plan on Sustainable Consumption and Production (PAN SCP) Green Public Procurement (GPP) becomes mandatory Development of a national voluntary scheme for environmental claims of products: *Made Green in Italy* These three elements are strongly interconnected and integrated with the promotion of the Circular Economy. Presently, the Ministry of Environment has published a draft regulation of the voluntary labelling scheme for open consultation. Main objectives of Made Green in Italy are: To promote the SCP fostering the adoption of innovative technologies and production protocols for the improvement of the products' performance and the reduction of the environmental impacts in their life cycles To improve the reputation, attractiveness and communication of Italian productions To strengthen the environmental qualification of Italian agricultural products To exploit strong synergies with GPP The main characteristics of the labelling scheme is the adoption of Product Environmental Footprint as method for the quantification of the environmental performance of the products. In addition, it is required an integration with social sustainability criteria and the safeguard of the landscape (in case of agricultural products). This is the first policy application of PEF in a member state and therefore the Italian experience is stimulating strong interest. The draft rules could be modified as result of the public consultation, but presently they requires that, where the PEFCR and the benchmarks (environmental impact of the representative product sold in the European market) are available at European level (from the PEF pilot studies), they are adopted and integrated with the additional requirements on social, landscape safeguard and GPP minimum criteria, where applicable. For the other products, not included in the PEF pilot phase, a procedure for developing Italian Product Category Rules is foreseen. A product can be awarded of the label «Made Green in Italy» when it fulfills the existing requirements to be labelled as «Made in Italy» (specific rules apply for each product category) and its environmental footprint is equal or better than the benchmark. A three year transition period is foreseen allowing enterprises to implement improvements in their products to achieve the benchmark.

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## **Product Environmental Footprint (PEF): Communicating uncertainties related to data quality**

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The European Commission's Single Market for Green Products initiative proposes a set of actions to overcome the problems companies and consumers face with the diverse amount of environmental information and methods available on the market. The aim of proposing the EU-wide Product Environmental Footprint (PEF) methodology is to measure the environmental performance of products and to develop a benchmark and performance classes per product group. Even though it is acknowledged that many factors involve uncertainties on results of environmental impact evaluation through Life Cycle Assessment (LCA), uncertainty on PEF results is not yet addressed clearly enough in recommendations by the PEF helpdesk (cf. Issue Paper "Determining the EF benchmark and performance classes" published in March 2016 by the PEF helpdesk). These uncertainties can be based on: Data uncertainty: related to the possible variations of input and output data of the assessed product, process or system; Uncertainty on modelling: this uncertainty has its origin from: the liberty given through the interpretation of specific PEF Category Rules (PEFCR) developed for specific product groups; the geographical representativeness of the chosen dataset in the LCA model; the technological representativeness of the chosen dataset in the LCA model; Uncertainty over datasets: a dataset may not be 100% accurate due to the different elements mentioned above. In this framework ArcelorMittal commissioned VITO to perform a PEF supporting study for steel sheets being produced by ArcelorMittal within the framework of the metal sheet PEF pilot in order to address several factors of uncertainty. Regardless the use of specific LCA software, a confidence interval for the results that will be communicated is built through the adaptation of the PEF Data Quality Rating (DQR) to the pedigree matrix introduced in the ecoinvent methodology. The presentation at the 22<sup>nd</sup> SETAC Europe LCA Case Study Symposium will illustrate the application of the methodology to assess uncertainties generated by data quality in PEF by means of the results of the PEF supporting study for the steel sheets produced by ArcelorMittal. The first outcomes of this methodology to assess uncertainties in PEF show that DQR-specific uncertainty factors need to be further defined and not only adapted from ecoinvent, as the effect of poor quality data on the precision of the ArcelorMittal steel sheet PEF profile is still underrated.

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## **Embedding Sustainable Strategy into Innovation: L'Oréal's Product Assessment Tool**

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Launched in 2013, « *Sharing Beauty With All* » program defines L'Oréal's 2020 vision and commitments in terms of sustainability. L'Oréal has targets for four key areas: Innovating sustainably, Producing sustainably, Living sustainably and Developing sustainably. Regarding sustainability performance at product level, L'Oréal is notably committed to: develop and launch a product only if its environmental or social performance is improved; provide data to consumer on the environmental and social performance of its products. These commitments rely on a "Product Assessment Tool" which aim at supporting this assessment process on all cosmetic products of the Group. It allows to assess an overall sustainability score per product, based on its quantitative environmental footprint as well as on its social score. The environmental assessment of products relies on a life cycle assessment methodology, which covers the all life stages of each product. The PAT tool integrates life cycle management (LCM) at the core of L'Oréal's global strategy in a pragmatic and efficient way. In order to ensure robustness and recognition, the PAT methodology has been established with an external stakeholder panel and in agreement with international standards such as ISO 14040 and 14044, Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and European Commission ILCD handbook. During this presentation several strategic and methodological aspects will be addressed, including: The use of multicriteria assessment (14 environmental indicators, in line with the Product Environmental Footprint (PEF) guidelines) The aggregation of all environmental impacts into a single environmental score using the "Planetary Boundaries" concept as a weighting framework The development of databases in order to allow the coverage of all L'Oréal products, packagings and Formula ingredients, requiring significant development in order to expand the coverage of existing databases. The Product Assessment Tool is a powerful tool that embeds sustainability metrics into day-to-day innovation: Product designers will be able to assess if a new design complies with L'Oréal sustainability strategy.

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## **Combination of OLCA and EMS: OES2 - Organization Environmental Sustainability System**

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One of the last important developments of Life Cycle Assessment (LCA) methodology is its application at organizational level that was recently standardized in the ISO/TS 14072. This new application was supported by different international initiatives such as UNEP/SETAC Life Cycle Initiative flagship project "LCA of organizations" and the European Organizational Environmental Footprint (OEF) Programme. The increasing importance of adopting life cycle approaches at organization level is also confirmed by the recent evolution of ISO 14001 standard that focuses on the importance of integration of products and organizational perspectives. In this context the present paper presents the development of a new approach named Organization Environmental Sustainability System (OES2) developed from the combination (Finkbeiner, 1998) of OLCA as the quantification tool of environmental burdens and ISO 14001 as the environmental management system (EMS). In OES2 the EMS stages are linked with OLCA stages consistently with company environmental sustainability goals. OES2 was applied to the most important Italian organization in the sector of beverage San Benedetto S.p.A. considering four different production sites located in Italy. A total of 350 different products have been monitored. The experience shows that OLCA allows the quantification of environmental impacts at different scales (e.g. total Italian group, production sites, product families, single products, single production machinery installed) (Manzardo et al., 2015) permitting temporally performance tracking and performance comparison and giving important feedbacks to the EMS in order to plan eco-design and eco-efficiency investments. The main opportunities deriving from OES2 are: the use of OLCA for prioritizing EMS goals, for introducing standardized impact categories in EMS performance evaluation stages and improving environmental data management. The main threats of OES2 were the acquisition of data needed and the complexity of the system. In order to face the identified threats in OES2 a specific data management tool was developed.

## Closing the loop: a sustainable use of resources (II)

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### Challenges in LCA modelling of multiple loops for aluminium cans

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Life Cycle Assessment (LCA) has traditionally played a key role in identifying the most efficient environmental design strategies and the best option for the end-of-life of products from an environmental point of view, within "one life cycle" approach. However, such an approach fails to capture one of the main features of circular product systems, i.e. the need to model multiple life cycles. There are some key methodological challenges that LCA has to face in order to exploit its potential in a circular economy framework, e.g. how to model the recycling of materials in multiple loops. We considered the case of closed-loop recycling for aluminium cans, where body and lid are different alloys, and discussed the abovementioned challenge. The Life Cycle Inventory (LCI) modelling of aluminium processes is traditionally based on a pure aluminium flow, therefore neglecting the presence of alloying elements. We included the effect of alloying elements on the LCA modelling of aluminium can recycling. First, we performed a mass balance of the main alloying elements (Mn, Fe, Si, Cu) in aluminium can recycling at increasing levels of recycling rate. The analysis distinguished between different aluminium packaging scrap sources (i.e. used beverage can and mixed aluminium packaging) to understand the limiting factors for multiple loop aluminium can recycling. Secondly, we performed a comparative LCA of aluminium can production and recycling in multiple loops considering the two aluminium packaging scrap sources. The results from the mass balance of the alloying elements showed that the limiting alloying element for continuous can-to-can recycling is Mn. Therefore we quantified the amount of Mn and primary Al that needs to be reintegrated in each scenario according to the recycling rate and used this information to perform an LCA of 30 recycling loops based on the actual alloy composition. From the comparative LCA the closed product loop option (i.e. using used beverage can scraps) turned out to have lower environmental impact than the open loop option (i.e. using mixed aluminium packaging scraps), at least with regard to climate change.

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### Creating an LCA end-of-life approach taking into account all the benefits of material-loops

M. Vargas Gonzalez, L. Hamon, Quantis; S. Duhamel, Eco-mobilier

In recent years, Circular Economy has gained enormous momentum and most countries encourage recycling loops as a sustainable and economically interesting way of handling the end-of-life of consumer goods. Currently, LCA is the favored method when evaluating these loops. However, under certain circumstances, LCA and circular economy have had opposing views. This is notably true in the case of

waste management, where energy recovery might be seen as the most environmentally friendly technique for some materials like wood or some plastics, going against the trend encouraging recycling and circular economy. This issue is a direct consequence of today's "next in line" approach, where environmental evaluations will only take into account the next life cycle of a recycled material, often forgetting that material-loops are rarely infinite and that energy content is not lost. In fine, most materials can still be used for energy production and the benefits should be shared between every life cycle. During this presentation, it will be shown how Quantis and Eco-mobilier collaborated and developed a new method to evaluate the environmental impacts and benefits of recycling, taking into account not only the direct benefits (avoided primary material production) but also the benefits occurring further along the value chain (energy recovery). Moreover, as every life cycle of a given material is taken into account, the developed approach can be used to take into account material dissipation in LCA, one of the major issues that must be tackled to develop circular economy. A case study, based on Eco-mobilier's experience with wood furniture recycling, will further illustrate how this method can be used operationally and Quantis' experts will discuss how to generalize this approach on other contexts and the limitations of the developed calculation method.

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### **Cloosing the loop: feasibility of new approaches for assessing resources conservation in anthropogenic systems**

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To assess properly the use of the resources by anthropic systems, and ultimately to keep resources in (close) loops, there is the need to better identify the points in the value chain where a resource can be considered as being not anymore available for human use or to be available to a lesser extent. According to the current LCA practice, depletion of resources is considered occurring only at the interface between nature and technosphere. Depletion of resources, due to the intrinsic properties of a product is not well captured (e.g. a specific design preventing the possibility of recovering valuable materials; the inherent properties of an alloy preventing the recovery of the dissolved elements or loses them into the slag phase; the combination of different materials or material connections,...). If the potential impact of resource depletion is only considered in relation to the exchanges of resources at the interface between ecosphere and technosphere, the information associated to what happens within the technosphere is irremediably lost. Hence, the burdens and benefits associated to depletion of resources are shifted exclusively to the life cycle stages where extraction of raw materials takes place and to the end-of-life in the case of recycling (e.g. through modelling of displaced primary resources due to recycling). This approach does not help in identifying how to depict and improve the resource efficiency of a supply-chain and to identify the life cycle stages that are responsible for causing losses of resources: as such, it is not fully aligned to what LCA aims at, as also stated in ISO 14040 "*shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided.*" Therefore, we developed a more comprehensive model for resource assessment compared to what is done in current LCA practices, acting on two levels: 1) Expanding traditional Life Cycle Inventories to track flows of resources also within the technosphere, 2) Defining a new characterization model to be applied to the newly built inventories: adopting characterization factors which associate a potential impact to the resource flows occurring also within the technosphere. The above approach will help to associate «depletion» of resources to those processes and life cycle stages which will not allow the recovery and recycling of resources and which should be seen as the focus for improvement in order to maintain resources in the loop.

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### **Sustainable circular bioeconomy in forest industries - How can LCA support the transition?**

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Finland has large forest resources and forest industries play a significant role in the economy. Originally a commodity and bulk manufacturing sector is currently in the need of renewal due to changes in a demand for traditional wood-based products on the global market. Transition to a circular bioeconomy is anticipated not only to offer opportunities to improve economic profitability, but also resource efficiency and an overall sustainability of the sector. Innovation and development of higher value-added products, establishment of new value chains and improved resource efficiency are the key to achieving the transition. In this paper we present conceptual examples of closing loops in production systems utilising wood biomass as a material feedstock - wood cellulose textile fibres and wood polymer composites. Both examples represent higher value added products. Moreover, both offer the possibility of being recycled multiple times and thus effectively contribute to closing the material loops. Wood cellulose textiles can be produced out of pulp, similarly to paper, and can be recycled practically within

the same process together with other cellulose-based fibres, such as cotton. Wood polymer composites can be produced out of sawdust, a pulp mill by-product, and plastics, e.g. recycled post-consumer plastic waste, and it can be recycled into a new composite. We provide a discussion on how life cycle assessment (LCA) can support the transition of forest industries towards sustainable circular bioeconomy, as well as identify the methodological challenges related to the LCA application in this area. In particular we touch upon the issues of multiple loop recycling, substitution and product life span. We present preliminary LCA results for the two example cases. Moreover, we discuss aspects of the transition in a wider context. The preliminary results indicate that the outlined system could deliver substantial climate change mitigation benefits, especially if multiple recycling loops are taken into account, substitution of virgin raw materials is assumed and the use of more carbon-intensive materials is avoided. Recycling of the studied materials could effectively slow down the release of biogenic carbon dioxide emissions into the atmosphere. Closing loops provides interesting renewal opportunities for Finnish forest industries in the transition towards the circular bioeconomy, but also challenges in the practical implementation.

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### **When logistics is significant for closing loops: A sensitivity analysis of distance and transport alternatives for different types of livestock manure**

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Anaerobic digestion is considered an efficient processing technology to reduce environmental impacts from livestock manure management. Manure processing at a biogas plant is one of the stages to close nutrient cycle loop from livestock production, when nutrients from digestate are used as organic fertilizer in cereal crops, and those are used to feed livestock. Biogas production can be conditioned by operation processes and feedstock methane production capacity. Additional constraints can vary the environmental effects of this processing technology, such as feedstock transport options. In this context, the objective of this research was to assess the environmental impact of manure processing at a biogas plant and to investigate the variability of results for manure biogas production capacity and transport alternatives. The environmental analysis was conducted using LCA. From the anaerobic codigestion of manure, electricity and digestate were produced. Digestate was separated mechanically in liquid and solid fractions. Emissions from fraction storages were included in the assessment. The system was expanded to take into account the avoided production of electricity from the grid. The functional unit was 1 kWh electricity. The analysis included anaerobic co-digestion of three manure biogas producing capacities (10, 15 and 20 m<sup>3</sup> biogas·t<sup>-1</sup>), with a 65% CH<sub>4</sub> content, and at a rate of 76% of manure and 24% of cosubstrate. For each type of manure, transport options were the combination of increasing distances (10, 20, 30 km) and medium and high loading lorry capacities (7.5-16 and 16-32 ton). Manure transported by tractor was also analysed. Primary data were from a biogas plant in the North of Catalonia, Spain. Secondary data were from ecoinvent v3 database. ILCD midpoint method was used for impact assessment. Results showed, for climate change potential, that alternatives with increasing biogas production capacity and equal distance and type of lorry, made the highest impact reductions (up to -62%). Comparing options with same manure biogas production capacity and type of lorry but increasing transport distances, impact increased up to 14%. The smallest differences were found comparing alternatives with the same type of manure and distance but different lorry capacity (reductions up to -4%). Transport by tractor could be limited for distances lower than 5 km. LCA has proved to be useful to assess hotspots and also in management decision support.

## **LCIA modelling of resources and emissions - new developments and applications (II)**

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### **Assessing the environmental impacts of integrated weed management strategies in pasture systems using LCA**

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Integrated weed management (IWM) in pastures employs multiple strategies including the use of chemical herbicides and physical removal to control established plants and competition from desirable pasture plants to limit the reinvasion of new weeds. The impact of serrated tussock (*Stipa trichotoma*) invasion, one of the worst perennial grass weeds in southern Australia, and subsequent IWM strategies in a wool enterprise based on temperate native pastures in eastern Australia was examined using cLCA. IWM strategies included application of the herbicide flupropanate by boom and/or spot spray and two stocking rates (0.5 or 0.75 animal units per ha). Systems were modelled using an AusFarm biophysical

model validated with on-ground data to estimate livestock production and emissions. The biophysical models used climate projections from 2015 – 2044 from the ECHAM5/MPI-OM global circulation model with a representative concentration pathway of 4.5. The model was set to supplement sheep intake with wheat grain when sheep condition score was < 1.5. Biophysical model outputs were used to populate a LCA model to estimate the impacts of producing 1 kg of greasy wool at the farm-gate. The co-production of mutton was dealt with using system expansion. IWM strategies were compared to a reference system of uninvaded native pastures providing the relative impact of changes to the system. Impacts of interest were climate change (CO<sub>2</sub>-e), landuse (ha yrs<sup>-1</sup>) and fossil fuel requirements (oil eq.). Impacts were cumulative over the 30 year period and climate change (CC) impacts were adjusted annually to account for atmospheric decay of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. Results indicated that impacts were driven primarily by supplementary feeding of wheat. Wheat has more energy than native pastures, resulting in more efficient rumination, a reduction in enteric methane and a lower CC impact. The use of wheat does require more land to produce wool and use of fertilizers/tractors for the wheat production which increased the fossil fuel requirements for the system. More wheat was required for systems that serrated tussock invaded relative to the reference system because serrated tussock displaced productive grasses. This suggests systems implementing IWM strategies will have a lower CC impact but greater landuse and fossil fuel resource impacts. The study demonstrates the ability of LCA as a tool to estimate the impacts of weed invasion in pasture systems and IWM strategies in these systems.

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### **Missing induced dinitrogen monoxide emissions in LCA**

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Several nitrogen-containing compounds are emitted from technosphere to the environment (ecosphere) by human activities, and deposition of reactive nitrogen causes "indirect" N<sub>2</sub>O emissions (sometimes called "induced" emissions). For this well-known phenomenon, the IPCC guidelines provide indirect emission factors for agricultural processes according to nitrogen volatilization and leachate. IPCC recommends using them for all activities, including non-agricultural ones. However in practice, the Life Cycle Inventory (LCI) databases and carbon accounting consider these indirect emissions only for agricultural production systems. The goal of this study is to quantify the consequences of the omission of the indirect N<sub>2</sub>O emissions for all the other economic activities. The Ecoinvent 3.1 (allocation, default) library is used in the present work. Over the 11,332 Ecoinvent unit processes, 7,275 are without GHG gases and without indirect N<sub>2</sub>O precursor (e.g. "market" type processes). Over the 4,057 remaining "GHG" processes (excluding the 236 agricultural products where it was already done), 2,735 processes show discrepancy for indirect N<sub>2</sub>O emissions (67% of the inventories). For 2% of the 4057 selected processes, the increase is more than 100%; for 12%, the increase is bigger than 10%; for 18% bigger than 5% of increase. The initially non-emitting processes (with now Climate Change scores due to reactive nitrogen) represent 7% of the set. Consequently, for 25% of "GHG" processes, new induced N<sub>2</sub>O emissions are significant (up to 5% of increase or new emitting processes). This work shows the inconsistency in the current N<sub>2</sub>O environmental flow between agricultural activities versus the others sectors. The LCA practitioners should therefore use nitrogen-emitting process with much care and consider indirect N<sub>2</sub>O emission calculation. On a mainstream LCA perspective, a solution to cope with this gap is the definition of new Climate Change characterization factors for nitrogen-containing substances, considering indirect N<sub>2</sub>O emissions as a part of ecosphere and thus at the life cycle impact assessment level.

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### **The zinc paradox - a problem for USEtox-based indicators of national chemical footprints?**

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Considering the immense problem of chemical pollution worldwide, there is a great need for methods that can be used to calculate indicators of chemical footprints. Such indicators can be calculated for products and services using life cycle assessment (LCA), but also for whole nations. Indicators of national chemical footprints may include emissions within the nation's borders only, or also emissions related to consumption (thus having a life cycle perspective). A limited number of studies (< 5) have attempted to calculate indicators of national chemical footprints using the USEtox consensus model for toxicity impact assessment in LCA. One of these is our calculation of indicators of a national chemical footprint for Sweden. Two other studies have made similar assessments for Europe. Using the national perspective of these studies enables a rough validation of USEtox results, since the indicators of national chemi-

cal footprint based on USEtox can be compared to non-LCA toxicity assessments done on national levels. Such validations are not possible for LCA studies of single products. Notably, the results of existing assessments of indicators of national chemical footprints, including our Swedish study, all pinpoint zinc as the dominating substance. Zinc typically accounts for >50% of the toxicity impacts for both ecotoxicity and human toxicity. For ecotoxicity, this is not unreasonable considering the notable toxicity of zinc to aquatic organisms. For human toxicity, this result is more surprising. Zinc is an essential trace element for humans that many take as a dietary supplement to prevent zinc deficiency. Non-LCA sources describe zinc as “relatively harmless” to human health. The World Health Organisation (WHO) does not list zinc among the top ten chemicals of major public health concern, although there are other metals on the list (mercury, lead, cadmium and arsenic). These contradictory claims about zinc’s health impact seem to constitute a paradox. We present a review of existing studies assessing indicators of national chemical footprints, and of toxicological research related to zinc. We further discuss potential causes of this zinc paradox, as well as implications for assessments of indicators of national chemical footprints with USEtox.

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### **Advancing the impact assessment of releases of nanomaterials: combining the USEtox and the SimpleBox4Nano models**

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To date only few LCA studies on manufactured Nanomaterials (MNMs) have been carried out, among others due to the gap of knowledge on fate, exposure and toxic effects – hindering the calculation of respective characterization factors for the impact assessment of releases of such particles into the environment (Miseljic and Olsen, 2014). For such an assessment of toxicological impacts, the USEtox model is seen as the default fate-exposure-effect model for organic and inorganic chemicals – however, so far this model is not suitable for MNMs. Within its activities in an on-going H2020 project, EMPA works on the expansion and adaptation of the USEtox model in order to cover releases of MNMs into the environment. This work is of great relevance in view of the development of a methodology in the area of LCIA for a sound and adequate assessment of human and toxic impact of releases of MNMs. To achieve this objective, we combine the principles of the recent, nano-specific fate multimedia model “SimpleBox4Nano” (Meesters et al., 2014) with the USEtox framework, defining three sub-compartments in order to describe the masses of free, aggregated and attached MNMs in each media. The fate of MNMs in air, freshwater, soil, and sediment environmental media is first evaluated at steady-state by the inclusion of nano-specific fate processes (aggregation, attachment) and calculated as first order kinetics. Hence, similarly to the USEtox model for organic substances, this established “USEtox-Simple-Box4Nano” multimedia fate model provides a fate factor (FF) of the examined MNM, expressed in term of a rate constant in day<sup>-1</sup>. Our developed fate environmental model has been tested and applied to several type of MNMs, ranging from metal oxide nanoparticles (i.e. nano-TiO<sub>2</sub>) to Carbon-based materials (i.e. Fullerene). In a second step these FF are then, in accordance with the USEtox framework, combined with according exposure factors (XF) and effect factors (EF) in order to provide Characterisation Factors (CF) for various MNMs. In a further step we have extended the approach further in order to propose a dynamic version of the above described “USEtox-SimpleBox4nano” model in order to study the time to reach a steady state situation; final objective of all these efforts being the definition of the USEtox model with a high level of specification for ENMs.

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### **Towards a consideration of operating orbits of the outer space into a new LCIA resource framework**

T. Maury, University of Bordeaux / ISMCyVi; P. Loubet, Bordeaux INP / ISM CyVi; J. Ouziel, Airbus Safran Launchers / Design for Environment; G. Sonnemann, University of Bordeaux / ISM CyVi

A rising sustainability concern is occurring in the space sector: 29,000 human-made objects, larger than 10cm are orbiting the Earth but only 6% are operational spacecraft. Space debris are today a significant and constant danger to all space missions. Also, according to recent requirements in the space law, operators of space missions have to ensure that space vehicles do not become space debris at the end of their mission. It becomes compelled to design all new space missions considering End of Life requirements in order to ensure a sustainable use of space orbits. LCA has been identified by the European Space Agency as an adequate tool in order to measure the environmental impact of spacecraft missions. Hence, our challenge is to integrate the space debris related impacts in LCIA to broaden the scope of LCA for space systems. In order to address space debris issues in a comprehensive way, impact pathways linking elementary flows to environmental mechanisms (midpoint) and damages (endpoint) should be defined. A particular concern when dealing with space debris is the fact that the outer space near earth is not included as such in the ecosphere, which complicates the perception of environmental



impact of spacecraft on their overall life cycle. The Area-of-Protection (AoP) "Resource" seems to be the most relevant to reflect the depletion of available orbits by the generation of space debris. Moreover a new perspective on criticality could be developed for the AoP "Resource" in the LCA framework because the focus on environment alone is not enough to address this AoP in an adequate manner.<sup>1</sup> The generation of debris in strategical orbits can damage operating satellites and thus, leads to a decrease of the resource availability so that a new creation of economic value would be constrained. The lack of access to this resource in the future (scarcity) could be handled as socio-economic impacts. Several «perspectives», dealing with Safeguard Subjects for the AoP Resource, can be defined<sup>2</sup>. Various environmental or socio-economic mechanisms are covered by the perspectives so that a first impact chain could be determined (from midpoint to endpoint). Based on this work, we propose a first attempt to establish impact pathways linking outer space use to resources. This framework will be the basis to define new indicators related to space debris. 1 G.Sonnemann, *et al.*, *J. Clean. Prod.*, 2015, **94**, 20–34. 2 J.Dewulf, *et al.*, *Environ. Sci. Technol.*, 2015, **49**, 5310–5317.

## Special session: LCA for policy evaluation and policy-making

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### Life cycle thinking and assessment supporting European policies: an overview

S. Sala, European Commission - Joint Research Centre / Sustainability Assessment unit; R. Pant, European Commission / Institute for Environment and Sustainability

Life Cycle Assessment (LCA) is a methodology for taking into consideration environmental impacts along the product life cycle, through multi-criteria assessment covering a wide variety of pressures and impacts associated with human health, ecosystem health, and resources. In a policy development context, by applying a life-cycle methodology, priorities can be identified more transparently and inclusively and trade-offs can be assessed. Hence, policies can be targeted more effectively so that the maximum benefit is achieved relative to the effort expended. Given their specific features, Life cycle thinking (LCT) and LCA have a high potential to be used more extensively in policy making. So far, several policies have already integrated LCT as guiding principle. Nonetheless, further development of LCA and adaptation to policy needs should ensure more consistent consideration of life cycle aspects in policy making, supporting the policy cycle in different steps, e.g. in policy impact assessment and target setting. Adopting an historical perspective, a review of current EU policies and communications explicitly mentioning LCA and LCT is performed. The review shows that over time LCA and LCT have been used in almost all the policy steps: from «Policy Anticipation and Problem Definition» up to policy implementation and monitoring. This review is the basis for analyzing the potential of further adopting LCA, especially in light of the recent «better regulation» communication of the European Commission, in which LCA is explicitly mentioned as a tool for policy impact assessment.

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### LCA in assessing the efficiency of Circular Economy Policies

T. Rydberg, H. Ljungkvist, Y. Zhang, M. Hennlock, IVL Swedish Environmental Research Institute

This project, recently started, investigates how existing and alternative combinations of policy instruments in Sweden can be systematically designed to correct for market failures along the entire life-cycle of products, by combining a Circular Economic (CE) approach with Life Cycle Assessment (LCA). Thus, together a CE-LCA *integrated assessment* will be able to address market failures and quantify policy effects of *efficient combinations* along the entire life-cycle of a certain product, from raw material extraction, production, consumption and waste management to recycling, reuse and remanufacturing. The quantitative CE-LCA integrated assessment is tested in two quantitative real case studies on the mobile phone markets (not further described here) and leisure boat markets in Sweden. The research question is: What existing and alternative Swedish and EU policy design combinations have the largest potential to efficiently increase life-cycle resource efficiency, improve life-cycle energy efficiency and reduce life-cycle CO<sub>2</sub> emissions from leisure boating (sail boats and motor yachts)? Early findings confirm to a large extent the hypothesis that decisions at the design stage have a large influence on the overall environmental impact of a particular product, as will be illustrated in the presentation, using leisure boats as the example. Work is under way to establish an indicator of the relative power of different decision makers influencing the impacts, covering both those decision makers acting along the value chain as well as those acting from a policy perspective.

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### Effects of European regulation and eco-design analysis of environmental impacts from domestic

**appliances: The case of vacuum cleaners**

A. Gallego Schmid, The University of Manchester; J. Mendoza, A. Azapagic, The University of Manchester / Sustainable Industrial Systems School of Chemical Engineering and Analytical Science

**Introduction and methods** The number of vacuum cleaners (VCs) currently in use in the European Union (EU) is equivalent to 213.8 million. Overall, they consume 400 TWh of electricity per year, equivalent to the annual electricity consumption by 9.8 million households. Additionally, as the market continues to grow and product innovation cycles become shorter, the replacement of VCs accelerates. As a result, the amount of VCs waste is growing. Both, the EU eco-design regulation on energy-related products (ErP) and the revised EU directive on waste electrical and electronic equipment (WEEE), are aimed to improve the energy efficiency and minimise waste generation from these products. However, the recently published EU circular economy package stresses that the eco-design of ErP should not only target energy efficiency but to integrate also the consideration of circular economy aspects, such as durability, reparability, upgradability or closed-loop recyclability. The results from a life cycle assessment (LCA) show how much the implementation of these EU regulations by 2020 would help reducing the environmental impacts associated with VCs. Also, a product eco-design analysis shows the hotspots for improvement in order to build circular business models for these products. **Results and discussion** Despite an expected 8% increase in the number of VCs by 2020, all the impacts categories considered would be reduced by 35-48%, except abiotic depletion of elements, with an increase by 4%. These improvements are mainly due to the implementation of the eco-design regulation and the assumed decarbonisation of the electricity. The environmental savings related to the implementation of the WEEE directive will be smaller. Additionally, the WEEE directive will not contribute to improve resource productivity if business-as-usual is applied in waste management. This regulation establishes that least 50% of the weight of the products should be recycled. However, open-loop recycling (product downcycling) would contribute to material losses. The eco-design analysis of a VC representative of the EU market demonstrated only 20% in the effectiveness of disassembly due to the complexity of the product architecture. Design for simplicity and modularity, parts standardisation and labelling, product light-weighting and material substitution were identified as key strategies to improve the "circularity" of the products, save material resources and reduce environmental impacts over time.

**29****Evaluation of Resource Efficiency in Research and Innovation Projects: Challenges and Recommendations of the MEASURE project for Industry**

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The world is facing a resource supply challenge: while the worldwide population is growing, a globalized and fluctuating market makes it difficult to predict market prices and the availability of resources. To tackle this challenge, regions and nations around the world are launching programs/initiatives to increase resource efficiency and reach defined targets. The industry has a key role to play in those programs, especially by getting involved in research and innovation projects. Resource efficiency programs around the world have launched calls to support such projects. In Europe, a portion of the calls from the Horizon2020 funding program focuses on research and innovation in industry, including those launched via the Public Private Partnership (PPP) Sustainable Process Industry through Resource Efficiency (SPIRE). Each of these calls require projects to reach targets (e.g., increase in "the resource and energy efficiency [...] by at least 20%") and project developers need to report the potential increase in resource efficiency achieved by their project. However, there is no consensus on how to calculate resource efficiency today and a wide range of approaches are followed in industry. This does not allow program leaders to compare project results and evaluate the contribution of newly developed technologies to regional or national resource efficiency targets (e.g., a decrease in non-renewable primary raw materials and fossil energy intensities by 30 and 20% by 2030, as set by SPIRE). First, this presentation will highlight the challenges related to resource efficiency evaluation in programs such as Horizon2020 and summarize the outcomes of the SPIRE project MEASURE (Metrics for Sustainability Assessment in European Process Industries) on that specific issue. The definition of resources and resource efficiency will be discussed, as well as the choices to be made by project developers regarding the scope of the analysis (gate-to-gate or life cycle), the resources to be accounted for (material, land, waste...) and the type of evaluation method (accounting or impact assessment method). The challenges associated with these choices will be illustrated by two case studies in the fields of the pharmaceutical industry and agro-waste management. Finally, the presentation will provide pragmatic recommendations to improve the calculation of resource efficiency in the context of innovation projects and the use of the results by industry and project program leaders.

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## **Life cycle assessment for policy-making: Case of the human health impacts from national NMVOC emissions in the EU-27 between 2000 and 2010**

A. Laurent, Technical University of Denmark / Division for Quantitative Sustainability Assessment DTU Management Engineering; M.Z. Hauschild, Technical University of Denmark

Anthropogenic activities results in emissions of chemicals potentially damaging to human health. Among them are the non-methane volatile organic compounds (NMVOCs), which are primarily released from road transportation and solvent use. NMVOCs can cause indirect health damages by contributing to the formation of tropospheric ozone, which induces respiratory and cardiovascular problems, and direct health damages via the toxic properties of some NMVOC compounds (e.g. carcinogens). To which extent do these substances contribute to health impacts, and how effectively have their emissions been managed at policy levels in the past? To answer these questions, we developed a methodology allowing for building national NMVOC emission inventories disaggregated at the level of sectors and individual substances. Using recommended life cycle impact assessment methods, we assessed the impacts on human health of NMVOC emissions for 31 European countries over the period 2000-2010. Results reveal that total NMVOC emissions correlate well with their indirect ozone-formation-related impacts, thus implying that total NMVOC emissions can be used to set up legislative frameworks for minimising this type of impact. In contrast, no correlation was observed between total NMVOC emissions and their direct impacts on human health. Using contribution analyses at process and substance level to identify hotspots, we tracked the causes of these direct impacts to a limited subset of substances, including formaldehyde, acrolein and furan, which primarily originate from transportation sectors and residential sources. The study shows that, although total NMVOC emissions decreased in most European countries between 2000 and 2010, cancer-related effects from NMVOCs increased in some. These results evidence that emissions of carcinogenic NMVOCs have not been reduced sufficiently, and that the total NMVOC emissions should not be used as a stand-alone indicator to frame legislation addressing their health impacts. The work provides a nice example of how LCIA methods and factors (from characterization, normalisation) combined with the use of process and substance contribution analyses can be used to inform policy-making in other fields than the regulation of products. In this context, our results points to the need to support air pollution abatement strategies with quantitative impact assessments, which allow for adapted country-specific management of emissions at sectorial and substance levels.

## **Closing the loop: a sustainable use of resources (III)**

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### **Residues allocation and uncertainty analysis in carbon footprint estimation of cement production in Brazil**

G. Moraga, UFRGS - Federal University of Rio Grande do Sul / PPGEC; I.M. Cruz, UFRGS - Federal University of Rio Grande do Sul / DECIV; A.P. Kirchheim, UFRGS - Federal University of Rio Grande do Sul / DECIVPPGEC; A. Passuello, UFRGS - Federal University of Rio Grande do Sul / DICLN

Cement industry plays an important role in greenhouse gases (GHG) emissions, being responsible for more than 8% of GHG worldwide, mainly due to clinker production. One way to effortlessly slowdown the use of Portland clinker are substitutions with Supplementary Cementitious Materials (SCM), such as industry byproducts, e.g. Fly Ash (FA) and Blast Furnace Slag (BFS), or carbonate materials e.g. Limestone. Standards define cement mixtures types, establishing different ranges of SCM, i.e. in Brazilian context CII series (similar to European CEM II) clinker factor can oscillate between 50-90%, showing uncertainties related with potential environmental impacts in cement production. LCA calculations frequently disregard waste reuse impacts, although its concentrations can reach up to 44% in cement mass. Since industries that produce FA and BFS are energy intense (thermal power plants and pig iron production, respectively), important byproducts contributions to GHG are expected. This work aims to evaluate the variation on cement carbon footprint considering different allocation strategies, presenting uncertainties related to cement mixtures through probabilistic analysis. The functional unit is 1 kg of cement type CII, produced with varying concentrations of FA (Z), BFS (E) and limestone (F), in a cradle-to-gate analysis. Data from Ecoinvent was adapted to the local context, considering information provided by national industry reports and the Brazilian electricity mix. Physical and economical allocation used information from Brazilian industry, applying IPCC 2007 method for impact analysis, and Monte Carlo simulation for uncertainty analysis. Results shows carbon emissions vary considerably according to the clinker factor and the allocation method used. Without allocation, impact values range between: 0,51-0,82 kg CO<sub>2</sub>-eq for CII-E; 0,66-0,84 kg CO<sub>2</sub>-eq for CII-Z and 0,75-0,87 kg CO<sub>2</sub>-eq for CII-F. CII-E and CII-Z emissions increased respectively 38% and 25% with physic allocation, 1,9% and 0,27% with economic allocation. Since byproducts market availability can limit SCM amount, the application of

different allocation strategies and uncertainty analysis enhances the understanding of waste reuse practices benefits, allowing more confident decisions related to the management of these byproducts.

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### **Estimating avoided environmental impacts of rare earth production through rare earth recycling from NdFeB magnet material**

R. Schulze, Öko-Institut e.V.; M. Buchert, Oeko-Institut / Resources Transport

The primary production of rare earths (RE) is associated with environmental impacts from mining and processing, and potential geopolitical supply shortages have been an issue in recent years. Recycling of those elements which are highest in demand and therefore determine production quantities has been discussed as a means to reduce primary production quantities and avoid overproduction of co-products (Binnemans and Jones, 2015). Previous LCA studies have demonstrated that RE production through recycling is advantageous over primary production from an environmental perspective. Whilst those studies investigated the environmental advantages associated directly with the respective technical processes, the issue of co-production has not been their focus. The output ratio in the joint production system is fixed by the RE content in the ore, but the primary production of RE is not in balance regarding supply and demand of individual rare earths. In a previous MFA study, we constructed scenarios to estimate future global recycling potentials of rare earths from NdFeB magnet material (Schulze and Buchert, 2016). The focus of this study is a consequential/ scenario LCA to determine potential environmental impact savings associated with the utilization of these recycling potentials. The potential estimates are combined with life cycle inventory data from the literature and market information to model the effects of recycling on primary production. Potential environmental impact savings achievable by partly meeting global Nd, Pr, Dy and Tb demand through recycling are quantified for two NdFeB demand scenarios for the years 2020, 25 and 30. Absolute saving potentials are dependent on the contents of the elements determining primary production quantities in the ores and secondary scrap, and overall quantities of rare earths which can be provided from secondary sources. The approach could be applied to other joint production situations. References Binnemans K, Jones PT. Rare Earths and the Balance Problem. *J. Sustain. Metall.* 2015;1(1):29–38. Schulze R, Buchert M. Estimates of global REE recycling potentials from NdFeB magnet material. *Resources, Conservation and Recycling* 2016(113):12–27.

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### **Identifying indirect effects of primary production of rare earth elements in consequential LCA**

D. Schrijvers, University of Bordeaux; P. Loubet, Bordeaux INP / ISM CyVi; G. Sonnemann, University of Bordeaux / The Life Cycle Group CyVi

Consequential Life Cycle Assessment (cLCA) is applied to identify the effects of a decision on the environment. This decision is often related to the increased or decreased production of a product. If this product is the output of a multi-output system, the co-products are modelled by substitution. A special case of co-production is the primary production of rare earth elements (REEs). There are no single-output production routes for REEs, and the substitution of an alternative production route can therefore not be modelled. Current modelling practice assumes that the increased demand for a single REE partly leads to increased supply from mining, and partly to a reduced use in other applications, where the demand for an alternative material is now increased. The co-products from the mining process can in their turn substitute the use of alternative materials in other applications. However, this modelling approach assumes that the market for all REEs is balanced. This is not the case, as for several elements a surplus exists. Increased production of these elements might rather lead to an increased supply to stocks, than an increased use in other applications. Stockpiling has already been identified as a missing element in cLCA.<sup>1</sup> We propose a framework for cLCA to identify the potential effects of the demand for a product including the element of stockpiling. We apply a system dynamics approach, assuming general market behavior. It has been argued that inventory modelling must be consistent, and that a single approach should be applied to co-production and recycling.<sup>2</sup> Our objective is to extend this consistency to special cases of co-production, such as the production of REEs. Therefore, the framework is applicable to all types of (co-)production. We identify the similarities and differences between the modelling of recycling, regular co-production and the co-production of REEs in cLCA, and we explore the expansion of the approach from the analysis of marginal changes to incremental changes. We conclude that the current modelling of REEs in cLCAs is too simplistic. We provide a framework that helps to identify the relevant consequences of any production and to point out the interactions that require special attention in the case of REEs. This approach contributes to increased consistency and realism in the LCI of a cLCA. Johnson et al., *J. Ind. Ecol.*, 2013, 17, 5, 700 – 711. Schrijvers et al. *Int. J. Life Cycle Assess.*, 2016

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## **Renewable feedstocks - Fuels vs. Chemicals context**

A. SEKAR, A. Shastri, SABIC Research Technology Private Ltd / Sustainability; S. DE BOER, SABIC / POLYMER; B. BOSMAN, SABIC; G. GOVONI, SABIC / Sustainability

Recent advancements in climate science warn of a dire need for drastic acceleration of efforts and significantly steeper reduction in global GHG emissions. The European Union has been one of the spearheads of this global mission & renewable energy has been key to EU's essential shift to a low carbon economy. The growth of biodiesel as a substitute for conventional fossil-derived diesel assumes greater significance over other biofuels by merit of the scale and rate of market adoption in recent years. Typical GHG savings from use of biodiesel in place of fossil diesel range from 36% to 88%<sup>1</sup> depending on the choice of bio-feedstock and to some extent on the choice of technology as well. Besides use as fuel blends, certain types of biodiesel can also be a potential feedstock for chemical industry. One example is use of HVO diesel (hydrotreated vegetable oil, produced from hydrotreating of vegetable oils and animal fats) as a steam cracker feedstock towards subsequent production of polyolefins. This work attempts to understand the scales of mitigation possible with such alternative uses of biodiesel in comparison to that possible when used as a transportation fuel. Such a comparison is not envisaged to help choose one application for biodiesel amongst existing and emerging alternatives but to gain understanding of the scales of GHG mitigation possible with such new developments. This in turn will pave the way for increased environmental benefits arising from wider market adoption of biodiesel for varied applications, which will be "mission-critical" in the coming years towards achieving steeper reduction in GHG emissions. This study is based on Cradle to Grave life cycle assessment of two potential options of use of 1 kg HVO diesel: 1. As a transportation fuel substitute for fossil diesel and 2. As a cracker feedstock substitute for naphtha. Biogenic carbon accounting was done based on PAS 2050 standard. The study concludes that both options for use of HVO diesel create significant mitigation potential in the range of 83-94% compared to conventional fossil alternatives. This work also reviews methodologies available today on temporary carbon storage for application in the context of this study apart from substantiating the value created by circular economy of bio feedstock derived plastics. This study also evaluates impacts from land use change & methane non-capture when palm oil based feedstocks are used for HVO diesel production.

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## **Life cycle environmental impacts of carbon fibre recycling and reuse in automotive applications**

F. Meng, The University of Nottingham / Department of Mechanical Material and Manufacturing; J. McKechnie, University of Nottingham / Mechanical Materials and Manufacturing Engineering; S.J. Pickering, The University of Nottingham / Department of Mechanical Material and Manufacturing

Carbon fibre reinforced plastic (CFRP) is being increasingly used in the transport industry to reduce energy consumption and carbon emissions through weight reduction while providing excellent mechanical performance. As a high value and energy intensive material to manufacture, recovering and reusing carbon fibre could achieve substantial energy and resource use savings. In this paper, we evaluate CFRP recycling by a fluidised bed thermal process and the manufacture of automotive components from recovered carbon fibre (rCF). The fluidised bed process oxidises the epoxy matrix, allowing CF recovery with minimal degradation of mechanical properties. Automotive components can then be manufactured from rCF by papermaking and compression moulding processes. We quantify the life cycle environmental impacts of CF recovery and use in place of conventional materials (steel, aluminium, GFRP) and virgin CF. Mechanical properties of rCF polymers are experimentally measured to ensure functional equivalence (e.g., bending stiffness). A vehicle bulkhead component, originally made of mild steel with the mass of 5.8 kg, is selected as a case study for the analysis. Model results demonstrate that rCF can be the lowest primary energy demand (PED) and greenhouse gas (GHG) emissions of the materials investigated. PED of the rCF components with epoxy and polypropylene (PP) matrices (both 30% fibre volume fraction) are reduced by 38% and 54% relative to mild steel, respectively, primarily due to high use phase energy consumption of the heavier steel component. Comparing with other lightweighting materials reveals that the rCF components can reduce PED by 24% to 51% relative to aluminium, glass fibre and vCF reinforced sheet moulding compound, and vCF reinforced polypropylene. Comparing the rCF materials indicates that rCF-PP can achieve lower life cycle PED and GHG emissions than the rCF-epoxy component due to lower energy use in manufacturing. Similar savings in GHG emissions are achieved, with rCF-PP and rCF-epoxy reducing GHG emissions by 48% and 30% relative to the reference mild steel component. The study findings are robust across a range of sensitivity analyses, including uncertainty/variability in CF recycling and rCF manufacturing processes and the lifetime of the automotive vehicle. Ongoing work will investigate the life cycle cost implications of CF recycling and potential rCF applications/markets.

## Special session: UNEP-SETAC Flagship project on global LCIA harmonisation and recommendation: case studies and application results from the Pellston Workshop in January 2016

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### Water footprint profile of virgin and waste cooking oils: assessing freshwater degradation and comparing the WSI and the AWARE methods to address scarcity impacts

C. Caldeira, University of Coimbra / Mechanical Engineering; P. Quinteiro, University of Aveiro / Department of Environment and Planning; . Castanheira, University of Coimbra; A. Boulay, CIRAIQ - École Polytechnique de Montréal / Chemical engineering department; A. Dias, University of Aveiro / CESAM Department of Environment; L. Arroja, University of Aveiro; F. Freire, University of Coimbra

This paper presents an assessment of the water footprint (WF) profile for three crop-based vegetable oils (palm, rapeseed and soya) and waste cooking oil (WCO), which are feedstocks for biodiesel produced in Europe. The assessment is performed following the ISO 14046 guidelines, addressing the water scarcity footprint and the environmental impacts due to freshwater degradation. The water scarcity footprint was calculated using the WSI and AWARE methods and the freshwater degradation impacts for freshwater and marine eutrophication (ReCiPe), aquatic acidification (IMPACT), and human toxicity and freshwater ecotoxicity (USETox). Cultivation, oil extraction, feedstock transportation and oil refining are included in the virgin oil systems whereas, for the WCO, the stages considered are the collection and refining. The following crop cultivation locations were considered: Colombia and Malaysia for palm; Argentina, Brazil and United States for soybean; and, Germany, France, Spain, Canada and US for rapeseed. Results obtained with the WSI and AWARE methods lead to same conclusions about the systems with higher and lower freshwater consumption impact and the stage contributing the most to this impact: cultivation. Nevertheless, the rank order obtained by the two methods differs for the oils systems with close results. This is because the indicators of each method are calculated on different basis: WSIs are calculated based on withdrawal-to-availability ratios while the AWARE characterization factors (CFs) are determined based on demand-to-availability ratios comprising the ecosystem and human water demands. Since the AWARE CFs represent the potential environmental impacts due to freshwater consumption more comprehensively than WSIs (because they are calculated considering the ecosystem and human water demands), the AWARE method seems more adequate to support decision. The freshwater degradation impacts of virgin oils are mainly caused by the fertilizers and pesticides used in the cultivation of oil crops. WCO systems present the lowest impacts for all categories except for human toxicity. The WF profile calculated can be used to optimize G\_oil blends" in biodiesel production.

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### Calculating the Water Scarcity Footprint using AWARE: The case of a Volkswagen car

Yasmine Emara, Technische Universitaet Berlin

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### Application of AWARE to bottled water and beverages

Sébastien Humbert, Quantis

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### Water scarcity footprint for green HDPE

Yuki Hamilton Onda Kabe, Braskem

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### Rate of climate change vs. long-term warming: Application of the revised climate change impact assessment method to a biogas power plant

C. Lausset, NTNU University / Energy and Process Engineering Industrial Ecology Programme; C. Jordan, F. Cherubini, NTNU / Energy and Process Engineering

Traditionally, LCA and carbon footprint studies quantify climate impacts of specific human activities by aggregating well-mixed greenhouse gas (WMGHGs) emissions into the so-called CO<sub>2</sub>-equivalents using the Global Warming Potential with a 100-year time horizon (GWP100) as the default metric. The latest IPCC Assessment Report shows a variety of characterization factors alternative to GWP100, most notably those based on the instantaneous surface temperature response (GTP). Different metrics focus on

different aspects of the climate system response to emissions, but these are rarely taken into account in LCA, where GWP100 is by far the most common metric. Despite its name, GWP does not equate climate forcing agents on the basis of their effects on surface temperature, nor does it consider them under a specific climate policy target, such as the goal to limit warming to 2 degrees above pre-industrial levels. Also, existing impact assessment methods only assess contributions from WMGHGs and do not take into account impacts from emissions of Near –Term Climate Forcers (NTCFs), such as aerosols and ozone precursors. The UNEP/SETAC Global Warming Task Force identified key insights from the climate science literature that are of relevance for advancing climate impact assessment frameworks in LCA, and came out with recommendations. GWP100 should be used to assess short term impact while GTP100 should be used for the long-term impact category. The shorter-term impact category provides information about the rate of climate change, whereas the long-term climate change impact category better inform about the future temperature peak levels. Because the confidence level in the characterization factors for NTCFs is lower than that for WMGHGs, it is recommended to perform a sensitivity analysis of the influence of NTCFs on shorter-term climate change using the range of characterization factors for both GWP20 and GWP100. In this study, a biogas power plant producing electricity through anaerobic co-digestion of sewage sludge and other organic wastes is used as a case study. Results show the importance of using two complementary impact categories (one based on GWP100 and one on GTP100) and the potential contributions from NTCFs. In this analysis, NTCFs cause a net cooling effect, because the cooling from mainly NO<sub>x</sub> (and to a smaller extent from SO<sub>x</sub> and organic carbon) largely offset the warming associated with emissions of black carbon and ozone precursors (CO and VOC).

## Special session: Application of Social LCA in industry - from methodology to practice (*Cancelled*)

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Cancelled

42  
Cancelled

43  
Cancelled

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Cancelled

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Cancelled

## Implementation of the land use framework into LCA practice

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**Global land demand in the future: food, feed, energy and forestry**

L. Fauvet, L. Hamelin, SDU / Dep of Chemical Eng Biotechnology and Environmental Tech  
With the growing bioenergy demand, rising World population and changing alimentation towards higher meat and protein-rich diets, it is well-acknowledged that integrated approaches to supply future food and energy demands are key to minimize the future land demand. The overall goal of this study is two-fold; it endeavours to quantify the global demand for land in the future and to assess the environ-

mental performance of various mitigation strategies addressing the agriculture/forestry/energy nexus. The present study attempts to present the food, feed, energy and forestry demand forecasts side-by-side, rather than looking at each of these sectors in isolation as typically done. A review of 16 leading global scenario development was performed, where the projections for short- and long-term future demand for food (breakdown per meat and crop types; including the grass for grazing animals), energy (electricity, heat, industry), transport (passenger cars, heavy duty, sea & aviation) and wood (pulpwood, industrial round-wood, wood fuel) were inventoried and extrapolated when needed. Only scenarios and sub-scenarios featuring a global trade, stabilizing population growth and rapid economic & technological developments were used. Results were compared in EJ of primary energy demand. On the basis of these insights, the potential of selected mitigation measures was tested in order to reduce the land demand for each sector. Our results showed that the future food demand (2050) is forecasted to reach 30 to 42 EJ y<sup>-1</sup>, including a meat demand varying between 5 and 13 EJ y<sup>-1</sup>. The feed demand is expected to reach up to 235 EJ y<sup>-1</sup>; the pasture needed for ruminant animals (bovine, ovine) representing up to 75% of this. Reducing this demand is therefore key to reduce the pressure on land. The overall biofuel demand is foreseen to rise to 4 to 15 EJ y<sup>-1</sup>, in comparison to ca. 5 EJ y<sup>-1</sup> currently. Though the demand for aviation fuels is expected to increase 3-fold, short- and long-distance road transport still completely dominate the future transportation demand (84% of the transport demand). The overall demand for wood varied between 22 and 31 EJ y<sup>-1</sup>. Results for mitigation measures showed that replacing 50% of the beef demand by chicken allows to reduce the feed demanded by ca. 20%. On the other hand, supplying all transport demand through biofuels would require up to 100 EJ y<sup>-1</sup> of biomass, which is ca. 3 times the food demand.

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### **Characterization factors development at a land management practice level: learnings from a forestry case study for land use impact assessment on climate change**

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The UNEP-SETAC guideline on global land use impact assessment in LCA, published in 2013 by Koellner et al., provides key recommendations to properly develop characterization models related to land use interventions, i.e. occupation and transformation. However, available characterization factors for such models are mainly site-generic and fail to consider different land management practices. This study thus aimed at assessing the feasibility of the development of characterization factors at a land management practice level, based on the UNEP-SETAC guideline. Two land use impact assessment models for climate change related to carbon sequestration potential were considered: the method published in 2010 by Müller-Wenk & Brandão as well as a new method recently developed by Benoist & Cornillier (publication under writing). These methods were applied to different forestry land uses. Several cases were performed in an attributional approach, considering three species (Douglas-fir, eucalyptus, chestnut) according to various silvicultural systems (coppice, short rotation coppice, high stand) with or without evolution of forestry practices (shortening of the rotation, intensification of harvest...). In a consequential approach, one case was studied: a harvesting intensification of eucalyptus short rotation coppice. Based on these applications, this work identified four main difficulties when applying the current land use framework: \n- Matching real dynamics to the framework modelling;\n- Allocating quality variations to land transformations and/or successive land occupations;\n- Developing characterization factors for the consequential modelling approach; and\n- Dealing with dynamic equilibria of land use properties.\nFinally the UNEP-SETAC guideline remains mainly theoretical and deals with generic issues, which can be insufficient when building characterization factors at a land management practice level based on field data.

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### **Spatial trends in soil erosion and runoff potential: Is it relevant to discriminate between crop-specific land use in a LCA context?**

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Current life cycle impact assessment (LCIA) methodologies generally provide characterization factors (CFs) for coarse land use type such as artificial surfaces, agricultural surfaces, forest and semi-natural areas, wetlands and water bodies. The increasing demand by life cycle assessment (LCA) applications for agricultural processes and products requires discrimination between different crop types beyond the simple distinction between irrigated or rain-fed cropland and intensive or extensive land cover types, but only a few research works address crop specific characterization in LCIA. This work aims to assess the relevance to develop crop-specific CFs to characterize land use impacts through two soil primary support ecological functions (soil resistance to erosion and runoff) in relation with the spatial character of this impact category and for three crops: maize, soybean and wheat. Spatially differentiation is pu-



shed way beyond the biogeographic archetypes up to a resolution of 30 arcmin grid cell. Results show that without knowing where the crop is grown, there is little relevance to use crop-specific CF and using actual generic agricultural CF is sufficient. When the production location is known, it becomes meaningful to distinguish between crop-specific CFs. Besides, computing land use characterization at high spatial resolution revealed that biomes cannot be considered relevant archetypes for the two ecological functions are assessed in this study. When displayed by the biome, the range of the CFs at high resolution overlaps significantly between them. The erosion and runoff CFs are applied on a LCA case study comparing thermoplastic starch (TPS) from maize and wheat and polyhydroxyalkanoate from soybean. The 4025 common production places of these three crops at 30 arcmins grid cell across the world are assessed. The impact scores demonstrate that the system with the least impacts (erosion or runoff) is the TPS from maize in 78% of the cells, thanks to the lowest inventory value ( $m^2 \cdot yr$ ). In the remaining 22% cells, impact scores of the two alternative thermoplastics show better results due to lower crop-specific CFs, demonstrating the relevance of discriminating land use by crop. However, spatial variability is greater than crop-type variability, so that gathering information on the location where the feedstock is produced is key to reducing the uncertainty of an LCA by two to six orders of magnitude.

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### **Capturing the benefits of responsible forestry practices in LCA: focus on biodiversity**

V. Rossi, S. Humbert, Quantis

Companies and communities are increasingly adopting responsible sourcing practices in their supply chain. However, the benefits of using responsibly sourced products are still difficult to quantitatively capture in the context of LCA in particular with regards to their benefits for biodiversity or ecosystem services. Nestlé, a company aiming at adopting responsible sourcing practices throughout its supply chain, UPM, one of their suppliers, along with Quantis, a company expert in LCA, have developed an approach to quantify the ecological benefits of responsible forest management practices using environmental indicators typically used in LCA, including impact on ecosystem quality (in  $PDF \cdot m^2 \cdot y$ ), land use (in  $m^2 \cdot y$ ), and GHG emissions. The aim was to build a methodology that can capture, within an LCA context, the relevant differences between conventional and responsible forestry practices for several case studies, of which semi-natural forest in Finland is presented. The study is for one cubic meter of wood, at mill gate, and encompasses the inputs for forestry management, activities on the logging site, logistics until the mill gate and the differences in energy inputs and outputs for heat recovered from wood residues in the mill. The use of the wood fibre based product and its end-of-life are not considered (considered identical for all types of wood sourcing). Carbon uptake and all GHG emissions are considered. The method for biodiversity accounts for four indicators, native tree species composition, deadwood volume and quality, protected valuable habitats, and forest structure, that are grouped into one indicator between 0 and 1. The results show that responsible practices have consistently lower impacts than conventional practices for all indicators, in Finland. For example, when quantified in  $PDF \cdot m^2 \cdot y$ , the impacts on Ecosystems Quality for responsible forestry practices are about half of those for conventional practices. This method can objectively capture the benefits of biodiversity protection in wood fibre production. Companies can use it in complex LCAs to consistently quantify impacts and benefits in supply chain. This method can be used to communicate externally about the benefits of biodiversity protection associated with responsible wood sourcing within an LCA context in a more robust way than what is done until now.

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### **Using LCA to assess impacts of maintaining Natural Capital in agricultural systems: A case study of soil organic carbon as a metric in cropping systems of Central NSW, Australia.**

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Natural Capital describes the stock of natural assets (e.g. soil) that provide goods and services essential for human existence, including agricultural industries that supply food. Soil organic carbon (SOC) has potential to be used as a metric for Natural Capital in agriculture because it facilitates water retention, pH buffering capacity and nutrient supply of soils. The Agricultural Production SIMulator (APSIM) was used to model two wheat cropping systems in Central NSW over a 30-year period. The first system was business-as-usual (BAU) with N applied according to regional practice. The second system was a change system (CS) that aimed to maintain SOC stocks (by applying N fertilizer at a rate that replaced N lost as grain protein and soils emissions to the atmosphere). The results of these simulations were used to inform a LCA model to assess impacts (Climate Change (CC), Eutrophication, HumanTox, EcoTox, Landuse) of the change system relative to the BAU system. The impacts were cumulative over 30-years and CC impacts were adjusted to account for atmospheric decay of  $CO_2$ ,  $CH_4$  and  $N_2O$ . Yield and SOC in the BAU system decreased over the period modelled whilst the change system maintained yield and SOC. The CS emissions from higher fertilizer application rates and production were less than those associated with BAU's displacement of wheat production to global marginal production and the loss of

SOC to the atmosphere. Similarly, BAU landuse required was greater than CS due to displaced production. HumanTox, Eutrophication and EcoTox impacts were greater for CS due to increased production and use of synthetic fertilizers. The conclusions drawn from this case study are that changing a system to one that maintains SOC stocks will have positive Climate Change and Landuse impacts but negative impacts on EcoTox, HumanTox and Eutrophication. As such SOC can be used as a Natural Capital metric in cropping systems, and LCA models can be used to quantify the environmental impacts of system changes that aim to maintain/increase Natural Capital stocks.

## LCA of urban water systems from resources to users: water withdrawal, water treatment & distribution, water use, wastewater sanitation and reuse (I)

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### Integration of freshwater impact in lifecycle assessment of three water technologies

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Today the utilities in Europe benchmark on e.g. energy, price, operating costs and water losses and in case of more complex decisions lifecycle assessments (LCA) are used to estimate the environmental impacts. Neither of these includes the freshwater impact as a standard (Godskesen et al. 2013). Since the main resource of the water supply is water, it is relevant to develop a method to evaluate the freshwater impact with a consistent and systematic approach. Internationally there are focus on estimating and manage water resources, often based on surface water methodologies and on regional/national scale. The Water Footprint Network argues for estimating the absolute quantity of water (Hoekstra 2016), where others argue for including local water stress in the freshwater impact (e.g. Boulay et al. 2015). Another study shows that the scale has a high influence on the potential impact (Hybel et al. 2015). Utilities are operating at smaller scale and are interested in a tool to compare between them and help prioritizing exploitation rate of well fields and locations for new abstractions. To increase the relevance for water utilities, we have developed the freshwater impact method so that it accounts for quality and are applicable for groundwater at the water utility catchment. In this study water supply technologies have been compared through LCA, including freshwater impacts: AWaRe, WSI and quality impacts. To demonstrate our method, we have conducted a comparative lifecycle assessment of three water technologies including the freshwater impact. The three scenarios are: a) Treatment of a groundwater contamination, with a transport of 5 km to water works (ww) b) Groundwater with a transport of 40 km to ww c) Infiltration of treated waste water and transport of 40 km to ww As predicted the water impacts dominates the LCA. The standard LCA without water impacts shows generally highest impacts for 1) groundwater (with 40km transport), followed by 2) infiltration and 3) treatment of groundwater contamination. The most contributing factors are the energy needed to transport the water and concrete for structures. Including the freshwater impact on local scale, tradeoffs become visible, since the water-stress is higher in the groundwater body with the contamination, than for the groundwater body without a contamination. The choice of methods and the scale highly impact the potential impacts and hence it is important to agree on standards and accepted procedures.

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### Up to what point the impacts associated to the supply of 1m<sup>3</sup> of tap water are different in contrasted locations?

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A water supply system includes withdrawal, treatment and distribution of water from different sources (river, aquifer, etc.) to water users (households, industry, irrigation, etc.). The availability and distribution of water in the earth is not equitable, neither in time nor between locations. Some areas receive large quantities of precipitation each year, while semi-arid and arid regions are characterized by a limited or scarce water supply. To solve that, some countries use alternative water sources such as desalinated water or inter-basin water transfer. Depending on the combination of water sources and the water supply technologies used in a given region (water supply mix), the environmental impacts will not be the same per m<sup>3</sup> supplied water. Therefore, it is essential to understand those differences and in consequence the need for Life Cycle Inventory (LCI) databases to contain such information for proper subsequent impact assessment. For that purpose, a comparative LCA study for the supply of tap water at two different spatial scales (country and watershed) has been developed. Three contrasted countries were selected: Tunisia, Spain and France. These locations were chosen in order to analyze the differences in environmental impacts arising between local water resources and water supply technologies, directly

linked with their local electricity mix and water scarcity. In addition, a comparison between two watersheds and their respective countries has been performed: Rhône-Méditerranée in the South of France and Guadalquivir in the South of Spain. For Tunisia, up to now, water data is only available at a country scale. The chosen functional unit was: "supply of 1m<sup>3</sup> of tap water" and the system boundaries were defined from the water withdrawal up to the housing distribution. The LCA was conducted using Simapro 8 and the ILCD 2011 Midpoint + was the chosen impact characterization method. Regarding the assessment of freshwater deprivation, the WSI midpoint impact assessment method and the new consensual indicator AWaRe by WULCA were used. The results show that the environmental impacts of supplying 1m<sup>3</sup> of tap water from mixed sources can vary greatly and are highly dependent on the countries and the watersheds. In conclusion, there is a need to include regionalized water mixes in LCI databases for reliable assessment of water-use impacts in LCA.

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### **LCA of loss reduction scenarios in drinking water networks including uncertainty management**

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In a context of increasing water shortage all over the world, water utilities must minimise losses in their distribution networks and draw up water loss reduction action plans. While leak reduction is clearly an important part of sustainable water management, its impacts have to be reconsidered in a broader objective of environmental protection than strictly the avoided losses in cubic meters of water. Reducing the volume of water abstracted reduces also environmental impacts associated to water production (the operation and infrastructure needed for abstraction, treatment and supply). In the meantime, activities for reducing water losses generate their own environmental impacts, especially because of the works, equipment and infrastructures used for this purpose. In this study, Life Cycle Assessment (LCA) was used to assess and compare two sets of environmental impacts: those resulting from the production and supply of water which will never reach subscribers and those caused by water loss reduction activities. This information can then be used to establish whether or not there is a point beyond which loss reduction is no longer effective in reducing the environmental impacts of drinking water supply. However, this information can be relevant or not depending on the uncertainty level of the results which is linked to the uncertainty level of life cycle inventory (LCI) data. It is thus necessary to perform an uncertainty analysis to make a proper interpretation of the results. For that purpose we used Monte Carlo simulation which calculates a statistical distribution of the impacts resulting from thousands of impact calculations each one based on a randomised set of input data (LCI). This analysis implies to define an uncertainty range for each parameter of the inventory. Results show that the improvement actions that start from a low water supply efficiency are clearly beneficial for ecosystems, human health and preservation of resources. When seeking to improve the efficiency beyond certain values (about 65%), uncertainty makes it impossible to conclude for an environmental benefit on all impact categories.

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### **LCA of softening water with nanofiltration integrating the effects at the domestic users**

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Hard water can generate burdens for domestic users due to the extra consumption of energy to heat water in calcified boilers or the extra consumption of detergents and acetic acid. Water services are continuously trying to improve the comfort of domestic users by providing higher quality level for drinking water. In this context, the Syndicat des Eaux d'Île-de-France (SEDIF), a public water service which supplies water for more than 4.5 million inhabitants in Paris suburban area, is currently considering centralized systems to improve water quality including softened water by using nanofiltration. While softening the drinking water lowers the impacts related to energy and chemical consumption at the users' places, it also generates burden shifting due to extra processes such as nanofiltration at the production plants. The importance of this study is emphasized by the fact that the energy required for heating the domestic water is generally 5 to 25 times higher than the energy required for supplying drinking water. Water managers need tools to assess the energy balance and the environmental impacts of the whole system for decision making. In this context, LCA is a well suited tool to evaluate the impacts of urban water system (UWS) in a holistic approach considering the supply and the use stage. The objective of this work is to evaluate the environmental impacts generated by the production and the usage of water depending on the level of water hardness in the SEDIF perimeter. Two plants that are currently providing water using a conventional treatment are studied. We compare different scenarios, including: (1) current water production plants supplying hard water; (2) conventional production plants + nanofiltration supplying softened water. Life cycle inventory (LCI) related to water treatment and distribution are based on operational data for the conventional treatment and from extrapolated data for

nanofiltration. LCI data related to energy consumption at water heaters and other domestic appliances and detergents and acetic acid consumption for domestic use are based on literature data. The results show that in regions where raw water varies from hard to very hard (25 to 35°F), centralized softening processes that are energy intensive enable to lower the overall environmental impacts. It demonstrates the high influence of water hardness on the energy use in UWS. LCA is shown as an efficient tool to compare different scenarios to help the decision makers.

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### **Impacts of storm events on the emissions of an urban wastewater system: case of the Greater Paris**

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In typical life cycle assessment (LCA) studies of urban wastewater systems (UWS), average conditions are modelled but there are many annual flooding events with releases of untreated sewage. Such peak conditions are not considered and present a high temporal variability which is not currently accounted for. In addition, the aggregation of the loads from several storm events could bring an issue for the impact assessment on the aquatic categories of eutrophication and ecotoxicity. Hence we are investigating the contributions of these wet weather-induced discharges relative to average conditions along with the inclusion of temporal variability in the life cycle inventory (LCI) for UWS. In collaboration with the Paris public sanitation service (SIAAP), this work aimed at identifying and comparing contributing flows from the UWS in the Paris area by a selection of routine wastewater parameters and priority pollutants. This collected data is organized according to archetypal weather days during a reference year. Secondly, for each archetypal weather day and its associated flows to the receiving river waters (Seine) the parameters of pollutant loads (statistical distribution of concentrations and volumes) are determined statistically. The resulting inventory flows (i.e. the potential loads from the UWS) can be used as inputs in a classical LCA to investigate the relative importance of episodic wet weather versus "continuous" dry weather loads coupled to uncertainty analysis using a Monte Carlo method. Results analysis showed that all storm events in 2013 contribute to one third of the total annual nutrient load from wastewater effluents on routine wastewater parameters. Regarding priority pollutants, results on the freshwater ecotoxicity category tend to be dominated by heavy metals, but further consolidation on the extent of included substances is required. With such significant contributions of pollutant loads at the LCIA level, further research is required on how to include temporally-differentiated emissions in the methodological framework of the impact categories of eutrophication and ecotoxicity, to better understand how the performance of an UWS system affects the receiving environment for given local weather conditions.

## **Passenger and freight transport: On the road to a more sustainable mobility system?**

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### **Default transport model for products produced and consumed in Switzerland**

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Improvements of current technologies as well as introduction of new ones is increasingly changing the transport sector and its environmental burdens. In order to be able to assess these changes, solid baseline data describing the current situation of the transport of goods all over the world is needed. Ideally, the amount of transport in a supply chain of a product would be based on transport statistics for this specific product, but these data are often not available. Excluding transport in the supply chain of a product, because of a lack of data, underestimates the environmental burdens. The version 3.01 of the ecoinvent database, published in the year 2013, includes default transport distances between the producers and the consumers for the main modes of transport (lorry, train, ship and aircraft) for all the products available in the ecoinvent. Using this generic global data is a good fall-back approach which ensures that all the products have at least the average global transport included. The intermediate step between product-specific and global data is regionalisation by means of transport values based on national transport statistics. The evaluation of the data generated by the global model proved that in some specific cases, region-specific data for this model are relevant. This study introduces regionalized default transport model for Switzerland based on the statistics from BSF - Swiss Statistics and other

sources. Switzerland is a small country with one of the highest GDP per capita in the world. Especially heavy and cheap products, produced locally, are also consumed locally. Simply because its price including transport is still higher than in the neighbouring countries and exports are not profitable. Typical example of this kind of products are construction materials. Concrete, cement and gravel produced in Switzerland are – in majority of cases – also consumed in Switzerland. The importance of the transport in the life cycle of any product increases with the weight of the product and the distance the product is being transported. The higher the importance of transport within the total environmental burdens of a products' life cycle is, the higher quality transport data in the background need to be. Evaluation of the results calculated using the newly introduced regionalized Swiss transport model proved, that this regional addition on top of the global modal improves the final results significantly and brings them closer to reality.

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## **Environmental assessment of the introduction of light-weight materials in the passenger-car fleet: feasibility and relevance of consequential LCA**

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The automotive industry has been facing stringent objectives in terms of vehicles' Greenhouse Gas emissions since several years, especially in the OECD countries. This fosters the reduction of passenger-car weight, which can be achieved by replacing conventional materials by lighter ones, resulting in additional challenges for Original Equipment Manufacturers and materials' suppliers. The latter require a solid argumentation in order to address the market requirements, including the assessment of the environmental impacts induced by the substitution of materials, especially iron and steel, in the passenger-car fleet. Such industrial change occurs progressively over time and at a large geographical and market scale, therefore the associated environmental consequences can occur at the level of the fleet production, use and end of life stages. Significant changes could be observed as well in other economic sectors. A Life Cycle Assessment (LCA) of these impacts requires a consequential approach for the Life Cycle Inventory (LCI) modelling, depending on the magnitude of the environmental consequences induced by the introduction of light-weight materials in passenger-car fleet. The presentation will focus on a study realised by the LIST in collaboration with an industrial partner in order (i) to prove the feasibility and relevance of consequential LCA for assessing the environmental impacts induced by the changes, and (ii) to specify the requirements for the full consequential LCI modelling. The study included the identification of the change drivers and magnitude, allowing the definition of several prospective scenarios according to which the automotive industry sector could evolve. For each prospective scenario, the European passenger-car fleet has been assessed using an Attributional LCA approach in order to compare its environmental impacts before and after the change. The chain of consequences induced by the rising demand for light-weight materials according to each prospective scenarios has then been identified, taking into consideration the global demand from sectors other than automotive industry. The study has then been completed by a simplified simulation of the potential direct and indirect consequences using a hybrid IO-process model and an economic computable general equilibrium model, respectively.

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## **Comparative LCA of traditional versus electric vehicles in urban area: does the car size influence the results?**

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Battery electric vehicles (BEVs) offer the potential to substitute Internal Combustion Engine Vehicles (ICEVs) for passenger transport, bringing to a reduction in greenhouse gas emissions and tailpipe emissions. Of course a Life Cycle perspective is needed when dealing with environmental benefits from changing energy carrier. Even if some of the main gaps in knowledge that found reviews on LCA studies (Hawkins et al. 2012, Nordelöf et al. 2014) have been covered by recent studies (Del Duce et al. 2014, Girardi et al 2015) there are still large uncertainties due to several influencing factors (Egede et al 2015). In this framework the purpose of this study is to compare the life cycle environmental performances of several BEVs with homologous ICEVs (gasoline and diesel), paying particular attention to four of the main influencing factors: the production of electricity that will charge the EV (i.e. considering an appropriate charging mix); the size of the vehicles, considering not only a vehicle market segment but a set of already existing electric passenger cars ranging from micro cars to family cars; the actual lifetime mileage of the vehicles, according to size and energy carriers (Weymar & Finkbeiner 2016); the fuel consumption, i.e. given the limited driving range of BEVs, it is reasonable to expect that urban areas will be the natural environment for the spread of BEVs and for this reason, we considered fuel consumption and pollutant emissions typical of a urban driving cycle. The selected car types are: Smart For Two,

Chevrolet Spark, Fiat 500, Volkswagen Golf, Ford Focus and Kia Soul. Results confirm that in general, regardless of the car size, EVs perform better than the same models of ICEVs in almost all impact categories they are expected to: Climate change, Deployment of natural resources, Particulate Matter formation potential, and Photochemical oxidant formation potential. Noticeable exceptions are represented by gasoline Fiat 500 0.9 L which, due to its high efficiency performs better than the homologous electric vehicle in terms of Air Acidification (and presents comparable performance in terms of Particulate Matter formation) and by Ford Focus Electric that due to its heavy weight in relation to size, shows higher scores in Particulate Matter formation. All EVs shows higher impact than ICEVs for Freshwater Eutrophication and Human Toxicity (regarding both cancer and non-cancer effect) due to car and battery manufacturing.

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## **Social and economic indicators integration toward a holistic consequential Life Cycle Assessment : application to a Bus Rapid Transit project in France**

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Cost-Benefit Analysis (CBA) is a methodology to: prioritize projects to settle a national funding agenda (goal G1), compare transportation modes for a same transportation offer development (goal G2), or even for technical variants on a same mode (goal G3). In France, conducting CBA is mandatory before launching a transportation project when national public funds are involved. The principle of CBA is to add every financial flows as well as monetized externalities of a project to compare costs and benefits, in order to provide a unique indicator - *the Net Present Value* - on the worthwhileness of a project over its entire life cycle for public welfare. Theoretically, costs encompass construction and operation as well as health troubles or damages to the environment, whereas benefits comprise mobility utility and enhancement. CBA has several limits as a decision-maker tool. First, providing a single indicator - the Net Present Value - is easier to understand for practitioners and decision-makers than multicriteria results, but externality monetization presumes the substitutability of burdens, respectively, of natural benefits, based on tutelary values (ex : 1 CO<sub>2</sub>eq = 22€ in France). These values are not the same in different countries. Then, considered environmental impacts are not covering all real damages. On the other side, environmental Life Cycle Assessment is a robust normalized method (ISO 14040 and 14044) to quantify potential environmental impacts of a system throughout its life cycle. Its specter encompasses numerous environmental aspects through many indicators, like eutrophication, eco- and human toxicities, primary energy consumption, contribution to climate change, etc. but does not address the question of localized, social or economic effects. It can also take into account the environmental effect of a change, with a consequential methodology. Considering that, the objective of the study is to investigate merging of CBA and consequential environmental Life Cycle Assessment (LCA) approaches to broaden the appraisal specter of projects for decision-makers. After describing the assessment methodology, we apply it on an Parisian region case study. The idea is to holistically compare situation with a new Bus Rapid Transit system called TZen 3 and without the project. The results obtained are thus used for goals G2 and G3. We then discuss pro and cons of this multicriteria methodology Vs the standard monocriterion analysis legally applied in France.

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## **LCA of polyurethane aircraft seating cushion**

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The aviation industry is bound by the goals set by the Advisory Council for Aeronautics Research in Europe (ACARE) in terms of reducing its environmental impacts. It has also to comply with the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) directive on chemicals. In the Clean Sky Project, a Public Private Partnership between the European Commission and the European aeronautics industry, a polyurethane (PUR) aircraft seating cushion was developed using bio-based polyols for polyurethane formulation and non-halogenated flame retardants (without any harmful substances). In order to verify and confirm, whether this new technology really improves the environmental footprint of aircrafts, a Life Cycle Assessment (LCA) was performed comparing the current and newly developed technologies. The results show that the new PUR using bio-based polyols for seating cushions contributes to a reduction of environmental impacts of aircraft seating cushions regarding their Global Warming Potential (GWP), Photochemical Ozone Creation Potential (POCP), Abiotic Depletion Potential (ADP), and Photochemical oxidant formation (POF). The study also shows a reduction within the impact category Human Toxicity Potential (HTP), with the avoidance of harmful substances in the production process by applying bio-resins for cabin interior, as the new formulation for foam naturally has flame retardant properties (bio-based polyol), thus not requiring the addition of flame retardant chemicals.

However, the new technology increases the Eutrophication Potential (EP), which is an increase in the concentration of nutrients in an ecosystem that results in imbalances. This is due to the use of fertilizers in soy bean cultivation. The development of the new material is an ongoing project, however, and new bio-materials are being investigated. With the support of the developed LCA tool, it can be identified, if any of them could contribute to reduce the Eutrophication Potential impact.

## LCA for agriculture: food, bio-material, bio-energy, including aspects of water use, land use, handling of pesticides, carbon accounting, end-of-life modelling (I)

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### **Soil Organic Carbon, climate change, and soil quality: a mapping of existing methods for LCA**

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Land use interventions lead to a great variety of impacts on the environment, including modification and fragmentation of habitats, or alteration of soil properties, resulting in effects on soil fertility, climate change, or water filtration and regulation. Among parameters describing soil properties, Soil Organic Carbon (SOC) plays a key role: it is one of the main descriptors of soil quality, closely linked to soil fertility, and it is also crucial for climate change as it represents a global carbon stock of 1500-2400 GtC, i.e. around three times that of atmospheric carbon. Consequently, SOC can be considered in many different methods for LCA, dealing with LCI or LCIA, with soil quality or climate change issues. There is thus a need for LCA practitioners to better understand the diversity of these methods, their various purposes and coverages, their differences and potential complementarities. This study aimed at mapping LCA-related methods dealing with SOC effects on climate change and soil quality. Some methods, not dealing directly with SOC but considering soil quality or effects of the carbon cycle on climate change, were also included for a more comprehensive mapping. More than 30 method proposals were identified in the literature and considered. Variations of a same method, i.e. based on a common principle but involved in different guidelines, or using different data, were grouped together. For instance, the characterisation models proposed by Milà i Canals et al. (2007) to assess land use impacts on life support functions, and by Brandão & Milà i Canals (2013) to assess land use impacts on biotic production, are based on the very same model but developed at different scales and using different data sources. Then, links between methods or groups of methods sharing a common conceptual baseline were clearly identified. For example, dynamic LCA as defined by Levasseur et al. (2010) to deal with temporal GHG emission profiles and ILCD recommendation to take into account delayed CO<sub>2</sub> emissions (EC-JRC, 2010) are based on a common theoretical principle but differ in terms of implementation. Finally, this mapping helps to differentiate between marginal variations and critical sound differences among the great diversity of existing methods. It also allows for identifying relevant methods and proposing specific recommendations to take into account SOC in LCA.

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### **Life Cycle Assessment of energy crops: the importance of site -specific nitrogen emissions**

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**Purpose of the work** Greenhouse gas (GHG) savings of maize-based biogas systems are usually calculated using the methodology outlined in the European Renewable Energy Directive (EU-RED). Generic emission factors provided by IPCC are used for calculating direct and indirect Greenhouse gas (GHG) emissions without taken regional-specific effects into account. For the forthcoming update of the EU-RED the Global Nitrous Oxide calculator (GNOC) will most likely be used for the calculation of nitrogen emissions. **Approach** Relevant emissions (CO<sub>2</sub>, N<sub>2</sub>O, NH<sub>3</sub>, and NO<sub>3</sub>) are measured on the field after the application of digestate and mineral fertiliser at five locations in Germany and compared to modelled results obtained from the IPCC approach and GNOC. **Scientific innovation and relevance** The project strives to develop precise but also generalisable statements about nitrous oxide emissions, ammonia volatilisation and nitrate leaching and provide recommendations for farmers to reduce particularly nitrogen emissions and policy makers. The results of the joint research project should lead to an improved environmental assessment of crop production systems for food, feed, bioenergy and material use.

**Results** N-emissions from maize cultivation vary substantially among the different sites. The IPCC methodology frequently overestimates ammonia and nitrate emissions and consequently indirect N<sub>2</sub>O-emissions. At the location with lowest emissions, ammonia emissions were four-times lower, nitrate

emissions twenty-times lower and nitrous oxide emissions three-times lower than the calculated emissions according to the IPCC method. Nitrate calculation with GNOC either follow the IPCC approach assuming leaching of 30% of the total nitrogen input or leaching of zero at locations where  $\Sigma(\text{rain in rainy season}) - \Sigma(\text{potential evaporation in the same period}) > \text{soil water holding capacity}$ . This condition can be fulfilled in a particular year or even not, although nitrate leaching has tremendous effect on the GHG-balance and the eutrophication potential. A more detailed analysis will be presented at the symposium.

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### Life cycle assessment of bioethanol from date waste in Tunisia

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To improve local and renewable energy sources, bioethanol from alcoholic fermentation of date waste offers an interesting alternative to fossil fuels. Unfit for the food or the agri-food industry, discarded dates represent more than 30,000 tons (40% of the production) per year in Tunisia and only a very small part is currently used as animal feed. Due to their sugar composition, these wastes constitute a potential feedstock for biofuel production. This study presents an environmental assessment of an industrial ethanol production system using the Life Cycle Assessment (LCA) methodology. The functional unit is defined as the production of 1 ton of bioethanol and the system boundaries include the transport of date waste, the processing, the bioconversion of the syrup (fermentative step) and the distillation. Along the process, 32 tons of dates generates 1 ton of ethanol and co-products (date kernel, skin and fibre) are managed by mass allocation. Sludge resulting from the distillation is treated in a wastewater treatment plant. Life cycle impact assessment was carried out with the ILCD method. Results are compared to the production of bioethanol from sugar cane and corn from the ecoinvent 3.1 database (default version). Lower or similar results are obtained for the bioethanol from date waste for the following impact categories: resource depletion potential, particulate matter, the three eutrophication indicators, land use and freshwater ecotoxicity. On the other hand, impacts of bioethanol from date waste are very substantial on climate change, ozone depletion and photochemical ozone formation. The contribution analysis shows that the consumption of electricity, mainly produced from natural gas in Tunisia, was the main contributor to almost all impact categories; the most energy intensive steps were the concentration of juice and the distillation of ethanol. The second contributor was the transportation. Mass allocation influences the acidification potential, human toxicity and freshwater ecotoxicity in favor of the modeled system. Compared to the other production systems, improvement of the environmental impacts can be discussed by increasing yield conversion (more efficient fermentative step) or by combining the current system with energetic recovery from secondary waste management system (anaerobic digestion of residual sludge). However the main way of improvement still remains a reduction of the electricity consumption by industrial optimization.

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### Sustainability Issues in the Food-Energy-Water Nexus in the UK dairy sector: Energy and Water Consumption

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The dairy sector in the UK accounts for the highest purchased quantities of food annually. Dairy products consume significant amounts of energy and water causing multiple adverse impacts on the environment, particularly since water and energy use in food production are inextricably linked. As a consequence, an understanding of these interactions in the food, energy and water (FEW) nexus is essential. Therefore, this work examines sustainability issues in the FEW nexus in the UK dairy sector with the aim of identifying hotspots and making recommendations for improvements. The following dairy products are considered on a life cycle basis: milk, cheese, yogurt, butter and cream. The results show that the dairy sector in the UK requires 98,200 TJ/year of primary energy. Milk and cheese are the main contributors, accounting for 70% of the primary energy demand with 38% and 32%, respectively. Yogurt is responsible for 17% of the total energy use, butter for 9% and cream for 4%. The main contributors vary by the product: for milk and yogurt, farm production and packaging are the hotspots; for cheese and butter, farm production and processing; and for cream, besides processing, retail and packaging are also relevant contributors to energy use. The annual water consumption by the sector amounts to 29 million m<sup>3</sup> of blue water and 8.45 billion m<sup>3</sup> of green water. The latter is used due to the cultivation of feed for the cattle. For blue water, farm production is the largest consumer with 62%, followed by the processing stage, which accounts for 26%. The former is mainly due to the water used by the livestock for drinking,



while the latter is mostly due to the water used for cleaning of dairy processing units. Therefore, depending on the product, different stages should be targeted for reducing the consumption of both energy and water in the dairy sectors. Besides farm production, the packaging materials should be optimised to reduce energy needs for milk, yogurt and cream, while for butter and cheese, the focus should be on the processing stage. Regarding the blue water consumption, the improvement opportunities lie in the cleaning processes in dairy plants as drinking water for cattle cannot be reduced.

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## **An analysis on how switching to a more balanced and naturally improved milk would affect consumer health and the environment**

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This study compares a premium brand of UHT milk, characterized by an improved nutritional composition, to conventional milk, in terms of both health effects and environmental impacts. Unlike enriched milks, in which nutrients are added to the final product, this premium product is obtained naturally by improving the diet of the dairy cows, thus also enhancing their life quality. The effects of milk consumption on consumer health have been analysed based on literature findings, while the environmental analysis has focused on those spheres of the environment where milk is expected to cause the higher impacts, and thus carbon (CF) and water footprints (WF) have been calculated. Five final products have been compared: 3 conventional (skimmed, semi-skimmed, whole) and 2 premium (skimmed, semi-skimmed) milks. As a functional unit, one litre of packaged UHT milk entering the regional distribution centre has been chosen. CF has been determined following ISO 14067:2013, the Publicly Available Specification 2050:2011, the applicable Product Category Rules and the guidelines of the International Dairy Federation. Regarding WF, the approach proposed by the Water Footprint Network has been followed, and thus a WF inventory analysis has been carried out (ISO 14046:2014). The improved composition of the premium milk is expected to decrease the risk of cardiovascular disease, due to its improved fatty acid profile, and to protect consumers against oxidative damage, as a result of its higher content of selenium. Concerning the environmental aspect, CF of premium products are, on average, 10% lower than their conventional equivalents, mainly due to the lower enteric emissions of caused by the improved diet. No significant differences were found between the WF of premium and conventional milk. Raw milk production at the farms is the main contributor to both footprints (on average, 83.2% and 84.3% of the total CF of premium and conventional milk, respectively, and 99.9% of WF). The results have been compared to those found in literature, and a sensitivity analysis has been performed to verify their robustness. The study concludes that switching to healthier milk compositions can help slowing down global warming, without contributing to other priority environmental issues such as water scarcity. The results should encourage other milk companies to commit to the development of healthier, less environmentally damaging products, and also to stimulate consumers to bet on them.

## **LCA of urban water systems from resources to users: water withdrawal, water treatment & distribution, water use, wastewater sanitation and reuse (II)**

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### **Assessing wastewater treatment in Latin America and the Caribbean: Enhancing life cycle assessment interpretation by regionalization and impact assessment sensibility**

F. Hernandez Padilla, Instituto de Ingenieria, UNAM / Nevironmental Engineering; M. Margni, CIRAI - École Polytechnique de Montréal / Mathematical and Industrial engineering; C. Bulle, UQAM, Ecole des sciences de la gestion; A. Noyola, Instituto de Ingenieria UNAM / Environmental Engineering; L. Güereca, Engineering Institute Universidad Nacional Autónoma de México / Environmental Engineering Life cycle assessment (LCA) was applied to evaluate two wastewater treatment plant (WWTPs) scenarios in Latin America and the Caribbean (LAC): extended aeration (EA) and pond system (PS). The main goal was to compare the environmental performance of two WWTP technologies and support the selection of the least impacting technology across all environmental impact categories, in selected methods, when developing new WWTP projects. As a complementary goal, we analyzed how regionalization enhances LCA interpretation through a case study illustrating the spatial variability of WWTP results for 22 Latin American and Caribbean countries. A generic LCA relying on averaged primary data from 158

WWTPs was first performed based on three LCIA methodologies: ReCiPe, IMPACT World+ (IW+) and Impact 2002+. The results were used to identify the parameters that most influence the impact scores and test the sensitivity of the choice of LCIA methodologies on the conclusion. While EA is the most impactful scenario for the human health (HH) and ecosystem quality (EQ) indicators according to Impact 2002+, ReCiPe considers it to be the least impacting option. For EQ, the PS scenario scores better because of a lower relative importance of global warming impacts (GWP) as compared to eutrophication impacts (FE) at the damage level. A sensitivity analysis was therefore carried out at the inventory level considering regional grid electricity mixes and at the impact assessment level characterizing eutrophying emissions with the regional CFs for the 22 LAC countries provided by the IW+ model. Results showed that the operating conditions of WWTP in countries with an electricity mix of over 54% fossil fuel tend to favour PS. Operating conditions in countries with an electricity mix of over 60% hydropower favour EA due to the significant decrease in greenhouse gas emissions. Locations with higher eutrophication characterization factors such as Brazil - where the residence time of water is higher - tend to disfavour scenarios with higher eutrophying emissions such as EA with higher EQ impact scores as compared to PS. We concluded that regionalization, both of the inventory and the characterization factors, adds relevance and discriminating power to the LCA, and we recommend addressing it in standard LCA practice. To do so, we propose a pragmatic and stepwise iterative approach that makes it possible to regionalize the greatest contributing inventory and the most impactful assessment flow.

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**Removing phosphorus from wastewater: Influence of treatment method**

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Phosphorus (P) can be removed from wastewater biologically or chemically. The availability of P for uptake by plants in chemical and biological solids is an area of on going research [1], though it is generally established that the P in solids containing high levels of metal is less available [2]. Very few LCA studies have investigated the effect of the bioavailability of P and, when lacking of reliable data on bio-available fraction of P, most of LCA practitioners assumed that 70% of the P present in the sludge, regardless its nature, is bioavailable. The environmental consequences of the implementation of S.C.E.N.A. technology [3] in a real WWTP was recently studied [4]. There, P is removed by chemical precipitation in the main water line and biologically in the anaerobic digester supernatant. In this contribution, the impact of the assumed availability of P in biosolids on the results is tested using high and low estimates of availability from the literature. For chemical sludge, part of the P is considered unavailable to plants and will eventually runoff, nullifying the aim of P precipitation, namely to prevent the eutrophication of natural water systems. Results of the sensitivity analysis of P availability in solids indicate that while the GWP of chemical P removal is reduced at high availabilities, the balance does not turn into positive results. Opposite to this, the results show the possibility to reduce dramatically eutrophication potential impacts by moving from a low to high P availabilities, which suggests that biologically P removal process should be preferred to chemical ones. Case specific P fertilizer replacement ratio assumption is recommended in order to avoid misleading conclusions. **<strong>References** [1] Bradford-Hartke et al. «Environmental Benefits and Burdens of Phosphorus Recovery from Municipal Wastewater.» *Environ Sci Technol* 49.14 (2015): 8611-8622. [2] McCoy et al. «Plant availability of phosphorus in sewage sludge compost.» *J Environ Qual* 15.4 (1986): 403-409. [3] Renzi et al. «Short-cut enhanced nutrient removal from anaerobic supernatants: Pilot scale results and full scale development of the SCENA process.» *Sewage Treatment Plants: Economic Evaluation of Innovative Technologies for Energy Efficiency* (2015): 295. [4] Longo et al. "Full scale nitrogen and phosphorus removal via nitrite: is SCENA system a good choice also for environmental sustainability?" *Proceeding of 3th IWA Specialized International Conference ecoSTP* (2016).

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**Are wastewater treatment plant construction inventories from Ecoinvent up do date?**

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The construction phase during Life Cycle Assessment of wastewater treatment plants (WWTPs) has been understudied. The WWTP construction inventories available in the Ecoinvent database were provided by a single study conducted in Switzerland in 2007 and has never been validated against new inventories. In this study we provide such validation, with comprehensive and detailed inventories from four Spanish WWTPs with capacities ranging from 1,500 to 21,000 m<sup>3</sup>/d, all of the same configuration (oxidation ditch) to remove carbon and nitrogen and with simple sludge treatment (thickening and dewatering). All components included in the detailed budget from the four WWTPs were included in

the inventory with no simplification. Up to 30 materials were considered (compared to the 15 in the Ecoinvent inventories), with larger diversity of metals and plastics and new materials (wood, mortars or precast pieces). The results show that Ecoinvent provides inventories with masses of materials 4 to 10 times higher than the ones reported in this study. Whereas 1,179 kg/(m<sup>3</sup>·d) of concrete are consumed for the Spanish WWTPs 6,900 kg were consumed for the Swiss WWTPs. Reinforcing steel consumption ranges between 21 and 55 kg/(m<sup>3</sup>·d) for the Spanish WWTPs and between 220 and 230 kg/(m<sup>3</sup>·d) for the Swiss WWTPs. The environmental burden was calculated using ReCiPe characterization factors. The results show that differences between Ecoinvent and this study become larger as the capacity of the WWTP increases. For a WWTP of 15,000 m<sup>3</sup>/d climate change and fossil depletion impacts are about 2.5 higher for the Ecoinvent inventories, and for metal depletion 1 order of magnitude higher. The obtained results indicate that a revision of construction inventories is needed and the study will stimulate discussion during the conference about data repositories upgrading since the wastewater treatment sector is rapidly progressing with new technologies to face emerging challenges.

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## **LCI model and tool for chemicals discharged down the drain. Case study on detergent formulations**

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Existing models for wastewater treatment in LCA reflect average conditions in wastewater treatment plants (WWTPs), rather than the specific fate of particular chemicals and they omit the impact of direct discharges. We present a model and tool to calculate life cycle inventories (LCIs) of chemicals in wastewater, WW LCI. It attributes the exchanges with the technosphere and the environment taking into account the expected behaviour of individual chemicals. The model covers treatment of organic and inorganic chemicals and the WWTP is modelled taking into account the partitioning of each chemical to air, sludge, treated effluent, and depending on its degradability, the transformation by microorganisms to CO<sub>2</sub> and excess sludge. Sludge is treated by anaerobic digestion and the fate of any fraction of chemical released to the environment (e.g. treated effluent, direct discharges) is assessed in terms of greenhouse-gas (GHG) as well as nutrient (N, P) emissions following degradation in environmental compartments. Sludge disposal includes incineration, landfilling and agricultural reuse. The model is programmed in Excel and accommodates simultaneous calculations for 30 chemicals, either individually or as a mixture. The resulting LCIs can be automatically imported into the LCA software SimaPro. The applicability of WW LCI is shown in a case study on three detergent formulations (powder, liquid, concentrate) including 28 chemical ingredients. The impact of these formulations is assessed for a functional unit of one wash, and the results are compared to those of the WWTP model developed for ecoinvent v2. The system boundaries include only the end-of-life stage, i.e. discharge of the three formulations after use in a washing machine, and the impact categories assessed are GHG emissions, freshwater and marine eutrophication and freshwater ecotoxicity. The results show that, when assessed individually, the impact of some chemicals can be orders of magnitude different when assessed with the ecoinvent model and with WW LCI. When assessed as a mixture (detergent formulations), differences are lower between models and the ranking of formulations is not changed. The main advantages of WW LCI over the ecoinvent model are that it addresses the impacts from direct discharge, relevant for developing countries where connection to WWTPs is limited, and second that it provides a complete substance flow analysis of the assessed chemicals across all environmental impact categories.

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## **LCA of tertiary treatment sanitation designed for micropollutants and nitrogen removal: what environmental benefits for which impacts?**

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Tertiary treatments to remove micropollutants are more and more requested to ensure a preservation of freshwater ecosystems. At the same time, these systems generate supplementary energy and reagent consumption and the question arises of what environmental benefits for which additional impacts. Recently, Irstea and Suez carried out a detail evaluation of the performances of a new wastewater tertiary treatment (Sophia-Antipolis, France) that was designed to ensure micropollutants removal by ozonation and nitrogen removal by biofiltration denitrification. The availability of detailed experimental data from this study was a opportunity to conduct a LCA.. In order to assess the eco-efficiency of the system, LCA impacts associated to effluent discharges from WWTP with and without tertiary treatment are compared using primary data such as nitrogen, phosphorous and micro-pollutants analysis. The contribution of these impacts (associated to water discharge quality) is then compared to impacts of the entire WWTP including energy, infrastructures, reagents, etc. The LCIA (Life Cycle Impact Assessment) was computed using the comprehensive set of ReCiPe indicators. Then a focus on toxicity and ecotoxicity 's impacts was carried out using the most scientifically relevant method for that purpose: Usetox. In addition to

usual pollutants, 68 micropollutants were analysed: 22 metals, 32 pharmaceuticals and 14 hormones. Even though all the metal's substances are characterized both by ReciPe and Usetox, only 12 pharmaceuticals and 4 hormones can be found in Usetox. Results show that when adding tertiary treatment to the plant's inventory, ReciPe's impacts raised of about 10%. This is vastly due to the use of electricity in the tertiary treatment. However if you compare the impacts of the secondary effluent it exceeded the addition of the tertiary effluent and tertiary treatment operation's impacts. Tertiary treatment improves effluent quality that balances its own operation's environmental costs. Accordingly, Usetox impacts highlight removal of several substances, like Trimethoprim and Estrone. It is especially important when the organic and pharmaceutical micro-pollutants can amount to 60% to 90% of ecotoxicity (depending of the substance accounted). The limit of the approach is the fact that all chemicals are not characterized neither by ReciPe or UseTox. Consequently the benefices of tertiary treatment are not comprehensively accounted yet while their impacts are.

## Teaching LCA in high level education systems (universities and continuous education)

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### Life cycle assessment - practice and reporting (LCA-PR): experiences from developing, teaching and further developing an LCA course for Industrial Ecology master students

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The institute of Environmental Sciences (CML) at Leiden University has a strong tradition in developing LCA methodology since LCA's earliest days. In addition, CML has been teaching LCA as part of educational curricula and research projects. The LCA-course currently taught in the master's program of Industrial Ecology organized by Leiden University and Delft University of Technology in the Netherlands is built on the experience from all these efforts. The course started as a purely theoretical class, shifted towards an online course and can now best be described as an intensive engaging experience for students in which theory and practice are combined to provide students the basis to responsibly perform an LCA study. The course starts with a "theory week" composed of lectures and exercises in which the four phases of LCA according to the ISO14040 framework are presented, discussed and brought into practice with exercises using CMLCA software, hand calculations and group exercises. The main philosophy behind the course is learning by doing. After the theory week, each student gets 12 weeks to work on a case study of their own choice. Students are highly encouraged to organize themselves to discuss any questions that come up for which a forum is available. Lecturers intervene when necessary and are available for discussing specific challenges encountered. A full day meeting with all students and lecturers is organized halfway the course. Students are expected to present their progress, but emphasis is put on presenting and discussing challenges and solutions encountered with the whole group to learn from each other. After 12 weeks the students are expected to deliver a 6000 word report and a working LCA model in the CMLCA software. The structured but also very interactive character of the course makes this a highly valued course. The course teaches students LCA methodology, research and reporting. With the experience from each course, lecturers constantly refine how to teach the topic of LCA. This course delivers students that can engage in thesis projects that are beyond straight forward LCA studies but are on the edge of contemporary LCA research. The main challenges in teaching this course are that we are only capable of teaching 2 times a max of 25 students a year for which the grading load is the most challenging for the lecturers.

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### Experiences from the use of web-based audience engagement systems in an LCA classroom

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In this years version of our annual Ph.D. course on "Advanced LCA" we have applied two types of free web-based audience engagement systems, namely an anonymous audience response system (also known as "clickers"; from webclicker.org) and an audience discussion system (consider.it). This presentation reports the teacher and student evaluation of the contribution brought to the educational context by these two tools as an addition to normal classroom interaction and group discussions. The clickers were used to obtain immediate (and sometimes repeated) feedback on simple questions like "Does the scale (size) of the studied change matter for the choice between attributional and consequential models?" in order to focus the teaching on the most relevant topics and to measure learning. The audience discussion system consider.it was used to solicit opinions and arguments on a slightly provocative question: "Does attributional LCA have relevant applications?" Students were able to state their

agreement or disagreement to the question, post arguments, comment on each others arguments, apply the arguments of others to build their own argued opinion profile, edit their own arguments and overall agreement/disagreement, over a two-day course period. The two tools were evaluated on one open question: "What are the three words that best describes your experience of [the tool]" and three more closed questions: - "Did [the tool] reduce or increase your involvement in the classroom discussions?" - "Did [the tool] focus or distract the discussions?" - "Did [the tool] make it more or less comfortable for you to express your opinion in the discussions? We applied the tools to the entire class and did not have more than one class, so we were not able to perform the evaluation as a controlled experiment.

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### **Making Life Cycle Assessment accessible for engineering students as well as professional occasional practitioners : what are the priorities? Example of urban planning in France**

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In the era of climate change and energetic transition, industrial players are driven to adapt their activities. Eco-design has emerged as a major approach to enhance the environmental performance of products as well as services. Yet it still needs to be developed for complex issues such as neighborhood development and urban planning. This is the very objective of the academic Chair on the Eco-design of building sets and infrastructure that was established in 2008 by ParisTech and Vinci, the well-known leading group in construction and infrastructure operations. The chair involves three schools with different specializations within ParisTech: "Mines" deal with energetics, "Agro" with biodiversity and urban agriculture and "Ecole des Ponts" (ENPC) with transportation and urban development. Objectives of the chair is double : training future engineers in LCA, as well as helping professional potential or actual professional practitioners to make good uses of LCA, in the group Vinci but also in a broader community as public events and communications are settle several times a year on the projects conducted in the chair. The aim of the presentation is, through the example of the one semester full-time specialization training for master students launched in 2014 at Ecole des Ponts, to discuss difficulties in reconciling academic, industrial/practical/application and teaching objectives around this class. The curriculum, targeted to the "eco-design of sustainable cities", is in two main parts: on the first hand, four specialist courses deal with spatial design, evaluation, urban modeling and big data, respectively; on the other hand, an intensive group project targeted to eco-design a sustainable neighborhood. We presents first the context of engineering education in France and its orientation towards sustainable development of cities, then the principles of the education program; next, we discuss the different objectives in both teaching and applied research perspectives. Lastly, some lessons and perspectives are drawn.

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### **TEACHING MANAGEMENT OF SUSTAINABLE INNOVATION IN EMERGING TECHNOLOGIES**

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In 2008, spurred by the nanotechnology hype, we developed a course to address sustainability aspects in the further development of this technology. Since then, the course has expanded to more generally cover emerging technologies. Developing a new technology requires much more than an economical cost-benefit analysis of production and performance. Many aspects will influence the success of an emerging technology at its final use stage. The course aim to study how we can assess the potentials and pitfalls of emerging technologies to optimize their development process. We define this "Sustainable Innovation process" as a directed process of balanced consideration of the influencing aspects to optimally guide the development of an emerging technology. The process involves a.o.: Actor network analysis of the many entities that can influence the technological field Analysis of governance and development of regulations and legislation in the field Environmental Life cycle check of the technology, and paths for optimizing the lifecycle to reduce environmental footprint. Resource supply security and forecasts of involved materials. Toxicological aspects and ecotoxicological aspects The historical development in the field and the fundamental limitations on performance Competing technologies and future market analysis The course aims at providing experience in performing an analysis involving a combination of these aspects in order to optimize the success of a product innovation process. In groups, the students analyse example cases of sustainable innovation in rapidly evolving technological fields, combined with state-of-art literature to give an overview of the methods being applied to guide the development. On this background they discuss and define which methodological elements the assessment method should include. They formulate their own project and work in groups on a selected case of emerging technology. During the course they present their analysis in oral presentations and a final report. They must account for their choice of method and formulate a substantiated recommenda-

tion for optimal development of the technology they investigated. \n \n The course hence gives a functional introduction and hands-on experience for performing basic actor network analysis, life cycle screening, and technology assessments etc. However, given the time constraints of three weeks (full time) it will not give a full in-depth explanation on the methods employed.

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**Digital Game Based Learning as an approach to increase LCA awareness and knowledge**

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During recent years sustainable products have become more and more important for companies. The first reason depends on the customers' awareness about sustainability and, in the second hand, companies understood the connection between environmental impacts reduction and cost savings. Reflecting this, companies have started to use instruments like LCA in order to calculate the environmental impacts from the Life Cycle Thinking point of view. One of the main problems companies deal with is the methodology to understand which data are required and how they can be related to the environmental indicators required by the LCA. The low level of knowledge of managers on environmental impacts and in particular on the Life Cycle Thinking approach reflects the increasing of the green economy interpreted as efficiency usage of resources and development of the recyclability of products. In order to provide a solution to the abovementioned LCA awareness and training issues, many different approaches have been recently proposed, ranging from traditional (e.g. frontal lectures) to more innovative (e.g. e-learning) ones. Among the innovative ones, digital game-based learning (DGBL) has been rarely used for LCA, even though its effectiveness has already been proved both for awareness and learning purposes in other fields (e.g. healthcare, management, mechanical engineering). To this respect, the Life Cycle Assessment (LCA) Game was developed in order to support non-expert students and industrial specialists to understand the goal and the approach of LCA while discovering at the same time the issues practitioners have to face in a real environment. The main idea of using a simulation game is to reproduce the industrial environment where LCA principles shall be implemented. The users has to move in a real factory, talk to the characters, collect and elaborate data and implement solutions in order to improve the sustainable aspects of a product. Thanks to the simulation game, the user can understand not only the LCA framework and phases, but also the limits of this procedure, e.g. how to request data to the industrial specialists and how to use that information in order to create a report and eventually provide suggestions. This way, the LCA Game can represent an engaging and user-friendly tool able to introduce LCA principles to novice users, getting them confident with the subject and preparing them for the subsequent interaction with advanced professional tools.

**LCA for agriculture: food, bio-material, bio-energy, including aspects of water use, land use, handling of pesticides, carbon accounting, end-of-life modelling (II)**

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**Worldwide mapping of freshwater deprivation effects integrating cascade effects: application to 3 water stress indicators**

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Freshwater consumption impacts are usually assessed at the midpoint level through water scarcity indicators computed from the amount of freshwater consumption related to water availability. As underlined by Loubet et al. (2013), impacts due to water consumption must consider the position within a given watershed to take into account cascade effects (upstream use causes greater deprivation than downstream one). Cascade effects can be considered relatively to watershed population, or area or water volume. In this study we identified three midpoints indicators : the water scarcity indicator (Pfister et al., 2009), the consumption-to-availability ratio defined by the Water Footprint Network (Hoekstra et al., 2012) and the AWARE (Available WATER REMaining) indicator proposed by the UNEP-SETAC WULCA working group. To compute cascade effects on these three indicators, water availability was computed for watersheds at the level 5 of Pfafstetter classification from discharge data obtained from the 30-arc minute resolution Composite Runoff version 1.0 database (Fekete, 2002). Water consumption was extracted from Hoekstra et al. (2012). Cascade effects were computed for the 3 indicators with Loubet methodology at year and month time-scales. Results were combined in global vector maps for all watersheds at world scale, considering watershed surface and population ponderation. Indicators are compared at the watershed level and the importance of cascade effect is discussed for two watersheds

(Seine in France, and Oum-Er-Rbia in Morocco). Influence of ponderation factor (area, population or water volume) is discussed as well. References : Fekete, B. M. High-resolution fields of global runoff combining observed river discharge and simulated water balances. *Global Biogeochem. Cycles*, 2002, 16, 1042. Hoekstra, A. Y.; Mekonnen, M. M.; Chapagain, A. K.; Mathews, R. E.; Richter, B. D. Global monthly water scarcity: blue water footprints versus blue water availability. *PLoS One*, 2012, 7, No. e32688. Loubet, P., Roux, P., Nunez, M., Belaud, G., & Bellon-Maurel, V. (2013). Assessing water deprivation at the sub-river basin scale in LCA integrating downstream cascade effects. *Environ. Sci. Technol.*, 47(24), 14242. Pfister, S.; Koehler, A.; Hellweg, S. Assessing the environmental impacts of freshwater consumption in LCA. *Environ. Sci. Technol.*, 2009, 43, 4098. Acknowledgements : This study was supported by the French Research Agency (ANR-12-TMED-0004, [https://www6.inra.fr/medina\\_eng/](https://www6.inra.fr/medina_eng/)).

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## **Environmental impacts of agricultural practices and Water and Soil Conservation Works : The case of the Merguellil catchment**

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Semi-arid agricultural areas are fragile territories where water and soil resources must be preserved. In such zones impact evaluation is difficult due to the lack of data. We focused on the upstream Merguellil watershed, located in central Tunisia, where several water and soil conservation works were built since 1990 to control water erosion and to protect the downstream area. The rapid expansion of such conservation measures raised the issue of their impact on soil and water resources. Our main goal is the impact assessment by LCA of the most relevant farming systems in our territory, taking into account on-site and off-site contributions to local and global impacts. Our strategy is to combine LCA with a participatory approach to integrate knowledge and perceptions of local actors and to provide elements on environmental impacts for all stakeholders. The first step was a territorial systemic participatory diagnosis to characterize the dynamics of the territory, to identify the natural resources and their uses, the developments of the agricultural practices and the characterization of the existing farming systems. This diagnosis was achieved through technical field visits and interviews with farmers. The second step was a territorial LCA of representative systems, mapping the different systems to consider the characteristics of their location (access to water, soil type, ...). Systemic territorial participatory diagnosis allowed to define a typology of production systems and to model the territory considering the interactions between these systems. Four types of production systems were identified to proceed with territorial LCA: olive and apricot system and olive and cereals system both in rainfed and irrigated combinations. LCA results are discussed for the most important midpoint indicators. This study demonstrated two major issues of LCA use for sustainable development in semi-arid watersheds: i) LCA results communication with stakeholders to fit with their understanding of the system and ii) localized impacts on soil and water resources, taking into account Water and Soil Conservation Works.

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## **Comparison of agricultural pesticides emission models for LCIA: an apple case study**

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Pesticide emissions can have a significant environmental impact when assessing agricultural products life cycle. However, results may vary strongly depending on the emission model used for the Life Cycle Inventory (LCI) and on the boundaries defined between Technosphere and Ecosphere. This led to an international consensus on the delineation between pesticide emission inventory and impact assessment for LCA (Rosenbaum et al. 2015). The present study intends to highlight the importance of these choices on an apple orchard case-study (apples are one of the most treated fruit with an average of 35 treatments per year). After application, pesticides follow a primary distribution to the several field compartments including, air, plant, soil and surface water if the pesticide is applied near a fresh water body. Several factors can affect this distribution, such as meteorological conditions, sprayer type, crop development stage and presence of buffer zones. After this primary distribution, pesticides redistribute following multimedia transport phenomena such as volatilization on plant and soil, wash-off, run-off, absorption and adsorption on soil. These phenomena take place during a lapse of time that can go from some hours to some days, weeks or months. The aim of our study was to compare different emission model hypotheses and the LCIA results of these hypotheses using Usetox. For that purpose, three main hypotheses and/or models were used to quantify the emissions of pesticide to the different environmental compartments: i) 100% of the emissions end on soil (cf. Ecoinvent), ii) emissions modeled using PestLci (considering only primary distribution and then secondary distribution), iii) emission distribution defined from experimental data and specific models (first without considering rain causing

wash-off and run-off, and secondly considering it). Results show great differences in toxicity results between the 3 different models (up to factor 10 or more). The conclusion is the need to implement a crop compartment in LCA in order to model the pesticide fate on plants and to adapt PestLCI model to better fit the Glasgow consensus recommendations.

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## **Calculation of on-field pesticide emissions for maize production in Northern Italy: how much do different soil typologies affect the results of PestLCI 2.0 model?**

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The calculation of emissions from the use of pesticides is a critical issue in LCA studies of agri-food products and is often not discussed in detail in literature studies. PestLCI 2.0 is a detailed model for calculating on-field pesticide emissions, which considers data about the application method of the pesticide as well as soil and climate data of the studied area. The model was developed for European conditions, but local circumstances may not be reflected in the modelling. Moreover, the model's database includes some general scenarios for European climate and soil conditions, which can be different from site-specific conditions. The goal of this study was to evaluate to what extent the results of the application of PestLCI 2.0 to a specific crop differ when different soil typologies are tested under the same climate profile. The production of maize in Vallevecchia area (Northern Italy) was used as case study. In the first phase of the study, eight site-specific soil typologies and one new climate profile representative for the studied area were added in PestLCI database. Model inputs such as pesticide active ingredient, crop type and application month, as well as application techniques and field characteristics were set to reflect local circumstances. Results highlight that both the emissions to air and surface water are scarcely affected or completely not affected by soil variation. As regards the former, they depend on meteorological conditions, on pesticide chemical properties and both pH and organic carbon content of soil, which in our case is moderate for all the soils considered. The latter depend mainly on the value of wind drift loss, which is correlated to the application technique and the field size. In contrast, soil type affects remarkably the emissions to groundwater, although the characteristics of the eight soils are quite similar. However, a clear relationship between soil characteristics and the fractions of pesticide reaching ground water could not be identified. Since the emissions to this environmental matrix are determined by many parameters, such as the type of pesticide, the type of soil and the meteorological conditions, the behaviour of the pesticide has a high variability. Currently, further soil typologies for maize production and characterized by a larger variability are tested, with the aim to assess if the differences in the results are large enough to justify modelling different soils when using the PestLCI 2.0 model.

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## **Accounting for spatial variability and speciation in Copper terrestrial ecotoxicity: Case study of wine consumption in Quebec**

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Wine industry applies around 13% of all synthetic pesticides used, while it occupies 3% of the European cropland. Copper-based fungicides are used in vineyards to combat downy mildew. Copper reaches the soil by different mechanisms, leading to accumulation in the soil and ecotoxic impacts. Current characterisation models in LCA disregard the fact that metals can exist in various forms with different behaviour and toxicity (speciation) in terrestrial environment, depending on the soil properties. This situation introduces bias and considerably affects the validity of LCA results since metal toxicity is associated with the bioavailable fraction. The objective of this study is to include copper speciation in the characterisation of its terrestrial ecotoxic impact and determine the influence in the conclusions. Recently, PestLCI 2.0 has been customized to better estimate the emissions, and subsequently the environmental impacts, of pesticides used in viticulture; however, this inventory model excludes inorganic pesticides such as copper. Therefore, and given the long lifetime of copper in soil, all copper emitted to agricultural soil was considered to contribute to the terrestrial ecotoxicity. Copper speciation was determined using WHAM 7 geochemical model, fate factors were calculated with USEtox from partitioning coefficients accounting for metal speciation and a bioavailable factor was introduced in the computation of the new characterisation factors (CFs). The LCA of a bottle of wine consumed in Quebec was performed, using the IMPACT 2002+ methodology. Eleven scenarios were analysed according to the wine market share by country of origin. Since grapevines grow in almost all kinds of soils, being climate the main limiting factor, this situation allowed us to compare the effect of using copper in different wine regions of the world. In fact, depending on the vineyard's soil properties, the new CF for copper span over 3 orders of



magnitude (from  $1.08E-02 \text{ PDF}\cdot\text{m}^2\cdot\text{y}\cdot\text{kg}^{-1}$  to  $1.16E+01 \text{ PDF}\cdot\text{m}^2\cdot\text{y}\cdot\text{kg}^{-1}$ ). With current IMPACT 2002+ CFs, the damage on ecosystem quality is dominated by copper emitted to soil during the viticulture stage. Using the new CFs accounting for speciation and geographic variability, the copper contribution to the terrestrial ecotoxicity drops from 98% to less than 1%, in average, for all the scenarios. These results show the need to include metal speciation and account for geographic variability of terrestrial ecotoxicity of copper in LCA.

## LCA of urban water systems from resources to users: water withdrawal, water treatment & distribution, water use, wastewater sanitation and reuse (III)

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### Life Cycle Assessment of Phosphorus Recycling Technologies from Sewage Sludge Ash: Primary vs. Ash-based Secondary Phosphate Fertilizers for German Agriculture

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In response to rapidly growing cities, the need for sustainable urban water systems is increasing worldwide. In this context, technologies to recycle phosphorus (P) from wastewater systems are being investigated in order to protect finite phosphate rock reserves and replace mineral fertilizers, which are associated with high environmental impacts. Technologies focusing on P-recycling from sewage sludge ash (SSA) are particularly advocated due to their high P-recovery efficiency. However, tests on the fertilization efficiency of secondary phosphates have delivered inconclusive results. The approach to **partially substitute** phosphate rock by **co-processing SSA** in established processes of the fertilizer industry offers a more economically viable solution which utilizes a secondary P-source without having to significantly compromise on quality or fertilization efficiency. By means of a cradle-to-grave Life Cycle Assessment this study aims to compare the environmental impacts associated with five different fertilizer alternatives for German agriculture. Functional unit is set to 1 kg plant-available P. Using a mix of primary and secondary data, conventional diammonium phosphate (DAP) and single superphosphate (SSP), their ash-based (hybrid) counterparts from co-processing, and 100% recycled calciumphosphate (CaP) are examined in terms of their global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), P-resource use and soil toxicity. Additionally, the water footprint (WF) of the fertilizer products is calculated using the newest indicator AWARE from the WULCA working group. First results showed that co-processing SSA can save up to 4% P-resource in the production of DAP, and 37% in the production of SSP. On the other hand, it increases the environmental impacts of conventional DAP in the categories calculated by 6-8%, and those of conventional SSP by 10-20%. Additionally, hybrid fertilizers have soil toxicity levels that are 2-4 times the toxicity levels of conventional DAP/SSP. However, they showed significantly lower environmental burdens in the impact categories GWP, AP and EP than 100% recycled fertilizers. The WF of the five fertilizer products is currently being evaluated and will be presented at the conference. Results of this LCA serve as a first basis for decision-making support in Germany (and Europe) to design superior SSA disposal options, sustainable P-management strategies and better integrated urban water systems.

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### Cost-benefit analysis of implementing innovative source-separated urine treatment

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Source-separated urine treatment becomes more and more appealing because of the conversion of waste into resource via the recovery of highly concentrated nutrients as fertilizers. The FP7 project ValuefromUrine investigated an innovative process (hereafter called VFU) to recover phosphorus as struvite via precipitation and nitrogen as ammonium sulphate based on bioelectrochemical system. The sustainability of the technology was demonstrated through LCA and LCC assessments. Previous LCA studies showed potential benefits of urine separation compared to conventional systems, but also underlined trade-offs between categories and issues related to data quality and uncertainty. The few available economic studies led to controversial conclusions and still faced significant uncertainties. To overcome these issues, process engineering knowledge was used in this project to increase data quality and transparency, and uncertainties were duly quantified and analysed. Three scenarios are compared:

(i) *Reference* (conventional wastewater treatment plant – WWTP), (ii) *SVFU* (small scale VFUs installed in buildings pre-treating 10% of urine) and (iii) *LVFU* (large scale VFU integrated in modified WWTP to treat 50% of urine collected by trucks). The functional unit is the treatment of 1 m<sup>3</sup> of wastewater, representative for the Netherlands where VFU pilot is located. The functioning of VFU at large scale is predicted from analytical functions (reaction equilibrium, electrochemistry, etc.) programmed in Python language. The consequences on WWTP are modelled using the process simulation tool SUMO, by calibrating a detailed treatment chain (adapted for LVFU scenario). The SUMO execution and the results download were automated with Python commands. The obtained foreground data fed both the life cycle inventory and impact assessment models built in Brightway2 and the LCC encoded in Python. Environmental and economic results can therefore be directly interpreted based on input variables (e.g. design choice, scenario assumption, prices). The latter were characterized using uncertainty distributions, propagated via Monte Carlo sampling and further analysed through sensitivity analysis. Preliminary results show negligible effects of SVFU scenario, while LVFU scenario presents trade-offs between water savings, lower WWTP efforts and fertilizers production, and additional consumption from the technology. Results, currently being consolidated, will be fully presented at the conference.

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### Life cycle assessment of a combined EGSB-CANON process for swine manure management

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Swine manure, if not adequately managed, can give rise to environmental and health concerns such as emissions of methane, ammonia, odours, and water quality deterioration [1]. The comparison of post-treatment processes for effluents from anaerobic digesters showed that the Completely Autotrophic Nitrogen removal Over Nitrite (CANON) technology is promising alternative to remove nitrogen from effluents generated in pig farms [2]. Therefore, the aim of the present study was to evaluate the expected environmental benefits arising from the installation of an advanced pig manure treatment plant as an alternative to conventional manure storage in anaerobic lagoons followed by direct soil application in Cadiz (Spain). The treatment plant scenario includes: (1) solid/liquid separation of raw manure, (2) treatment of liquid manure in Expanded granular sludge bed digestion (EGSB) reactor, followed by CANON, (3) land application of solid manure and fertigation with treated liquid effluent. The environmental impacts were evaluated following existing standard, assessing the impact categories as follows: (i) Global Warming Potential (GWP), Terrestrial Acidification (TA), Freshwater Eutrophication (FE) and Marine Eutrophication (ME). The inventory data were obtained directly from the plant managers and complemented with other data from the literature. The comparative LCA indicated that conventional scenario has the worst environmental performance for nearly all environmental impacts, except for marine eutrophication. So, the EGSB-CANON scenario reduced 27% of the GWP due to reduction of CH<sub>4</sub> and N<sub>2</sub>O released to the atmosphere as well as 59% of the TA and 48% of the ME due to the significant decrease on NH<sub>3</sub> emissions. On the contrary, the minor amount of N fertilizer avoided and the higher energy consumption caused a 20% of increase on FE. LCA has then served to quantify and validate the better environmental performance of the EGSB-CANON process as a suitable option for swine manure management. **References** [1] Burton CH, Turner C. Manure management: Treatment strategies for sustainable agriculture. Wrest Park: Silsoe Research Institute; 2003. [2] Figueroa M, et al. Is the CANON reactor an alternative for nitrogen removal from pre-treated swine slurry? *Biochem Eng J* 2012; 65:23-29.

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### Environmental and Water-Saving Impacts of On-Site Water Reuse in Hotels

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Increased tourism is projected for the Costa Brava. Environmentally, this could translate into increased water use, which is exacerbated during summers characterized by low rainfall. As a result, sustainable water management strategies are needed to ensure continuity in existing water resources. One possible solution is greywater reuse. With generally less contaminants to treat than conventional wastewater, greywater can be used for higher-level non-potable uses such as toilet flushing as well as irrigation. Therefore, this study aims to determine the environmental and water saving impacts of greywater reuse by the tourism industry on environmental impacts, using the city of Lloret de Mar as a case study. To carry out this study, two scenarios are modeled via a hotel water consumption simulation program. One is a "no-reuse" scenario in which potable water is used for all services in all hotels in the city of Lloret de

Mar. The other is a greywater reuse scenario in which water from the shower and kitchen is treated via membrane bioreactors and sent to flush toilets, and irrigate gardens, lawns and golf courses. Life cycle assessment (LCA) is used to estimate the endpoint indicators, while taking into account the midpoint indicator, water deprivation. Preliminary results show that greywater reuse of shower and sink water for toilet flushing in a large hotel in Lloret de Mar can lower the potable water use about 16%, wastewater production about 19%, yet increases the energy associated energy use about 6% due to the addition of a new technology. Final results would show the environmental impacts of the implementation of a greywater reuse system in each hotel in the municipality and if the water savings warrants these environmental impacts.

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## **Comparative LCA of water reuse and other options for water supply in a coastal mediterranean village**

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Reuse of treated wastewater can form a valuable alternative for different water uses in water-scarce areas of Europe. Within the EU research project DEMOWARE (#619040), different case studies and types of water reuse are analysed in their environmental benefits and impacts, using the method of LCA and water footprinting (WFP) to compare different scenarios of additional water supply and quantify the effects of water reuse on the overall environmental footprint. This study presents results of LCA and WFP at the coastal city of El Port De La Selva in Catalonia, where local water resources are limited and seasonal touristic activity puts additional pressure on low groundwater levels. Besides traditional options for additional water supply such as pipeline delivery of water from other areas or seawater desalination, the reuse of treated wastewater for different purposes is a potential alternative to alleviate this water stress. A tertiary treatment system for particle removal and disinfection is in operation at the wastewater treatment plant (WWTP), providing water with sufficient quality for reuse in public or private irrigation. Within the DEMOWARE project, the infiltration of tertiary treated water into a local aquifer is tested to recharge groundwater resources and thus provide additional water for drinking water production. In order to provide optimum quality of reused water and minimize additional risks for human health, tertiary treatment should be extended by a granular activated carbon filter to remove bulk organics and organic micropollutants. Another option would be a hybrid membrane system combining ultrafiltration and reverse osmosis to reach maximum effluent quality for infiltration. The LCA of the different options for augmenting water supply is based on primary data of the system and complemented by data of feasibility studies and other DEMOWARE sites. The results show that water reuse is a competitive option with lower energy demand and associated greenhouse gas emissions compared to the delivery of water via pipeline or seawater desalination. Another environmental benefit of water reuse is the decrease of nutrient emissions in the ocean with the WWTP effluent. WFP shows that water reuse can significantly reduce the direct WFP of water supply in El Port De La Selva, although seawater desalination has the lowest WFP but very high energy consumption. Overall, LCA results help to promote the implementation of water reuse for local stakeholders.

## **Energy: conversion, supply and storage systems (I)**

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### **LCA as a support for energy-policy-making: Multi-scale analysis of environmental impacts of electricity generation in the world from 1980 to 2010**

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Electricity generation is known to cause important damages to environment and human health. The political awareness of the global challenges posed by climate change and resource depletion has guided several countries to gradually move from a dominant use of fossil fuels towards more utilisation of renewables. However, have such moves led to environmental burden-shifting? Are there any identifiable patterns or hotspots across regions or impact categories that could serve to draw recommendations for energy planning? To address these questions, we collected annual data on electricity generation for 199 countries and territories for the period 1980-2011, differentiated per types of energy sources. These data were combined with region-specific life cycle inventories from ecoinvent 3 database to assess a broad range of environmental impacts. The results show that environmental impacts from electricity generation have increased over the considered period but they have intensified globally over the last decade. Large variations at national and regional levels are however observed, with overall developed countries, such as in North America or Europe, tending to stabilise their environmental impacts while developing countries, headed by China, are associated with important increases in their impacts. The hotspot analysis at national level, using adjusted normalisation principles, also revealed that environ-

mental burden-shifting had occurred in several countries over the considered period. The work provides a nice example of how LCA knowledge, including LCI and LCIA methods and factors (from both characterization and normalisation) can be used to inform policy-making in other fields than the regulation of single products. In that context, our findings therefore call for linking electricity planning with quantification of all relevant environmental impacts of the foreseen energy systems, to prevent or minimise problem-shifting and ensure environmentally-sound energy transition.

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**Environmental pressures of global electricity generation: applying the inventory that matches regionalized impact assessment methods**

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The electricity sector has featured greatly in LCA studies, including on a global scale, the resolution of which, has, so far, been mostly on a country level. Recently, we have begun a concerted effort to create a global georeferenced inventory of power plants emissions for use in LCA and beyond. The aim is to obtain a complete view of the environmental pressures due to global electricity generation, including emissions to air and water, as well as water consumption, all on a power plant level. Equipped with such a regionalized inventory, we can not only match regionalized impact assessment methods, but we can also gauge how close or far off country or other-level estimates of the associated impacts have been, offering insight into the issue of complexity vs simplification in electricity sector LCI data, and resulting uncertainties. We have started this effort by focusing on freshwater thermal pollution caused by steam-electric power plants with once-through cooling systems. Global power plant data have been acquired and gaps populated in previous work. Moreover, efficiencies and, where applicable, thermal emission rates have been calculated on a generating unit for ~92% of the global installed thermoelectric capacity. Here we present the results of combining the global inventory of heat emissions with two models: i) a global hydrological-water temperature model, and ii) a global thermal pollution impact assessment model. Both analyses are on 0.5° resolution and highlight thermally polluted watersheds, the former via water temperature increases (midpoint level) and the latter at endpoint level via monthly impacts on aquatic biodiversity within the LCIA framework. In the latter, watershed-level impacts were compared via two calculation routes, namely a combination of i) 0.5° grid cell level inventory & impact assessment and ii) watershed level inventory & impact assessment. Median thermal pollution impacts during warm months are three orders of magnitude higher than those in cold months. 52% and 37% of global annual impacts are due to emissions from coal and nuclear power plants, respectively, entering commercial operation mainly during or before the '80s. Half of the 10 most thermally polluted watersheds worldwide are subbasins of the Mississippi. Other areas of concern include central-eastern European watersheds, as well as ones in eastern China. In our analysis we identify these and other geographical, temporal and technical thermal pollution patterns.

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**Regionalized Life Cycle Inventory of Power Producing Technologies and Power Grids in India**

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The Indian electricity production mix, power plant technological level and local production conditions vary considerably on the state level across the 29 Indian states and 7 Union Territories. Hence, national level Life Cycle Inventory (LCI) of Indian power producing technologies and power systems as presented in ecoinvent v3.2 may not represent well this high variability. The aim of the present study is to evaluate the necessity of regionalized inventories of power production in India and to collect relevant LCI data to create a consistent regionalized model. Data collection covers domestic power production and inter-exchanges among the grids and with other countries in 2012-2013. Further, region-specific key parameters (e.g. efficiency, solar yield) are collected. Such regionalization work faces some data availability challenges. Power plant parameter data (e.g. efficiency, fuel quality, exact technology used) are mostly unavailable on plant level: if at all, relevant data are available on a state level. Moreover, local emission data are also mostly unavailable except emissions of CO<sub>2</sub>. Emission values for other important emissions (NO<sub>x</sub>, SO<sub>x</sub>, CH<sub>4</sub>, CO, PM) are therefore calculated based on assumptions and literature information. The impact assessment results show high variations among the various power grids due to different grid mixes, key parameter values and electricity losses during transmission and transformation (T&T). As an example, power from the Eastern grid shows nearly four times higher Global Warming Potential (IPCC 2013 GWP 100a) scores (1.6 kg CO<sub>2</sub>eq/kWh) than the North-eastern grid (0.4 kg CO<sub>2</sub>eq/kWh) and also considerably higher than the Northern (1.1 kg CO<sub>2</sub>eq/kWh) and Southern grid (1.2 kg CO<sub>2</sub>eq/kWh). The Western grid also corresponds to relatively high GWP score (1.4 kg CO<sub>2</sub>eq/kWh). Moreover, relatively high T&T losses have been inventoried. For example, in the Eastern grid, GWP scores for high, medium, and low voltage grids are 1.7 kg CO<sub>2</sub>eq/kWh, 1.8 kg CO<sub>2</sub>eq/kWh, and 2.1

kg CO<sub>2</sub>eq/kWh, respectively which corresponds to up to 17% technical losses along the chain from gross production. To compare, in ecoinvent v3.2, the GWP score for the national average of Indian electricity supplied at high voltage is 1.3 kg CO<sub>2</sub>eq/kWh. This confirms the need of regionalised inventories for countries with large mix and key parameter variations in order to provide higher quality information and higher accuracy in life cycle studies. \n

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## **Life cycle impacts of energy system infrastructure: comparing coal generating station retrofits for conventional and steam-treated wood pellets**

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One of the key advantages of steam-treated pellets is their compatibility with existing storage, handling, milling and combustion infrastructure at coal-fired generating stations. In contrast, firing conventional white pellets typically requires substantial investment in covered storage, dust suppression systems, and burner modification/replacement. To comprehensively assess the relative environmental impacts of the two pellet types, it is necessary to evaluate both fuel cycle (biomass supply, pellet production, combustion) and infrastructure impacts. However, energy system LCA studies commonly ignore infrastructure, assuming that this will have a small relative impact. In this study, we undertake a hybrid modelling approach that employs process-based LCA (fuel cycle) and EIO-LCA (retrofit infrastructure) to better understand trade-offs between steam-treated and conventional pellets and impacts relative to conventional fuels. Models are applied to a case study of pellet production and use in Canada, with operating data from pellet manufacturers and generating stations using steam-treated pellets, conventional pellets, and coal. While steam-treated pellet production is more energy intensive than conventional pellet production, this has a negligible impact on environmental impacts. Greenhouse gas reductions of more than 90% can be achieved relative to coal, while air pollutant emissions (NO<sub>x</sub>, SO<sub>x</sub>, PM<sub>10</sub>) are also reduced. The impacts of retrofit infrastructure are more significant for conventional pellets due to more extensive retrofit requirements. Infrastructure contributes an additional 10 gCO<sub>2</sub>eq./kWh (14% of total life cycle emissions) for conventional pellets but 2eq./kWh for steam-treated pellets for typical thermal power plant operation. The “fixed” impacts of retrofit infrastructure become increasingly significant at lower electricity outputs. When operated to provide peak power (capacity factor ~10%), infrastructure contributes 50% of total life cycle GHG emissions for conventional pellets, resulting in total GHG emissions of 150 gCO<sub>2</sub>eq./kWh, double that of steam-treated pellets. However, while infrastructure is found to be significant in terms of life cycle impacts of wood pellet pathways, total emissions are still far less than those for the reference coal (1,015 gCO<sub>2</sub>eq./kWh) and so retrofit infrastructure does not impact the conclusion that the wood pellets can effectively reduce GHG and air pollutant emissions in the electricity sector.

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## **Poster Spotlight**

## **LCA for agriculture: food, bio-material, bio-energy, including aspects of water use, land use, handling of pesticides, carbon accounting, end-of-life modelling (III)**

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## **Assessing environmental performance of humidification technology used in supply of fresh fruit and vegetables**

S. Fabbri, M. Owsianiak, DTU Technical University of Denmark

Distributions chains in Europe of most fresh fruit and vegetables follow a pattern where fruit or vegetables produced in southern European countries are typically transported to countries in the central or northern parts of Europe. The relatively complex supply and distribution chain with many actors involved (from farmers, through wholesalers, to retailers) highlights the need for minimizing food loss in the post-harvest to optimize the overall environmental performance of agricultural systems in Europe. Humidification is an emerging technology that can potentially contribute to minimize post-harvest losses of fruit and vegetables. Humidifiers release a fine mist thereby reducing the difference in water vapour pressure at the surface of the fruit or vegetable and in the air, preventing dry-out of fruits and deterioration. In addition, humidification provides cooling as a result of the evaporation of the droplets into the unsaturated air, without exchange with the environment (adiabatic cooling effect). The overall

environmental performance of the humidification technology is expected to be determined by the trade-offs between lower environmental impacts stemming mainly from a reduction in loss and associated agricultural efforts and increased impacts mainly due to the need for new equipment and increased water use. We assessed environmental performance of humidification technology in the European context. Lettuce produced in Italy and transported to Denmark was chosen as a case study, and sensitivity scenarios considered strawberries, flat peaches, asparagus, and table grapes. The results show that the technology has the potential to reduce life cycle environmental impacts, provided that it allows reducing food loss in the post-harvest. When compared to the conventional supply chain of lettuce without humidification, the impact scores are reduced on average by 2.6, 6.0 and 7.4% when the total losses of the supply chain are decreased by 2, 5 and 6%, respectively (corresponding to low, medium and high efficiency of the technology). This is true for all impact categories, except resource depletion which is driven by the humidifier production and disposal stages rather than agriculture. Thus, depending on the performance of humidifying units, humidification may have the potential to reduce environmental impacts stemming from supply of fresh fruit and vegetables in Europe.

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### **Environmental impacts of agro-municipal resource use in an Alpine municipality**

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The declining agricultural use of Austrian Alpine grassland calls for alternative biomass utilization strategies such as biogas production. Steam explosion (SE) pretreatment allows for co-digestion of lignified materials such as late harvested Alpine grass with agro-municipal organic wastes. SE pretreatment not only accelerates biomass decomposition but also increases biogas yields. The assessment presented here quantifies the environmental impacts of producing biogas locally from lignified hay and agro-municipal wastes, enabled by SE pretreatment, relative to the status quo of grassland and waste management. Using a life-cycle assessment approach, a hypothetical local biogas system (LB scenario) with steam explosion pretreatment is modeled. Its substrates are mainly hay from currently unused Alpine grasslands, supplemented by organic wastes. This scenario is compared to the status quo situation (SQ scenario) where Alpine grasslands are not used and municipal organic waste is managed outside the community in a local waste management center. For simplicity, and to allow comparison with other biogas LCAs, a functional unit of 1 kWh of electrical output at a combined heat-and-power (CHP) module was chosen as a functional unit. An assumed biogas plant size of 500-kWh<sub>el</sub> was modeled based on the potential regional hay supply and efficiency considerations with respect to the SE pretreatment. In both the SQ and LB scenarios, the CHP is assumed to operate 7,470 hours per year, combusting 240 m<sup>3</sup> biogas per hour at an electrical efficiency of 38%. The environmental impacts of providing system infrastructure are considered in both scenarios. Disposal of this infrastructure was considered negligible. Local biogas was shown to have a significantly lower global warming potential (0.366 kg CO<sub>2</sub>-eq/kWh<sub>el</sub>) than the status quo scenario (0.498 kg CO<sub>2</sub>-eq/kWh<sub>el</sub>) under the assumption that the heat produced from the local biogas plant would replace heating oil for residential heating. Scenario results proved to be highly sensitive to the mix of heating sources being replaced by heat from biogas production. Nevertheless, biogas production augmented by SE pretreatment was shown to have the potential to reduce greenhouse gas emissions while preserving Alpine grasslands. Additional results for other impact categories (CED, acidification, eutrophication) will be presented, as well as parameter uncertainty estimates and sensitivity analyses of scenario and model uncertainties.

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### **Understanding regional variability on impacts of cropping systems; a case study of wheat in Central NSW, Australia**

A. Simmons, NSW DPI

Intra-regional variability in broadacre cropping systems occurs due to variables such as climate, soil type and management actions (e.g. fertilizer inputs). To date, LCA models of crops have focused on modeling the average or median practices for a region. A method for estimating impacts on a regional basis is presented as a case study for the production of 1 t of wheat in Central NSW, Australia. The method uses a publically available calculator developed by CSIRO that estimates crop yield from the total nitrogen (N) available to the crop from four pools; inorganic N at sowing (1), N provided by fertilizer (2), N mineralized during the growing season (3) and N supplied/tied up by stubble from the previous crop (4). Data required for pools 1 and 2 were the mean and standard deviation for the region and were obtained from research and/or agronomic databases. The mean and standard deviation of pool 1 were obtained from a bootstrapped distribution whereas regression analysis was used to link pools 2 and 3 to rainfall across the region to account for climate differences and to avoid relatively high yields occurring

in areas of relatively low rainfall. The mean and standard deviation for the region was then estimated using the distribution of regression outputs. Data for pool 4 were estimated using the C:N ratio and stubble mass of the previous (wheat) crop. Data were used to populate a LCA model and a Monte Carlo simulation was run to estimate regional distributions of yield and impacts. The model estimated that the yield for wheat (protein of 11.5%) in an average rainfall year was  $2.32 \pm 0.51 \text{ t ha}^{-1}$ . Landuse impact for the production of a tonne of wheat grown in the region was  $0.447 \pm 0.095 \text{ Ha.years}$ , the Fossil Fuel impact was  $32.85 \pm 8.67 \text{ kg oil eq.}$  and the Climate Change impact was  $137.2 \pm 37.42 \text{ kg CO}_2\text{-e.}$  The Monte Carlo simulation also produced a dataset that could be analyzed by parametric statistical methods. Regression analysis indicated that Fossil Fuel and Climate Change impacts were negatively associated with N use efficiency (NUE) and the amount of N supplied to the crop by non-fertilizer sources. The method outlined here demonstrates that uncertainty of LCA results associated with regional variability can be estimated using conventional statistical methods. Further, the LCA model outputs can be interrogated to identify agronomic variables associated with LCA impacts.

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## **LCA of rapeseed and sunflower oils as the basis for guidelines on LCA in vegetable oil sector**

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The aim of the study is to promote eco-design in vegetable oil sector by using LCA as a tool. In 2011, the vegetable oil sector participated to the French national experimentation on environmental labeling for two standard oils: sunflower oil and rapeseed oil. The complete life cycle of oils has been studied from the seed production to the end of life of the packaging. The data have been collected from different industrial sites that illustrate the diversity of French crushing, refining and packaging sites. The results of this study are a relevant overview of sunflower and rapeseed oils produced in France. Nowadays, companies from the oil sector use these values to compare them to their own process values and to evaluate the improvement due to their eco-design strategy. Since 2011, some methodological aspects changed: (i) update of background data (new version of Ecoinvent database), (ii) new data available on agricultural stages (AGRIBALYSE® program), (iii) new recommended methods for environmental indicators, (iv) new pattern for end of life, etc. Effects on LCIA results could be huge, even if life cycle inventories for industrial transformation (yield, energy consumption, etc.) are still the same, that could lead to misunderstanding of LCIA results by stakeholders. In this context, ITERG (French institute of vegetable oils and fats) helped industrials to deal with these changes. This work highlights the importance to fix, for a given industrial sector, methodological aspects for all the stakeholders of the sector. ITERG, FNCG (French federation of vegetable oil sector) and Terres Inovia (Interprofessional organization for vegetable oils and proteins), with the help of Terres Inovia (technical center for oilseed crops, grain legumes and industrial hemp), wrote guidelines for assessing the environmental impacts of vegetable oils. The aim of these guidelines is to set sector-specific procedural rules to be used. These guidelines give recommendations on functional unit, allocation method, environmental indicators to be considered, and propose default values that are not readily accessible or that have little impact on the LCA results, and a list of data that can be excluded from scope of the study. Alongside this research work, ITERG has also developed an Excel tool for assessing the environmental impacts of the entire vegetable oil industry product range. This tool substantially reduces the timespan to calculate environmental impact of vegetable oils.

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## **Integrated assessment of the pressures associated with raw food production on biodiversity in view of an absolute ecological sustainability assessment**

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The concept of planetary boundaries was proposed by (Rockström et al., 2009) and actualized by (Steffen et al., 2015) to outline a safe operating space for humanity that would carry a low likelihood of harming the life support systems on Earth. While acknowledging the difficulty to set a relevant threshold for biodiversity integrity, the estimated extinction rate suggests that this ecological boundary has already been transgressed. Besides, (Rockström et al., 2013) pinpoint that food production needs to undergo major changes to meet rising demand and ensure food security in the context of growing ecological pressures. The aim of this paper is to propose and test a method of prioritization of the ecological pressures that are exerted on biodiversity by food production. We build on the developments of (Bjørn and Hauschild, 2015) who mobilized the planetary boundaries framework to propose a method of normalisation of LCA midpoint impact categories based on ecological carrying capacity. The method that is proposed is based on the use of the Agribalyse database, developed by (ADEME, 2013), that references environmental impacts that are linked with the production, at farm, of plant and animal raw food products, using midpoint indicators recommended by ILCD. These midpoint indicators are

then normalized with normalization reference values proposed by (Bjørn and Hauschild, 2015). Thus, to each food product can be associated a normalized “ecological budget” expressed in unit of person. year that can be interpreted as the “environmental interference corresponding to the annual personal share of the carrying capacity” for the considered impact (Bjørn et al., 2015). It is assumed that the highest ecological budgets correspond to the most critical food products’ ecological pressures. However, our study highlights some limits to this assumption. Indeed, some ecological pressures that threaten biodiversity are not taken into account by the midpoint indicator framework recommended by ILCD. Besides, some ecological pressures that are identified in the literature as the main driver of biodiversity loss, such as habitat loss related to livestock breeding (Steinfeld et al., 2006; Kok et al., 2014; Machovina, Feeley, & Ripple, 2015), do not appear as priority impacts with the carrying-capacity normalization reference method.

## LCA and uncertainties: How to deal with uncertainties in LCA studies and their interpretation?

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### **An integrated method for identification, classification, and quantification of uncertainty in Life Cycle Assessment studies- case study application to a building.**

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Life Cycle Assessment (LCA) studies are often used to support decision-making processes and policy development. It is thus important that these studies measure the accuracy of the results, as this can help the decision-maker choose the most appropriate solution. Since complete (cradle-to-grave) LCA studies cannot be fully validated, uncertainty analysis can be used to give an estimate of the error. The complexity of LCA studies, however, complicates this as it involves quantifying the uncertainty of decisions made based on unscientific approaches, such as expert opinions and value-choices. This complexity, as well as the lack of knowledge for conducting an uncertainty analysis, has led to uncertainty analysis being ignored in practice. An integrated method for uncertainty analysis in LCA studies was developed that integrates the identification, classification and quantification of uncertainty into each stage of the LCA process as defined by ISO 14044. A new classification system that identifies types of uncertainty that arise in LCA studies is also presented. This can be used to determine the uncertainty quantification method to apply, and the types of uncertainty that can be considered irrelevant to the overall result. The integrated uncertainty analysis method was applied to an environmental process LCA of a building. The data sources used include the Bill of quantities for the building and the ecoinvent database. It was found that this method was very time consuming, however, from the results it was found that some uncertainty types could be eliminated to decrease the time for the analysis, while still giving an appropriate measure of the total uncertainty.

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### **Addressing high variability in LCA with Global Sensitivity Assessment: from a single parameterized model to multi parameterized clustered models**

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The application of Life Cycle Assessment (LCA) has been traditionally based on deterministic models that provide estimates of the environmental impacts of complex processes through sets of single-value parameters. Too often, this approach neglects to provide the potential distribution of the response of specific systems linked either or both to uncertainty (due to lack of knowledge in parameters, models and practitioner’s decisions) and to variability (caused by inherent differences between locations, technologies and temporal frames for example). Global sensitivity analysis (GSA) is an efficient method to quantify the impact of both causes of LCA results variance from each input’s variation and to support LCA model simplification. However, uncertainty and variability have different implications when refining



LCA parameterized models to enhance their quality, so the identification of the main cause of variation is an essential step. If uncertainty is the major source of variation, the improvement of the LCA model may be obtained by collecting additional information of the system that allows: i) a deeper knowledge of the model parameters, ii) the development of a more detailed and relevant model or iii) a change in arbitrary decisions affecting LCA results. On the contrary, the predominance of variability reveals the existence of potential significantly different alternatives of the modeled process. Consequently better qualified estimates of the environmental impacts cannot be obtained by acquiring more precise input data. In this work, we propose a method to improve the quality of LCA results linked to variability-based variation in complex models by 1) Identifying whether variability is actually the main cause of variation or not, 2) Grouping the different alternatives into a relevant set of system typologies. Such clustering step does reduce the range of LCA results for each typology, 3) For each cluster, setting a simplified parametrized model based on key parameters responsible for most of the cluster's variability. We apply this approach to the quantification of the greenhouse gas (GHG) emissions from the building sector by taking as an example the residential building stock of a representative town in Luxembourg. The method reduces the GHG estimates variability induced by a generic single parameterized LCA model for all existing types of buildings by establishing multi parameterized clustered models based on building type-specific key parameters.

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## **Sensitivity analysis and uncertainty propagation to investigate the results' robustness of building life cycle assessment**

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Building life cycle assessment (LCA) tools aim at helping the decision-making towards more sustainable built environments. In order to reach this goal, such tools need to be robust. However, practitioners are facing many choices in a project, leading to uncertainties in the results. In order to understand which factors induce the most uncertainty, sensitivity analysis (SA) is commonly applied, followed by uncertainty analysis (UA). Of particular interest is the possible influence of the uncertainty on the ranking of compared alternatives. UA&SA methods were applied on a case study consisting of a single family house. 22 uncertain factors were investigated, mostly concerning the building's envelope, occupancy, lifetime and context. The building LCA tool novaEquer, linked with the dynamic building energy simulation tool Pléiades+COMFIE, was used. Twelve indicators were calculated based on environmental data from ecoinvent. SA methods enabled to identify the most and less influential factors. For the less influential, default values can be used so that practitioners can focus on the most influential ones for the data collection. The results given by four SA methods were compared. Local SA, Morris screening, ANOVA on the Hadamard matrix and global SA methods have different computation time versus precision compromise. All of them identified the building lifetime, the electricity production mix and some parameters affecting the energy consumption (e.g. thermal bridges) to be very influential. But the relative influence of the factors varied according to some characteristics of the methods (consideration of linearity; type of probability distribution; calculation of effects or variance). In our comparison study, UA was performed to study the impacts difference between two alternatives: using electricity or gas for heating and preparing hot water. For each indicator, the probability that an alternative had smaller impacts than the other was calculated. Choosing a different sampling strategy yielded small changes in the probability for a given number of simulations. However, the precision of the uncertainty characterisation (definition of probability distributions) influenced the results. In a next step, UASA will be done considering a wider range of uncertain factors of the building LCA model, and will be extended to the district. The influence of long term scenarios will be investigated in a prospective approach.

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## **Uncertainty propagation in ABM/LCA coupled models**

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The evolution of life cycle assessment (LCA) from a merely comparative tool for products to a policy analysis tool proceeds by incorporating ever more complex modelling approaches. In more recent studies of complex systems, such as the agriculture sector or terrestrial mobility, agent-based modelling (ABM) has been introduced as a complement to the life cycle inventory. Such ABM/LCA coupled models constitute an improvement of the current LCA practice, as it brings an additional level of complexity to the assessment and allows a bottom-up modelling of aspects related to human behaviour, not possible to grasp by purely economic modelling. The acceptance of this new emerging approach depends, among other things, on the handling of uncertainty and variability forthcoming from various sources of both modelling parts. As the complexity of a methodology increases, it also becomes increasingly challenging to adequately handle uncertainty and variability, and be confident about an inference. In the case of ABM/LCA coupled models, the different nature of both parts (non-linear computational ABM and linear deterministic LCA) pose an additional challenge. The sources of uncertainty and variability and the preferable propagation methods differ for both parts and clear guidance is needed. Yet no study to our knowledge has addressed this issue, although an interest from several authors has been expressed. To make uncertainty analysis of ABM/LCA coupled models operational the different sources of uncertainty in both models are identified and a systematic classification is proposed. The efforts in both fields to propagate uncertainty of these sources are reviewed and discussed against three criteria (applicability, accuracy and computational effort). We introduce a formal nomenclature for the coupled model, that facilitates the identification and propagation of uncertainty from all relevant sources. A transparent and thorough framework for quantification of uncertainty and variability in the output of ABM/LCA coupled models is presented with an emphasis on the trade-off between computation time and accuracy. In a first proof of concept the framework is applied to an ABM/LCA coupled model describing the evolution of the Luxembourgish agriculture sector under different scenarios and the related environmental impacts.

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### Discussion

## Energy: conversion, supply and storage systems (II)

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### LCA of varying electricity supply with relevant shares of intermittent renewable generation based on highly time-resolved electricity market data

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Increasing shares of intermittent renewable electricity generation, e.g. realized within the German energy transition, lead to fundamental changes of the electricity supply resulting in strongly fluctuating supply mixes and therefore varying environmental impacts. In contrast to fossil fuel based supply systems with regular electricity generation profiles, the feed-in of renewable energy leads to profiles which vary within short time periods. Fossil-fueled power plants need to be operated more and more flexible to counterbalance intermittent renewable generation and to guarantee security of electricity supply. This leads to an increased load cycling of fossil-fueled power plants with frequent part-load operation, startups and shutdowns resulting in lower efficiencies and higher emission factors. Existing LCA approaches use annual aggregated generation mixes with average efficiencies and emission factors. GaBi Databases e.g. use average efficiencies, calculated based on IEA World Energy Statistics and for EU countries emissions published under the Large Combustion Plant Directive (LCPD). Applied to electricity supply systems with regular generation profiles, these approaches lead to results with high accuracy. However when applied to supply systems with high shares of intermittent renewables, they are not able to capture resulting varying environmental profiles which show high amplitudes caused by situations with maximum and minimum renewable generation. The presented approach developed in the project "Power&Biomass to Gas" aims to capture the environmental profile of electricity supply in an hourly

resolution. For this purpose German power plant operation data from an electricity market model of the Institute of Combustion and Power Plant Technology (IFK) at the University of Stuttgart is used. The approach provides the combination of a market model and load-dependent efficiency and emission factors of coal and natural gas power plants with existing LCI data for production, use and end-of-life. This combination enables the integration of efficiencies and emissions during part-load operation, startups and shutdowns as well as the consideration of individual power plant operation times. The presentation summarizes the structure of the developed approach and shows results for German electricity supply for 2015. Potential future applications, like e.g. the integration in a holistic energy system LCA model or in LCA of storage systems, are shown subsequently.

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## **Life Cycle Assessment of Electricity Storage Technologies for Different Discharge Durations and Scales**

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As the penetration of renewable electricity increases, storage plays a more important role in the energy system to deal with its intermittent supply [1]. Previous studies investigating the life cycle GHG emissions of electricity storages are often limited in terms of scope by selective choice of storage applications. For example, Olivera et al [2] assigned the environmental burdens of a fixed amount of storage facility to each kWh of electricity stored, based on single estimate of electricity stored during the lifetime. Other studies considering the operation of energy storage often concluded that the contribution of electricity feeds into the storage is high in life cycle GHG emissions [3]. But this might not always be true, because storage operates dynamically for various or even combined applications based on the market price of electricity or acting as power reserve. Associated environmental impacts will change accordingly. This study has therefore taken into account the storage performance variations based on different discharge durations and unit sizes in the life cycle inventories, and assessed the life cycle GHG emissions for different storage technologies and applications. Evaluated technologies include pumped hydro storage, lithium-ion battery, compressed air storage and power-to-gas-to-power. Two storage sizes (in terms of power rating) are selected: 1 MW and 100 MW, aiming to represent decentralized and centralized storage, respectively. Discharge durations range from number of seconds to seasons. The results show that the consideration of storage application is important, and ranges of storage performance should be incorporated in LCA, as some of these performances may have wide range of uncertainty, which also needs to be taken into account in result interpretation. [1] A. Evans, V. Strezov, T.J. Evans. Assessment of utility energy storage options for increased renewable energy penetration. *Renewable and Sustainable Energy Reviews*. 16 (2012) 4141-7. [2] L. Oliveira, M. Messagie, J. Mertens, H. Laget, T. Coosemans, J. Van Mierlo. Environmental performance of electricity storage systems for grid applications, a life cycle approach. *Energy Conversion and Management*. 101 (2015) 326-35. [3] M. Messagie, L. Oliveira, S. Rangaraju, J.S. Forner, M.H. Rivas. 11 - Environmental performance of lithium batteries: life cycle analysis A2 - Franco, Alejandro A. *Rechargeable Lithium Batteries*. Woodhead Publishing 2015. pp. 303-18.

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## **Including storage in local grids - the case of an island in the North Sea**

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On the island Borkum in the North Sea, wind turbines and PV panels have been established to contribute to power supply for private consumers, municipal utility and industry. Otherwise the island is connected to the mainland with a medium voltage cable and the municipal utility runs also gas-powered CHP plants that contribute to the grid and district heating. The project NETfficient (Horizon 2020 grant 646463, duration 2015-2018) addresses a transition of the grid as a central case study. As an additional step, storage options for low voltage and medium voltage are now introduced on the island. This requires also the use of advanced control and connection equipment to establish a stable and reliable grid. Environmental assessments are carried out throughout the project. First, data for new elements are collected to identify hotspots in a screening analysis to inform designers about potential drawbacks of planned layouts and enable ecodesign. From the start of operation, environmental impacts of introducing new elements will then be assessed for several use cases. These also contribute a thorough analysis of the demand side, additional to information for the use phase of devices needed to facilitate the implementation. Data will be collected for the pilot use cases to evaluate different systems designs. Data that are specific for the pilot case are identified and modified to create general modules in addition. The local case and up-scaling potentials also will be integrated in a wider grid model to evaluate interaction effects. From a methodological point of view, different aspects will be considered. From the use cases, different functional units are derived and tested including households, districts and the entire community with a time perspective that covers also seasonal fluctuation in demand and supply. Temporal aspects are also essential for the evaluation of the effects of implementing the ap-

proach on a wider scale. This clearly needs to consider a future national grid in Germany, which according to energy policies will include less fossil-fuel based power plants. Less emissions for electricity from grid are anticipated. Different scenarios have been suggested and will be tested for modeling a future grid. The transition from the current grid to a future equilibrium will also be considered with intermediate scenarios. The case study will be presented based on current results and upcoming tasks.

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### Prospective Life Cycle Assessment of Sodium-Ion Batteries

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Sodium-ion (Na-Ion) batteries are emerging as a potential alternative to current lithium-ion based technologies. They are considered to be economically and environmentally advantageous due to the use of earth-abundant sodium instead of lithium. Nevertheless, no studies on the environmental impacts of the production of such batteries have yet been published. We present the first prospective life cycle assessment (LCA) for the production of a Na-ion battery with a layered transition metal oxide as positive and hard carbon as negative electrode material on battery component level. Benchmarking the Na-Ion battery against existing studies on Li-Ion based technology allows for providing a first impression of its future potentials. For this purpose, existing LCA studies on Li-Ion batteries are analyzed and recompiled using common average values for key parameters, providing thus a well-funded basis for comparison. In spite of the uncertainties intrinsically associated with a prospective assessment of a new technology, the results indicate that Na-Ion batteries are potentially promising under environmental aspects. Environmental impacts per kWh of storage capacity are at the lower end of the range published for current Li-Ion batteries. Furthermore, still significant improvement potential is identified, especially by reducing the environmental impacts associated with the hard carbon production for the anode and by reducing the nickel content in the cathode active material. For the hard carbons, the use of organic waste can be considered a promising approach for minimizing the potential impacts associated with its production. Nevertheless, when looking at the energy storage capacity over lifetime, achieving a high cycle life and good charge-discharge efficiency are fundamental. This represents the main challenge especially when competing with LFP-LTO type Li-Ion batteries, which already show extraordinarily long lifetimes. As first prospective LCA study on Na-Ion battery technology, the study provides highly valuable information to researchers and battery developers about environmental hotspots and improvement potentials of this upcoming energy storage technology.

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### Discussion

## LCA and LCM in industrial sectors, including public disclosure and reporting of sustainability metrics

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### Environmental impacts of alcoholic beverages

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**Objective of the study:** This study documents the total environmental impact of the product portfolio of the Nordic Alcohol Monopolies, expressing the environmental impacts in monetary units, in addition to the underlying physical units. The intended use of the results are to focus the environmental strategy of the Nordic Alcohol Monopolies and may be used in various communications e.g. with suppliers.

**Methodology:** The current study has been commissioned as a so-called environmental profit and loss account (E P&L), which is an organisational LCA with full monetarisation of the environmental impacts. The study is carried out using the consequential modelling approach following the requirements of the ISO standards 14040 and 14044. As background database the study uses the EXIOBASE v.3, a global multi-regional input-output database based on the national and international statistical accounting of trade between industries and between countries. This ensures a complete coverage of the global economy and thus overcomes some of the problems of incompleteness and cut-offs often found in traditional LCA databases. The biodiversity impacts and CO<sub>2</sub> emissions from indirect land use changes (iLUC) are included with Schmidt's accelerated denaturalisation model. We have added more detailed data for the most relevant activities in the most relevant countries of origin of the beverages, as well as

for international transport and consumption activities. **Main results:** The following three impact categories were identified as the most significant contributors: Global warming ( $N_2O$ ,  $CO_2$ ,  $CH_4$ ) Respiratory inorganics (air emissions: particles, ammonia,  $NO_x$ ,  $SO_2$ ) Nature occupation (biodiversity) The largest contributing life cycle stage is agriculture and upstream (including indirect land use). Packaging, especially one-way glass bottles, are identified as another large contributor and an obvious target for improvements. For spirits, the energy use at the distilleries is identified as a possible target for improvements. **Discussion and conclusions:** The variation between producers (and between countries) is very large, and will be a subject for identifying further improvement options.

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## **A benchmark for LCM in shoe companies - Environmental impacts in the Swedish market of six trade categories of footwear**

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The Swedish Shoe Environmental Initiative (SSEI) runs a project with purpose to reduce the environmental impacts of its products. An important tool in this initiative is an LCA tool for which impacts can be estimated already in the design phase, allowing for simulations of different designs. (Danielsson et al, 2014: Platform presentation at NRWC, Stockholm 2014-11-05--06). Another and also important tool in this initiative is an analysis of the (Swedish) shoe market in order to establish a reference level for impacts for various shoe types. Thus, an analysis was carried out on the impacts of shoe consumption (annual sales) in Sweden between 2000 and 2010, with a model combining life cycle assessment, product flow analysis and material flow analysis. (Zhang and Gottfridsson, 2015: M Sc thesis, Chalmers University of Technology, Göteborg, Sweden). The annual consumption was defined as the net inflow of shoes into Sweden during one year. The shoes were categorized according to the Combined Nomenclature (CN) system used for trade and statistics, which generated six footwear related groups; Waterproof (6401), rubber & plastic (6402), leather (6403), textile (6404), others (6405) and shoe parts (6406). In order to produce a valid benchmark, the same LCA models as for the design tool were used in the shoe market calculations. When calculated per pair of shoes, the outcome is not so pleasant for leather shoes, as these are in the order of 20-300 % worse in terms of environmental impacts (for potential for Acidification, Eutrophication, Global warming and photo-oxidant formation), compared to the other categories. If, on the other hand, the use of the shoes is included (in assumed, but realistic scenarios), the picture is quite different. Leather shoes do not appear so bad if the lifelength is included in the analyses. It is quite unclear how much longer service life leather shoes have compared to other categories, but already if a doubled service life is assumed, the leather shoes will display lower impacts for most categories. The results are intended for use on two levels: 1) it allows the industry sector (here SSEI) to calculate the overall impacts associated with the Swedish shoe market, and its change over time; 2) it provides a benchmark for each category, so that a shoe designer/trader can compare the impacts of any new shoe type in their product portfolio with a category benchmark, based on the sum of shoes in the market.

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## **LCA supporting a wood-panels «Factory of the Future»**

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«Factory of the Future» (2012-2016) is a project funded by the Life+ Programme of the European Commission, aiming to create a more self-sufficient production facility while maintaining or increasing the production volume and quality. The expected general results of the new equipment and process optimisation are to cut the initial fossil fuels consumption by 90% and the initial drinking water use by 75% through a full-scale production optimisation with a maximum on-site reuse of wood and water. Depending on wood humidity, the facility uses now 55% of the town water of the project referential, the rest of the reduction could be obtained through the use of rainwater. Optimisation effort brought the use of fossil energy to almost 25% compared to the project referential. A project proposal solution to attain the rest of reduction is to install a wood-energy Combined Heat and Power (CHP) unit. This will surpass the fossil energy objective and will also generate "green" electricity to the power grid. The under-installation CHP unit is larger than in the proposal and is estimated that the consumption of wood-energy will double the proposal provisions with a half of wood-energy imported from the region. Special attention is given to the management of the supply chain in order to increase the availability of wood without pressuring on the forests cycle. The use of LCA for each project year is essential not only in dynamically evaluating the consequences of the eco-design, but also of variation of supply distances for wood-energy, in avoiding the transfer of pollution along the lifecycle of the products; as well as for monitoring the progress and converting the reductions in LCIA indicators. An expected outcome of this project is to demonstrate the viability of the concept of «eco-design of a factory» through a full-scale facility optimi-

sation and modifications of the supply-chain. The internal re-use of wood waste increases autonomy in the manufacturing and also the economic sustainability of the facility. The experiences gained in this process could be extended to other units of the Kronospan, a worldwide group, considering however that not all facilities use the same input wood type and have the same availability of waste wood. Hopefully this project could be regarded as an example by competitors of the same industry which could emulate and adapt its eco-design solutions, thus decreasing the environmental footprint of current wood-panels.

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**Environmental sustainability benefits from the use of a new multilayer structure in menstrual pads**  
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The use of menstrual pads has significantly improved feminine hygiene during menstruation and has become the most commonly used form of feminine hygiene product in developed. Menstrual pads are single use products. While creating improved hygiene and comfort, they use resources and generate consumer waste. Life Cycle Assessment (LCA) studies on this product suggest that the sourcing and production of the raw materials used in a menstrual pad may account for up to 80% of the most relevant indicators. Therefore, in order to reduce environmental impacts, producers of menstrual pads need to collaborate with their suppliers to optimize resource uses along the supply chain. An EU Life+ CELSTAB project has been started to 'eco-design' a new multilayer material concept and technology with the objective to meet consumer product, quality and industrial-scale production process requirements (absorbency, dryness, comfort, etc.) while saving 15-25% on materials and waste prevention and targeting a 10-15% saving on global warming. The LIFE program is the EU's funding instrument for the environment and climate action. On a voluntary basis, industry partners can apply for co-financing projects with European added value. All current design options achieve and sometimes significantly exceed environmental sustainability targets. The design of this new multilayer structure, targets 55% of the total menstrual pad weight and it is therefore expected that on a total menstrual pad basis important benefits may be achieved. The presentation will discuss the initial LCA results for the various design options and analyze the main drivers for the calculated benefits for reduced resource use and emissions.

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**Use of life cycle thinking to steer sustainability within innovation portfolio management**

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As a global diversified chemicals major, SABIC's future growth depends significantly upon our success in innovation from our technology & development activities. To create solutions for emerging global challenges, our technologists need to embrace sustainability thinking every day, enabled by a process that builds consideration of sustainability into every project every step of the way. We needed effective life cycle based tools to analyze and steer our innovation portfolio. Two years ago, we integrated sustainability assessment within each stage-gate of our innovation process. The assessment has two phases, both founded on a life cycle approach – (1) a qualitative scoring for all projects and (2) a quantitative (LCA) study for mature projects. Leveraging 5+ years of in-house LCA practice, we created a qualitative assessment that includes: Assessment on the environment, society and economy dimensions by comparing the project with multiple market alternatives Performance measurement in six areas: GHG emissions, energy consumption, water use, material loss, resource use and health and environment Hot-spot concepts by recognizing relative impact of lifecycle stages, and relative importance of various environmental dimensions in a given market segment using tailored weightage factors The implementation strategy involved systematic training and education of over 500 researchers across 15 global R&D centers, to enable them to assess more than 800 projects. The assessment was successfully applied to projects from multiple business units (commodity and specialty chemicals and polymers, metals and fertilizers) with project types ranging from chemical processes to polymer applications in multiple markets segments. Within 6 months we arrived at the first map of our innovation portfolio – clearly distinguishing projects with excellent, moderate and poor sustainability characteristics. Trade-offs across impact categories or between life cycle stages could be clearly seen, and projects at risk were highlighted. It enabled researchers to focus on improvement opportunities from early stages, and improved collaboration between marketing, strategy and research teams. We could prioritize projects that required more detailed analysis via LCA and quantified 50+ projects in one year of using different levels of LCA. This paper presents details of the lifecycle based assessment, outputs and how these are further integrated with other business metrics to assist decision making.

## Life Cycle Sustainability Assessment of Emerging Technologies (I)

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### **LCA for ex-ante environmental assessment of new technologies**

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For the development of new sustainable technologies it is important to assess the potential environmental impacts of these technologies in early stages of design and development. Life cycle assessment (LCA) is one of the main tools to assess environmental impacts of product-service systems. However, LCA relies on abundantly available data for the systems studied, its application to novel technologies is therefore more complicated. Some of the methodological challenges of applying LCA to novel technologies are discussed and analyzed in a number of recent studies (ex-ante LCA, anticipatory LCA, prospective LCA). However, a number of recently published LCA case studies on new technologies do not explicitly take into account these challenges, but still seem to present insightful outcomes. In a review study based on recent peer-reviewed LCA studies on novel technologies we analyzed the challenges encountered and solutions used to overcome these challenges. Depending on the technological complexity (high- / low-tech), development level of the technology and the goal of the assessment we find different challenges ranging from problems in the system definition to lack of data. Potential solutions to these challenges require the use of scenario tools, scaling laws, simulations and theoretical models as well as increased use of sensitivity and uncertainty analysis. Insights from this work are used to provide straightforward and hands-on approaches for the assessment of emerging technologies in different phases of technology development. The approaches range from qualitative life cycle based discussions to flowcharting and the use of scenario's for the fore- and background system to obtain quantified data to arrive at the insights and answers these studies aim for.

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### **Scale-up in Life Cycle Assessment: a case study of a surfactant production based on seaweed**

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A common issue for environmental impact assessment of an innovative production system is the unavailability of real data: developers are working, at laboratory level, on fractions of the whole system verifying the feasibility of the scheme while LCA practitioners have to assess the expected system at industrial level. The challenge here is comparing an emerging technology with optimized and industrialized alternatives. This implies a scale-up from data collected at laboratory level (with small size devices) to try assessing the industrial system. This issue is well-known in process engineering and the purpose of the current work is using this knowledge into an LCA task. Four tasks have mainly to be done: (1) redesign of the system to consider recirculating flow as at industrial scale the uses of reactants are minimized, (2) find expected functions of some unitary processes to allow the use of available industrial proxies in LCA databases, (3) compute energetic demand of processing to ensure that lab-scale energetic consumptions are able to be extrapolated, and (4) use process engineering guideline as dimensional analysis. We use this approach into a collaborative research project on the design of new surfactant production scheme from seaweed. This system is composed by seaweed supply (with an offshore biomass production system or with seaweed picking on seabed), transportation, alginate extraction based on a previous study and chemical transformation to make a bio-based surfactant for industry. Each partner is working on their own step and LCA task is to define the interconnected processes chain from data where consumption, emissions and waste management are not optimized. In this work, ILCD guidelines are followed for selecting studied environment impacts. The transition between the LCA at laboratory scale and the LCA with extrapolated data for modeling industrial scale reduces the environmental impact of the surfactant by 86% on average (min 54% and max 96%). This underlines the interest of focusing the LCA work on scale-up for guiding the ecodesign process.

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### **Life Cycle Sustainability Assessment of rare earth permanent magnets**

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Permanent magnets are used in many modern technologies due to their high density of electromagnetic energy. Typically neodymium, praseodymium and dysprosium, three rare earth metals, determine these technical properties. Whereas the demand for rare earth increases constantly, controversial debates emerge in parallel concerning environmental impacts during rare earth production, pressure on

market prices due to almost monopolistic production in China, failed attempts to set up western production routes or missing acceptance from local communities at production sites. Therefore, rare earth metals provide an ideal subject for a Life Cycle Sustainability Assessment (LCSA) considering environmental, economic and social aspects. Given the current situation in rare earth production, this study compares three major supply chains from three different rare earth element (REE) deposits: (1) *China* represents the largest REEs producer worldwide (85%) with its biggest mine in Bayan Obo; (2) *Australia* is the second largest producer worldwide (8%) and the largest one in the Western World. While mining and beneficiation take place in Australia (Mount Weld mine) the separation is carried out in Malaysia; (3) The Mountain Pass mine in the *United States*, as a former third largest producer worldwide (3%), is assessed also. Today, the subsequent production of a typical neodymium iron boron magnet (NdFeB) is conducted in China only. Setting up this case study contributes to further develop LCSA methodology more generally, while at the same time giving inside into sustainability aspects of rare earth production in more detail. However, data availability especially for China is one of the biggest problems. For each rare earth supply system a basic process chain is set up and then analysed for the three dimensions, ecology, economy and social aspects using different levels of aggregation. Based on these results different approaches to normalize, weight and aggregate the different indicators of the three dimensions are applied. The results indicate that the supply chain with REE from the USA has the lowest social and environmental impacts as well as low cost. The supply chain from the Chinese REE deposit shows very low costs as well. However, the environmental and social impacts are much higher for this option than for the other two. Only when economic reasons are weighted more important than environmental and social effects China can catch up with the western countries.

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#### **Prospective life cycle assessment of adipic acid production from forest residue**

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Moving from a fossil-based to a bio-based economy requires the development of novel technologies for the production of bio-based chemicals and materials, and the Swedish forestry sector may play a major role in this. These technologies may become part of novel biorefinery concepts that combine the production of bulk and fine chemicals. This paper presents the life cycle assessment (LCA) of such a technology, in its early stages of development, which targets the biochemical production of adipic acid from Swedish forest residue. Adipic acid is a bulk chemical and its yearly production is approximately 2.3 million tonnes. It is mainly used as a precursor in the production of nylon, and its current fossil-based production process emits significant quantities of nitrous oxide (N<sub>2</sub>O), a strong greenhouse gas. Preliminary calculations showed that, compared to conventional adipic acid production, eliminating the emission of N<sub>2</sub>O would lead to a reduction of GWP by 75%, and that switching from a fossil-based to a biomass-based feedstock would reduce GWP by an additional 10%. This LCA focused on the technology for producing adipic acid, but also considered its connection with other technologies in the biorefinery concept. An anaerobic digestion process is used to produce biogas from the waste water. As well, lignin is produced as a by-product. The heat from biogas and lignin incineration can be used to meet the energy demands of the adipic acid production. Lab-scale experimental results were used in the assessment, and scaling up these results to an industrially relevant process capacity was done by using process modelling and simulation. Furthermore, an assessment was done of the impact of extracting forest residue from the Swedish forest. The results of this LCA show that the environmental impacts of producing adipic acid from forest residues, except for acidification potential, are significantly lower than those of its conventional production. The environmental hotspot of the technology is the downstream processing stage due to its need of additional energy which was assumed to be fossil. This additional energy is needed because of the low concentration of adipic acid in the fermentation broth. Further improvements can thus be made by minimizing fossil energy use in this stage, or by aiming for a higher end concentration of adipic acid in the fermentation broth. Lastly, the extraction of forest residue was found to only marginally contribute to global warming.

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#### **LCA of solvents for electrolytes of lithium-ion batteries**

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The development of new technologies for electrochemical energy storage is one of the main challenges the energy and mobility sectors will face in the coming decades. Lithium-ion batteries (LIB) could be the best choice for both electric vehicles and stationary applications—e.g. supporting wind turbines or photovoltaic cells. The performance of LIB can be improved by developing more efficient electrode



materials or by optimizing the electrolytes used. Electrolytes compatible with high-density LIB must be stable against oxidation and fulfil a number of specifications such as high ionic conductivity, low viscosity, and good wettability towards separator and electrodes among others. To achieve these specifications, a mixture of lithium salt and two or three organic solvents are commonly used. As part of a critical review focused on the physicochemical and electrochemical properties of electrolytes for LIB, we evaluated the state-of-the-art of LCA on solvents used for the aforementioned electrolytes. We investigated eight solvents, with an average of two production routes per solvents:  $\gamma$ -butyrolactone (GBL) Tetrahydrofuran (THF) Dimethoxyethane (DME) Sulfolane (TMS/ SL) Ethyl methyl sulfone (EMS) Dimethyl carbonate (DMC) Ethylene carbonate (EC) Ethylene acetate (EA) Five of the eight solvents we took into account were already included in Ecoinvent, but only for ethylene acetate there was more than one production pathway. In most cases the information used to build the LCI—e.g. process efficiency, energy requirements, etc.—was generic. We did not find any additional LCA literature on alternative routes except for dimethyl carbonate. We built the LCI of the remaining production pathways based on peer reviewed publications, patents, and the existing Ecoinvent processes. We also developed characterization factors in USEtox for those chemicals lacking them which could potentially be released in some of the processes evaluated. Preliminary results indicate the potential for substantial differences between production routes based on the reagents selected. Nevertheless, it is our opinion that for a balanced comparison between solvents, we need process specific inventories that do not rely on generic data.

## LCA of large-scale systems - from urban to national scale including territorial LCA, urban metabolism and their nexus with circular economy (I)

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### Implementation of LCA within EIA procedure: an innovative methodology applied on two wastewater treatment plants case studies

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Life Cycle Assessment (LCA) has been identified in the literature as a promising tool to support Environmental Impact Assessment (EIA) of projects. Yet, it appears that few publications proposed an applied methodology for a practical integration of LCA within EIA, let alone tested it on real case-studies.

Hence, this research aims at providing an operational methodology for implementing LCA within EIA and testing its applicability on Waste Water Treatment Plants (WWTP) case-studies. Based on literature review, we identified four EIA steps that could theoretically benefit from a LCA implementation, i.e. (a) the environmental comparison of alternatives, (b) the scoping step, (c) the impact assessment and (d) the impact of mitigation measures. For each of these steps, we propose to implement LCA with specific goal and scope as well as their associated sets of indicators. This methodology is applied on two contrasted WWTP case-studies and the results of the EIA procedures conducted without and with LCA are compared. The results show that the implementation of LCA leads to significant differences. First, the environmental assessment of alternatives and mitigation measures was not carried out in the original studies. This additional step shows that other technologies, less polluting, could have been chosen. Regarding the scoping step, the selected environmental concerns are essentially different. Global impacts, such as climate change or resources depletion, are not considered in the original EIA studies. Impacts other than those occurring on the project site (off-site impacts) are not assessed either. On the other hand, unlike current LCA applications, EIA usually addresses natural and technological risks and neighbourhood disturbances such as noise or odour, which are very important for the public acceptability of the project. For the impact assessment, even if the conclusions of EIA without or with LCA turn out to be partially common for local in-site impacts, LCA gives crucial additional information on global impacts and off-site impacts that should be mitigated, and highlights the processes responsible for the impacts. In the end, for all EIA steps investigated, the interest of LCA has been demonstrated on the two case-studies. The feasibility in terms of skills, time and costs of such implementation has been assessed. The areas offering research opportunities for a more comprehensive integration of LCA in EIA are also discussed.

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### **Application of the Solid Waste Infrastructure Management System (SWIMS) model to support regional and national decision making**

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Solid waste management (SWM) is an essential municipal service provided by government. Given the rapid population growth and socio-economic development that is projected to occur around the world, nations must ensure that they have sufficient infrastructure capacity to maintain this vital service. There is also increasing pressure on the SWM sector to improve its environmental performance. Despite increasing budgetary pressures, SWM decision makers are being required to make important strategic and investment decisions whilst simultaneously maintaining reliable, low-cost SWM services and identifying and pursuing opportunities to reduce their environmental impact. To alleviate this burden, regional and national SWM decision makers require information and tools to help inform management, planning, and investment in their SWM systems. The Solid Waste Infrastructure Management System (SWIMS) model is a life cycle-based decision support and optimisation tool for SWM. SWIMS forms part of a system-of-systems model, known as NISMOD-LP, which was developed in the UK and enables the analysis of interdependent national infrastructure systems. SWIMS models the infrastructure capacity requirements of a given area and tracks these requirements through time. Flows of waste materials through the SWM system are simulated from the point of generation through collection, treatment, and disposal/recycling/reuse. Potential environmental and financial impacts associated with the management of these waste flows are quantified through life-cycle process modelling. The model is able to explore every possible way through which waste streams can be managed within the system, both now and in the future, and of optimising waste management and investment based on a defined optimisation goal (e.g. minimising costs, reducing CO<sub>2</sub>e emissions, maximising materials recovery), a given set of management constraints (e.g. restrictions on waste to landfill), and a range of possible future scenarios. SWIMS can model any area of any geographic scale and can thus be used to represent a city, region, or nation (including the cities and regions within that nation). The purpose of this presentation is to provide a description of the SWIMS model and to highlight its novelties compared to other SWM decision support and optimisation tools. To demonstrate the value of the tool to decision makers, a case study of its application in the context of SWM at the UK regional scale will be presented.

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### **LCA of time-differentiated electric vehicle deployment in Copenhagen between 2016 and 2030**

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Although the transport sector is a major contributor to several environmental impacts, recent technological advancements show great opportunities for improvements. Life cycle assessment (LCA), which quantifies the potential environmental impacts of systems in a life cycle perspective, need to be applied to ensure that these developments are made with as low impact as possible. Until now, LCA has rarely been applied with a systemic approach to transportation systems; it is often used in analyses with restricted system boundaries and without a future-oriented perspective. This study aims to bridge these gaps by assessing the time-differentiated deployment of EV at a full urban scale, using the city of Copenhagen for the period 2016-2030 as case study. The assessment is performed and interpreted at two levels: (1) technology level, where four types of non-conventional cars, i.e. battery-based, range-extended, fuel-cell-based and hybrid EV, are compared to internal combustion engines vehicles on the basis of 1km driven in Copenhagen, and (2) systemic level, where LCA has been applied to the entire private car fleet of the Copenhagen area from 2016 to 2030, including the vehicles, the charging infrastructures and the electricity and fuel support systems. These three major components of the transport systems are all differentiated in time. Four scenarios have been developed, differentiated by different degrees of implementation of the different EV technologies in Copenhagen. Results show that fuel-cell EV perform better in general, having the best scores in ten categories and being the worse only for Ozone Depletion. Range-extended EV present a high potential as a transition technology and future LCA studies should thus take them into consideration. The results show that charging infrastructures had a minor contribution to the total impacts of the system compared to vehicles and the energy system. In the systemic analysis, the ranking of the scenarios varies across the different impact categories. However, S4, a scenario promoting disruptive technological advances related to fuel cells EV, appears to be the best option at midpoint for nine impact categories out of 15 and at endpoint for the three areas of protection. Though the analysis focuses on the case of Copenhagen, these results suggest that the focus of technology developers and urban planners should be put on pushing the development and

deployment of fuel-cells and range-extended EV on the market.

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## **Defining consequential LCA of mobility policies focusing on a specific demographic group: the case of cross border commuters**

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French cross border commuters (CBCs) working in Luxembourg summed up to 80000 in 2014. This represents about 50% of the total number of cross border commuters traveling from their residence country to their work country. This phenomenon is important as it is also present in other European regions. The inhabitants of the regions in question suffer from bad air quality, partially due to exhaust emissions of vehicles. In the case of the socio-demographic group of French CBCs working in Luxembourg, up to 70% of them use their private passenger car, and the remaining 30% use public transport, including mainly trains and buses. As the phenomenon is raising in the priority lists of policy makers, it is important to understand the potential implications of new policies directly aimed at reducing environmental burdens or at fostering alternative ways of structuring daily life with an influence on the mobility related burdens. In the CONNECTING project, we use an agent-base model (ABM) to study from a consequential life cycle assessment (CLCA) perspective the environmental impact of the policies related to mobility of a specific socio-demographic group. As opposed to traditional scenario-based approaches, the impact of the policies is the aggregated outcome of the interaction of a large number of agents, not known beforehand. We have identified a challenge in modeling a specific socio-demographic group in the context of CLCA using ABM, related to the definition of the different story lines to consider as potential evolutions of the mobility system. The CBC setup implies that the policy makers belong to different countries with different influences on the territorial limits of the system. Moreover, the different stakes and priorities of policy makers from different countries may lead to non-coherent decisions. We have chosen a participatory approach to build the different story lines by working closely with the actors involved in the CBC mobility. A workshop held with the actors has allowed us to identify key groups of variables to be considered. During the symposium presentation, we will share our experience in developing the story-lines and their implications as its importance is manifold. It has a strong influence on the story lines to be explored, on the different elements to consider to build the life cycle inventories and on the behavioral aspects of the agents in the ABM.

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## **Large-scale hybrid LCA of passenger multimodal mobility policies and scenarios**

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Every day 80000 commuters cross the France-Luxembourg border. The current transportation infrastructure is barely sufficient to face this number and how it grows annually. To face the future challenge of sustainable mobility, policy-makers need support and advice on potential investments and policies focusing e.g. on road and rail infrastructure and promoting private or public transportation. Indeed, potential transportation shifts come along with additional and/or avoided environmental impacts, which are complicated to predict as they arise from the combination of single transportation choices by each individual commuter. Furthermore, road and, more particularly, rail passenger transportation have a high infrastructure to passenger-km impact, which highlights the importance of the lifecycle environmental impact contribution of infrastructure construction, operation, decommission, and overheads. In the CONNECTING project we are addressing the question of assessing the consequential lifecycle environmental impacts of different mobility policies by using an agent based modelling approach to derive the consequential foreground lifecycle inventory model. To comprehensively inventory the background system, we use hybrid LCA-input-output (IO) methods. Hybrid techniques remediate the "truncation bias" of process-based LCA by completing life cycle inventories with inputs from an IO background. The case of transportation is ideal to illustrate this challenge. The inherent regional scope of environmentally-extended IO tables is well adapted to quantify the environmental impacts of a whole territory or region. We present here the hybrid modelling of existing and future passenger ground transportation modes available in the CONNECTING integrated agent-based modelling framework. Focus is brought on the hybrid results, and the gap with common process-LCA results, as well as the upscaling of various combinations of transportation modes, depending on three scenarios. These policies are deployed over the upcoming decade, therefore the prospective impact assessment includes changes in regional economies: electricity mixes, technology efficiency, or emission regulations. Transportation is undergoing deep changes, and the status of the road or rail infrastructure will differ a lot, even at a 10-year horizon, depending on the roadmap that decision-makers will follow. The objective is to demonstrate the relevance of hybrid LCA techniques in territorial policy decision-making.

## Innovation through design of more sustainable systems: Eco innovations arising from LCA

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### LCA case study: comparison of different chemical pathways for the production of ethyl and n-butyl acetates

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**Keywords:** Ethanol, Butanol, Esterification, Coproduction, Environmental impact assessment, Sustainability, Life Cycle Assessment Ethyl acetate (EtAc) and n-butyl acetate (n-BuAc) are one of the most used solvents (Khire et al., 2012). They have been commonly synthesized through direct esterification of acetic acid with the corresponding alcohol (ethanol for ethyl acetate and n-butanol for n-butyl acetate), in the presence of a homogeneous acid catalyst (Peters et al., 2006). The use of these homogeneous catalysts presents many disadvantages such as multiple side reactions, difficult product/catalyst separation, and equipment corrosion. In order to avoid these problems and in a context of sustainable development, the use of heterogeneous catalysts for esterification such as ion exchange resins (Sert and Atalay, 2011) has been studied. The production of ethyl acetate and n-butyl acetate was investigated through two different pathways: either by independent reactions or by coproduction. In the coproduction pathway, the n-butyl acetate was produced by re-using the byproducts of the synthesis of ethyl acetate. This study provides a comparison of the environmental impacts of these two pathways using an attributional Life Cycle Assessment (LCA). A cradle-to-gate analysis, up to the synthesis, was performed for this evaluation. Most of the inputs/outputs were directly collected in the laboratory. The inventory data that were not available in the Ecoinvent 3.1 database were estimated thanks to literature or proxys. Evaluations were thus performed on the SimaPro 8.1.1 LCA software, using a derivative of ILCD 2011 1.05 as the life cycle impact assessment methodology. This innovative coproduction of ethyl and n-butyl acetates led to interesting results both from a technical and environmental perspective, with a clear reduction of the environmental impacts. In a context of sustainable chemistry, this appears to be a very interesting way of production. **References :** Khire et al. (2012). *New Mathematics and Natural Computation* 19, 342–350. Sert, E., and Atalay, F.S. (2011). *Chemical and Biochemical Engineering Quarterly* 25, 221–227. Peters et al. (2006). *Applied Catalysis A: General* 297, 182–188.

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### Eco-design of an innovative environmental biorefinery to produce added value chemicals from waste

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**Purpose:** In order to face current environmental challenges we need to progressively shift from a global and fossil-based production to a local and bio-based production. Using locally produced organic waste to fuel the production of chemicals represents, then, an attractive option because of high availability and low feedstock costs. The aim of BIORARE project (Investissement d'Avenir ANR-10-BTBR-02) is to evaluate how bioelectrochemical technologies could be combined to existing waste treatment facilities, namely two steps anaerobic digestion processes in order to encourage environmental biorefineries producing "waste-based" chemicals. A strategy for life cycle assessment-based eco-design was elaborated in order to help to refine the biorefinery concept and to identify environmentally sensitive parameters. **Methods:** From complete laboratory testing and proof of concept, BIORARE scenario was fully simulated for the production of bioethanol and niche market molecules. Two environmental assessment phases were carried out: a LCA of BES materials and operation to eco-design this core element of the BIORARE scenario and a LCA of BIORARE scenario compared to current bio-based chemical production scenarios. **Results:** LCA results and sensitivity analysis showed that BES components could generate high impacts depending on the way they are implemented in the process, especially when BIORARE scenario is compared to alternative current agro-based production scenarios. Moreover, important CO<sub>2</sub> emissions were identified in the BES unit and the waste treatment line. Improvement strategies were thus implemented to recover CO<sub>2</sub> streams in the purpose of allocating lesser environmental impacts and a higher added value to BIORARE. **Conclusions:** Lots of strategies and technologies have been developed to recycle at best different types of waste whilst fitting in the concept of circular economy. Environmental biorefineries relying on bioelectrochemical systems are an attractive concept since it aims at producing useful platform chemicals from waste derived outputs (CO<sub>2</sub>, organic substrate, elec-

tricity and heat). We manage to model various implementation schemes for these biorefineries through a LCA methodology, in order to identify key environmentally sensitive design parameters and to select best potential implementation strategies, thus illustrating how LCA approaches could be used to steer eco-design of innovative processes.

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## **Eco-design of a micro-algae fractionation process by coupling process simulation and environmental Life Cycle Assessment**

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Nowadays, one of the main challenges to improve the environmental performance of companies is to eco-design manufacturing processes. Currently, industrial processes are considered as a global and irremovable operation in environmental analyses. However, some criteria like operating conditions or the chain sequence of unit operations can notably modify environmental burdens associated with processes. Biorefineries are particularly concerned by the area for improvement, because they are based on the use of renewable resources. The improvement of production processes can be performed by coupling environmental Life Cycle Assessment (e-LCA) and process simulation. Indeed, it is possible to model the functioning of biorefinery processes to obtain mass and energy balances of each unit operation which constitute the studied process. They can be then used as input data for the inventory of the e-LCA. This methodology offers the possibility to perform dynamic e-LCA, i.e. to automatically note changes on the LCA results after a modification of operating conditions in the process simulator. So, it allows the determination of the operating conditions and the unit operations arrangement which will generate the lowest environmental impacts. The case study is a fractionation process of microalgae, composed by four main unit operations. The first step consists in a bead mill of the solid biomass, to permit the cell disruption. Then, a centrifugation is performed, to isolate the liquid part, containing the most valuable fractions. On this phase, a liquid-liquid extraction is realized, followed by an ultrafiltration step on the extract. This global process leads to the extraction of lipids, proteins, polysaccharides and pigments from microalgae. Models are created for each unit operation, and a simulation of the whole process is launched. Then, an attributional e-LCA based on mass and energy balances is performed, with a cradle to gate approach. Additional data are used, coming from Ecoinvent v3.2. For this assessment, the ReCiPe midpoint (H) method is used. This iterative methodology allows to study the evolution of environmental impacts influenced by several operational parameters, such as temperature, time, pressure, solvent quantity, and so on. Moreover, this assessment highlights that a change on several parameters could lead to a decrease of environmental burdens, while maintaining similar extraction yields.

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## **Ecoinnovation applied to an LCA framework of a small-scale gold mining in Colombia.**

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The sustainability of artisanal and small-scale gold mining (ASM) in Colombia represents the main focus of this research. The ASM activities provide an important source of livelihood for rural communities, but at the same time have caused considerable environmental contamination and human health complications. The main cause is represented by mercury pollution. In fact 450 tonnes of mercury are emitted annually worldwide from artisanal and small-scale gold mining, and it is estimated 50% of which originates from Latin American operations. The areas interested by ASM coincide with mercury hot spots, which are characterized by high concentrations of mercury in soils and sediments. The environmental hot spots include sediments and aquatic biota that contain high concentrations of readily bio-available methylmercury. Therefore the main goal of this research is to ensure maximum health security conditions to the local population and to promote the conservation of the high local species richness, both endangered by human activity. Starting from these considerations, a survey was carried out in strong collaboration with local communities followed by the devising of a pilot project aiming the reduction and remediation of dangerous contaminations. Life Cycle Assessment is the methodology used first to

identify the crucial mining activities during which it is more high the release of contaminants and afterwards to assess the environmental and productive efficiency of the new technologies destined to the implementation of the pilot project. Parallel to finding technical solutions, it was paid attention to the underlying economic and social issues of the target community in order to increase the chance of success of the mine development. Through LCA analysis it was possible to point out the appropriate technological measures for minimizing contamination introduced in the pilot project. According to the first monitoring results, the mercury emissions were dramatically reduce. Further it is on-going the identification and application of a bioremediation plant to pursue the restoration of the polluted areas. Both the results and the high level of collaboration with the local community suggest that it is possible to improve sustainability by applying LCA framework in social complex context. Acknowledgements This study is based on the research project carried out thanks to the collaboration established between CeTamb LAB, ACVC Association, UniPaz.

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### **Bringing the life cycle perspective into the Cradle-to-Cradle certification: the case study of aluminium cans**

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With the current political emphasis on circular economy, the Cradle-to-Cradle® vision (C2C) has gained an increasing visibility in industry. To allow companies to monitor and market their progress towards the C2C vision, a certification program (Cradle to Cradle Certified™ Product Standard) was established. It includes a series of requirements divided into five quality criteria, being scored on a 5-grade scaling system (from basic to platinum). The quality criterion "Renewable Energy and Carbon Management" (RE&CM), which translates the second C2C principle ("use current solar income") only includes a partial life cycle perspective. For all the grades but platinum in the scaling system, energy use only at the manufacturing stage of a product is considered, thus leaving out the energy use during raw materials extraction, product use and end-of-life. In this study, we aim to provide decision-makers in industry with a demonstration of the benefits of introducing a life cycle perspective in the C2C certification programme with respect to the "solar energy income" principle. We considered the case of aluminium beverage cans in the UK market (hereafter AIC system) and compared different Life Cycle Assessment (LCA) scenarios: (1) the current AIC system, (2) the AIC system with 50%, or 100% use of renewable energy in the manufacturing stage (reflecting C2C certification requirement for gold and platinum for the RE&CM criterion), and (3) the AIC system with consistent use of renewable energy throughout the life cycle, considering different aluminium-producing countries, namely China and Europe. Through the comparison of the environmental performances of the three AIC systems (20 scenarios), we quantify the influence of including a life cycle perspective in the C2C certification requirement RE. Our results show that compliance with the current C2C certification framework offers some benefits, i.e. up to 10% reduction for most impact categories. However, the environmental benefits of introducing increasing shares of renewable energy in the whole life cycle can greatly exceed the environmental benefits brought up by compliance to the C2C certification, e.g. with more than 50% reduction of impacts on acidification and particulate matter in the case of primary aluminium produced in China. We therefore warn decision-makers against the limited gains and the risk of burden-shifting associated with a sole reliance on the C2C certification.

## **Life Cycle Sustainability Assessment of Emerging Technologies (II)**

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### **Assessing the green credentials of continuous flow hydrothermal synthesis for the production of titania nanoparticles**

P. Caramazana Gonzalez, The University of Nottingham / Advance Materials Research Group; J. McKechnie, University of Nottingham / Mechanical Materials and Manufacturing Engineering; E. Lester, The University of Nottingham / Advanced Materials Research Group

Titanium dioxide (TiO<sub>2</sub>) is one of the most used and studied nanomaterials due to its properties, such as catalytic and photocatalytic activity, and applications in pigments, paints and medical uses. Continuous-flow hydrothermal synthesis (CFHS) offers substantial advantages over conventional processes, including control of material properties, superior quality, compatibility with a wide range of precursors, and scalability. In this study, we investigate a range of hydrothermal synthesis operating parame-

ters, precursors, material properties and production capacities to identify optimal production routes in terms of life cycle environmental. Life cycle assessment (LCA) model is developed to assess the “cradle-to-gate” environmental impacts, using global warming potential (GWP) and cumulative energy demand (CED) as indicators. We evaluate five precursors, which ranges from a simple manufacturing, like titanium oxysulphate (TiOS), to a high grade, such as Titanium bis(ammonium-lactato) dihydroxide (TiBALD). Production parameters are evaluated in laboratory to determine optimal conditions for nano-TiO<sub>2</sub> yield, crystallinity, and size distribution. Experimental insights are corroborated with operational data of a demonstration-scale and process design expertise from current construction of a full scale plant to estimate mass and energy balances of industrial scale production (>1000 t/yr). In general, increasing the reaction temperature resulted in larger nanoparticles, less impurities and higher conversion rates. Also, TiOS samples produced biggest nanoparticle sizes and broadest size distributions, in contrast to TiBALD, which shows higher quality in terms of purity, size and monodispersity. The LCA results indicate that precursor selection is the main factor in determining environmental impacts, due to the impacts of precursor production (>80% in some cases) and the consequences for CFHS (solvent or post-treatments). Nano-TiO<sub>2</sub> production from TiOS shows the lowest GWP (11 kgCO<sub>2</sub>eq/kg-TiO<sub>2</sub>) and CED (149 MJ/kg-TiO<sub>2</sub>) due to a simple production, the use of water as solvent and its high conversion rate. The unfavorable option is TiBALD (86 kgCO<sub>2</sub>eq/kg-TiO<sub>2</sub> and 1952 MJ/kg-TiO<sub>2</sub>), due to the need for additional post-synthesis steps, complexity of the precursor manufacturing. Concluding that TiOS precursor is the greenest option, if quality requirement is not extremely high, in which only TiBALD could satisfy the need despite of the environmental consequences.

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## **A life cycle assessment study of photocatalytic active nanomaterials in view of their potential for a more sustainable hydrogen production pathway**

R. Hischer, B. Salieri, EMPA / Technology and Society Lab

Hydrogen (H<sub>2</sub>) is an energy carrier that can be derived from several feedstocks by a variety of different technologies (including e.g. thermochemical, photolytic and electrolytic processes). Currently, more than the 96% are derived from fossil fuels. Being the most economic pathway, this way consumes in the same time fossil resources and is a source of CO<sub>2</sub> emissions – i.e. is far from making H<sub>2</sub> a “green energy”. Photocatalytic hydrogen production is seen as a promising, but so far challenging new technology on the way towards a more sustainable production. It is based on clean, renewable solar energy and water, resulting in no undesirable pollutants and/or by-products. Crucial role in this technology plays the photocatalyst – a material that ideally shows a high chemical stability, corrosion resistance, good visible light harvesting and suitable band edges. Within the framework of a FP7 project, the hierarchical assembly of functional nanomaterials into novel nanocarbon-inorganic hybrid structures for a photocatalytic hydrogen production has been investigated over the past 3 years. Empa participated to these activities by investigating the environmental performance of the developed, new materials and processes and by establishing a first baseline comparison of such a new photocatalytic H<sub>2</sub> production pathway with today’s means for the production of H<sub>2</sub> in order to illustrate the risks and benefits of this new technology and its materials from the point of view sustainability. For this, data from experimental activities of the various project partners on a lab scale level have been combined with recent findings about the upscaling of nano-enabled technologies. Results are the energy and material flows related to a future pilot-scale production pathway for such nanocarbon-inorganic hybrid structures and their application in a 40 m<sup>3</sup> photoreactor for the hydrogen production. The main challenge encountered was to ensure the comparability of this new technology with the various (current and/or future) competing technologies for the H<sub>2</sub> production. We identified two critical issues in order to get a qualified idea of the (ecological) potential of this new technology – the uncertainty related to the upscaling of Lab-scale data (including the fact that for most nanomaterials no reliable and comprehensive LCI data are currently available), and the uncertainty related to the actual use of this photocatalytic material (e.g. its efficiency and its lifetime).

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## **Lessons from early assessments of production processes for the nanomaterial graphene**

R. Arvidsson, S. Molander, Chalmers University of Technology / Environmental Systems Analysis

Graphene is a new nanomaterial with many promising applications, including in composite materials, transparent displays, electronic components and biosensors. We have conducted a number of life cycle assessment (LCA) studies of emerging production routes for this material. The studies cover the three production routes that currently have the most patents and largest scientific interest: Exfoliation, chemical vapour deposition (CVD), and epitaxial growth on silicon carbide. From these studies, a number of results have been obtained, which provide environmental guidance towards less impacting graphene production at an early stage in technology development. Results for exfoliation show that although some processes (chemical and thermal reduction) are energy-intensive (in the order of 1000 MJ/kg),

others (ultrasonication) have life cycle energy requirements below those of today's energy-intensive materials (

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### **Life Cycle Assessment of commercial-scale graphene production**

M. Cossutta, University of Nottingham; J. McKechnie, University of Nottingham / Mechanical Materials and Manufacturing Engineering; S.J. Pickering, The University of Nottingham / Department of Mechanical Material and Manufacturing

Graphene is an emerging material with a diverse range of potential applications. Few LCA studies have investigated nanomaterials; those that have been undertaken typically find production to be substantially more energy-intensive than conventional materials. Understanding the impact of commercial-scale production from an environmental perspective is crucial to steer development towards sustainability and a key part of this is to understand the energy consumption required in the manufacture of graphene production at commercial scale. This study aims at better understanding the life cycle impact of graphene production and the impact of a potential mass production for three production routes: electrochemical exfoliation of graphite; chemical oxidation of graphite with subsequent chemical or thermal reduction; and chemical vapour deposition. The chosen functional unit is the production of 1 gram of graphene and three scenarios are evaluated: laboratory case (based on experimental measurements); simulated commercial-scale production; and future commercial-scale production assuming a decarbonised electricity generation mix that might be available in the future. We find environmental impacts of graphene production to vary significantly by production route and production scenario. Across the three production scenarios, chemical oxidation with thermal reduction achieves the lowest environmental impacts. Simulation of commercial-scale production indicates the potential to reduce impacts by approximately half (e.g., 0.046 kgCO<sub>2</sub>eq./g vs 0.080 kgCO<sub>2</sub>eq./g at laboratory scale). Electrochemical exfoliation becomes an environmentally favourable production route in future (e.g., 0.06 kgCO<sub>2</sub>eq./g) provided that a renewable-dominated electricity mix is available. Results show that the chemical vapour deposition route has the highest impact (6,000 kgCO<sub>2</sub>eq./g); however, this production route provides graphene in a single layer which may be required for specific applications. The results of this cradle-to-gate study will inform future investigations of graphene applications and thus help to comprehensively understand the benefits and disadvantages of diverse graphene uses.

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### **Combining Prospective Modelling and Uncertainty Assessment to Evaluate our Capacity to Differentiate Future Development Scenarios Using the Example of Graphene Production**

D. B St-Pierre, R. Hischer, EMPA / Technology and Society Lab

Graphene is currently considered by researchers and governments all over the world to be a key contender for the improvement of various high-tech applications like high-speed electronics or solar cells. This nanomaterial has gained a lot of attention in the last decade because of its diverse exceptional properties (e.g. high electrical and thermal conductivity and optical transparency). So far graphene applications are still mostly theoretical, but experts believe that they will gradually reach consumers during the 2020–2035 timeframe. A recently published, prospective life cycle assessment study of two production processes has shown the energy-intensive nature of graphene. However, the study only considered foreground processes because the authors felt that future electricity production might radically change in the next decades. Therefore, conclusions of their sensitivity analysis on environmental hotspots are valid only within this scope. To overcome this issue in the current context of Graphene development, we propose to use a combination of prospective scenario modelling and uncertainty assessment. This strategy allows for a comprehensive life cycle analysis of future graphene production processes with the possibility to clearly identify when input modelling data is too uncertain and prevent from differentiating options. To do this, the evolution of energy production, transport alternatives and efficiency improvements are considered and modelled at five-year intervals over the 2020–2040 timeframe. Data from models of the international energy agency (IEA) and the NEEDS project (<http://www.needs-project.org/needswebdb/>) is used to define future energy production. Sites of Graphene production are outlined by governmental investments and other aspects like the current location of experts. Increases in production efficiency are extrapolated from the trends that have been observed in the last decade (i.e. 2007–2016) and from expert inquiries. The pedigree matrix is then used to calculate the uncertainty of all input data that define the prospective scenarios. Finally, the environmental impacts assessment of the production methods are compared with corresponding uncertainties. In our presentation, we will show when differentiation is possible and will provide relevant insights on ways to develop graphene production. The whole procedure will mainly define how the limit of prospective assessment can be identified based on our current level of knowledge.



## LCA of large-scale systems - from urban to national scale including territorial LCA, urban metabolism and their nexus with circular economy (II)

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### Integration of morphological analysis in early-stage LCA of the built environment at the neighborhood scale

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LCA has been increasingly used to assess environmental impacts of construction products and buildings, and there is a new trend towards the application to larger systems like urban islets or neighborhoods. This change of scale is driven by the need to address district scale levers to reach higher environmental performance. One particular challenge to reach low energy settlements stems in the fact that buildings energy demand is largely affected by masterplanning decisions that arise at early-stage in the project development. Urban morphology (that is based on geometry, presence of vegetation, type of mineralized surfaces, etc.) has an influence both on neighborhood embodied energy level related to the building materials and on operational energy demand that depends on interactions with climate factors such as solar irradiation. Existing LCA approaches are not suited for neighborhoods early design phases; they are either too generic to account for the influence of masterplanning decisions on buildings energy requirements, or they require a level of data that is not yet available at this stage. In this study we investigate how the LCA of an urban development project can be enhanced with a morphological analysis. We focus on two indicators; primary energy consumption and climate change. We propose two models that provide inventory data for (1) building materials quantities and (2) operational energy demand depending on urban morphology parameters. The first model, is based on a decomposition of buildings in macro-elements, for each of which quantities are automatically extracted from a 3D model. The second one is based on metamodelling for annual heating and lighting needs developed for a set of generic urban forms. Metamodels are built from polynomial chaos method which require large simulation samples. This is done by means of specific modeling tools (EnergyPlus and Radiance) that are called from a parametric modelling interface (Rhino/Grasshopper), allowing for exploration of large samples of urban forms. The LCI data is then converted to impacts using two indicators: primary energy consumption and climate change. A sensitivity analysis on both models will be presented as well as an application on two real case studies (an urban renovation project in Lyon and a new development project in Bordeaux). Finally we discuss the integration of these developments in NEST, an existing tool, for the LCA of the built environment at the neighborhood scale.

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### Carbon footprint of urban lawns

P. Tidåker, JTI - the Swedish Institute of Agricultural and Environmental Engineering

Lawns cover a significant part of all green open spaces in urban and semi-urban areas in private gardens, public parks, cemeteries, golf courses and along roads. In Sweden, the average lawn coverage in cities is 28%, i.e. 153 000 ha in total. Golf courses cover additional 28 000 ha. Urban lawn management is relying on frequent mowing and other maintenance activities which emit greenhouse gases (GHG). However, soil organic carbon (SOC) sequestration can offset GHG emissions from management operations to varying extent. In this study, GHG emissions from management of urban lawns (utility lawns mowed regularly and meadow-like lawns mowed once or twice per year) and golf courses (fairways and roughs) in the municipality of Uppsala, Sweden, were assessed and compared to the estimated annual SOC sequestration. Emissions of GHG ranged from 0.035 Mg CO<sub>2</sub>-equivalents (eq.) per ha and year for meadow-like lawns to 3.1 Mg for fairways. Management of utility lawns emitted 0.21 Mg CO<sub>2</sub>-eq. per ha and roughs 0.5 Mg CO<sub>2</sub>-eq. Attributing the differences in SOC between the lawns and surrounding agricultural croplands in the region to the lawn management turned utility lawns and roughs into a sink for GHG and reduced the GHG emissions from fairways considerably. Converting cropland into public lawns and golf courses when cities are expanding means that former agricultural products need to be produced elsewhere. However, this indirect land-use change is commonly not accounted for when addressing carbon footprint from lawn management. A conclusion from the study is that SOC sequestration can outweigh the emissions from extensively managed lawns. However, more intensively managed turf systems, such as fairways, contribute to climate change because of considerably more management operations performed and application of nitrogen (N) fertiliser. Lowering the N fertiliser rate is thus of particular importance, since GHG emissions originate from both the manufactu-

ring phase and from N turnover after application. Emissions of N<sub>2</sub>O from decomposition of grass clippings are a potential hotspot for GHG emissions from turf management that needs further investigation, since the high level of uncertainty makes it difficult to determine these emissions for specific management regimes.

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### **Determination of the Carbon Footprint of all Galician production and consumption activities based on the territorial LCA methodology**

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Galicia is an Autonomous Community located in the north-west of Spain. Its particular climatic characteristics make necessary the development of individual studies to evaluate GHG emissions and their expected climatic effects in the region, as a starting point to propose mitigation and adaptation procedures (MAGRAMA, 2016). So far, the only regional GHG inventories available (IGE, 2013) are limited to the direct emissions of those productive activities which are expected to cause major environmental degradation. An alternative approach has been followed here to quantify all the direct and indirect GHG emissions related to all Galician production and consumption activities. The carbon footprint (CF) was calculated following the territorial LCA methodology for data collection, that combines bottom-up and top-down approaches (Loiseau et al., 2013). The most updated statistical data and life cycle inventories available were used to compute all GHG emissions. The CF of the yearly consumption activities that take place in Galicia is 17.8 MTCO<sub>2</sub>e/year, 88% allocated to the Galician inhabitants and the remaining 12% to tourist consumption. Regarding the CF of the inhabitants, the major contributor is housing (32%), followed by food consumption (29%). Within the CF of tourist consumption, the share of transport is much higher (59%), followed by housing (27%). The CF of the Galician production reaches 36.9 MTCO<sub>2</sub>e/y, and its major contributor is electricity production (25%), followed by food manufacturing (19%). Our inhabitant consumption results (5.7 t CO<sub>2</sub>e/inhabitant/y) have been compared to those found with various methodologies for Spain (10.29 t) and other countries, and the main differences and weaknesses of all the approaches have been discussed. Our production results (36.9 MT CO<sub>2</sub>e/y) are much higher than those available (27.5MT), which highlights the relevance of this approach. We believe that this CF, which considers all the upstream and downstream emissions related to the community, can complement the information available and lead to more effective decision making. **REFERENCES** IGE, 2013. Emisións de GEI por actividade. <http://www.ige.eu/igebdt/selector.jsp?COD=6883&paxina=001&c=0101006>. Loiseau, E. et al., 2013. Adapting the LCA framework to environmental assessment in land planning. *Int. J. LCA* 18, 1533-1548. MAGRAMA, 2016. Galicia. [http://www.adaptecca.es/administracion-autonomica-local/comunidades-autonomas/ccaa?field\\_ccaa\\_value=12](http://www.adaptecca.es/administracion-autonomica-local/comunidades-autonomas/ccaa?field_ccaa_value=12).

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### **Comparison and complementarities between Eurostat and Territorial LCA methods for land planning based on a Mediterranean case study**

G. Junqua, Ecole des Mines d'Alès; U. Forcier, A. Gonzalez-Roof, Ecole des mines Ales; M. Lopez-Ferber, Ecole des Mines d'Alès / LGEI

Designing appropriate scenarios of socio-ecological transition, and comparing different options of land planning of a territory, require the knowledge of pressures and impacts linked to the material and energy flows resulting from its human activities. Both Eurostat Material Flow Accounts (MFA) and Territorial Life Cycle Assessment (T-LCA) are holistic methods that take into account a wide range of direct and indirect material and energy flows generated by human activities, yielding different quantitative indicators to characterize pressures or impacts, respectively. However, these assessment methods should be tested and validated at this scale. This study aims at comparing the weaknesses and strengths of these two methods, for each step of implementation (goal and scope, inventory, results, interpretation), in order to analyze their possible complementarities. The case study is the new metropolitan area of



Aix-Marseille-Provence, South of France. It is the largest metropolitan area of France (3 173 km<sup>2</sup>), with a population of 1.83 million, the 2nd Mediterranean harbor. It has steel and iron, refinery, petro chemistry, and aeronautics industries. These activities generate transit flows of raw materials, environmental emissions, intermediary or manufactured products, and transform important quantities of material and energetic fossil resources, making this area suitable for the comparison of these methodologies. The results show that the inventory of indirect and offsite flows are specific to each of them. Oxygen and water flows are differently considered, which must lead to modify the two methods, due to their importance to balance the inputs and the outputs. This study reveals that the indirect flows and offsite impacts are larger than direct flows and onsite impacts. Their assessment can characterize a transfer of pressures or impacts to other territories, asking for a global view of them, to support land planning decision. These methodologies have identified hotspots and are interesting tools in order to propose scenarios integrating global initiatives of circular economy and regulations changes as well as local initiatives such as industrial ecology. Lastly, consequential LCA may be more adapted for this typology of territory, with many activities having strong interactions on their hinterland and other harbor cities and a strategic importance for a country.

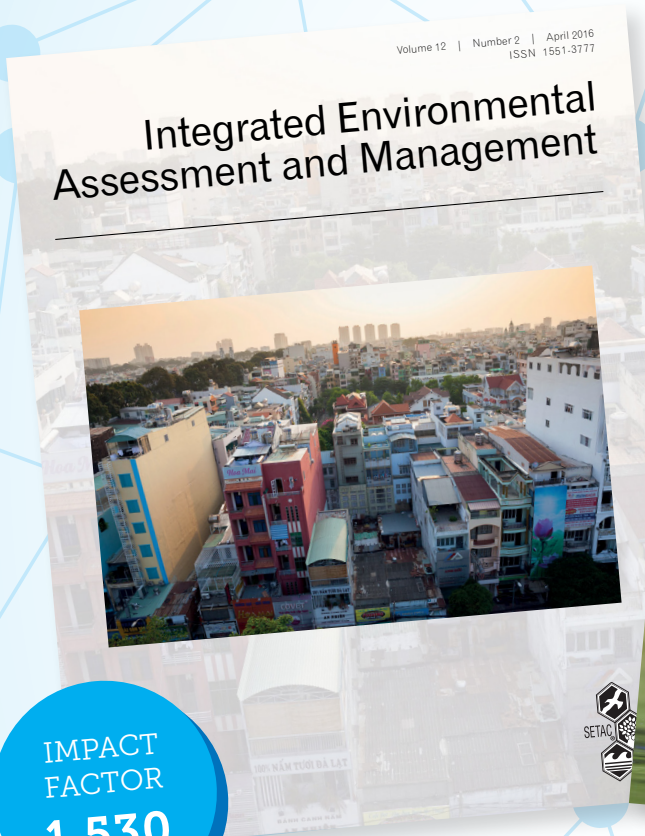
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### **Evaluation of alternatives for the calculation of the final demand carbon footprint of a region**

L. Roibás, Universidade de Santiago de Compostela; E. Loiseau, National Research Institute of Science and Technology for Environment and Agriculture - Irstea; A. Hospido, Universidade de Santiago de Compostela / Department of Chemical Engineering Institute of Technology Universidade de Santiago de Compostela Santiago de Compostela Spain

This study compares four different alternatives for the calculation of the household consumption carbon footprint (CF) of a region, through the case study of Galicia (NW Spain). Consumption items have been split into five categories: food, goods, services, transport and housing. In the first alternative (A1), the methodology defined by Loiseau et al. (2014) has been followed: the CF of transport and housing has been calculated through process LCA and the remaining categories using the US Environmental Input-Output (EIO) database (Suh, 2010). EIO approaches are used to calculate the CF of all categories in the remaining approaches: A2 relies solely on the US EIO database, while A3 and A4 use multi-region data: World Input Output Database (WIOD, Dietzenbacher et al., 2013) and Exiobase (Tukker et al., 2013), respectively. The CF results are 5.7 (A1), 6.3 (A2), 8.4 (A3) and 8.1 (A4) T CO<sub>2</sub>e/inhabitant/y. The main differences arise when comparing the emissions of goods and services among A1 and A2 alternatives (1.3 TCO<sub>2</sub>e), and A3 (4.0 TCO<sub>2</sub>e) and A4 (4.3 TCO<sub>2</sub>e). The CFs of housing and transport are very similar among A1, A3 and A4 (2.8 ± 0.2 TCO<sub>2</sub>e), and slightly higher in A2 (3.4 TCO<sub>2</sub>e). The results point at the unsuitability of using a single-region database (A1 & A2), which implies that each product is obtained with the same technology regardless of its country of origin, and can lead to important differences when compared to multi-region IO results (A3 & A4), which implicitly consider different technologies. Being USEIO the oldest database (2002) may also affect its results compared to WIOD (2011) and Exiobase (2007). Both of them offer good approximations to the CF of transport and housing, requiring much less data than process LCA (A1). WIOD contains fewer categories than Exiobase, which reduces computation times but may affect the accuracy of the results. REFERENCES Dietzenbacher, E. et al, 2013. The construction of world input-output tables in the WIOD project. *Economic Systems Research* 25, 71-98. Loiseau, E. et al, 2014. Implementation of an adapted LCA framework to environmental assessment of a territory: important learning points from a French Mediterranean case study. *Journal of Cleaner Production* 80, 17-29. Suh, S., 2010. CEDA 4.0 User Guide. <https://www.pre-sustainability.com/download/manuals/CEDAUsersGuide.pdf> Tukker, A. et al., 2013. EXIOPOL-DEVELOPMENT AND ILLUSTRATIVE ANALYSES OF A DETAILED GLOBAL MR EE SUT/IOT. *Economic Systems Research* 25, 50-70

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## Poster Abstracts

### Conference poster session: Life Cycle Innovation for the transition to a sustainable society

#### P01

#### **Life Cycle Assessment of DMSO solvent, comparing an open manufacturing system with a closed one**

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**Introduction** – DMSO (dimethyl sulfoxide) is frequently used as a solvent for chemical reactions and is also extensively used as an extractant in biochemistry and cell biology. DMSO can be efficiently recovered from aqueous solutions - even though contaminated with volatile and/or nonvolatile impurities - by distillation due to its high boiling point (189 °C). In the project called “DMSO contaminated industrial waste water recycling by distillation” the factory of the Project Promoters S-Metalltech 98 Ltd. produces arsenic, phosphorus, iodine and fluorine removal adsorber for drinking and technological waters. During the production process 1m<sup>3</sup> high DMSO content hazardous waste water is produced daily, which needs to be collected and transferred to the incineration plant to be burned. The transferred DMSO need to be replaced with fresh solvent in the production process. Beside 20 w/w% DMSO the waste water contains: Soluble polymer – ethylene-vinyl alcohol copolymer (EVOH) Minerals such as cerium-hydroxide The aims of the project are to reduce the volume of the hazardous waste water and to reuse the recovered solvent and water in the production process accordingly to turn the open manufacturing system into closed and analyse the environmental, economic and social impacts of these two processes with LCA, LCCA, S-LCA. **Results and Discussion** - Within the framework of the project we planned to study the followings: identify the components of waste water with qualitative and quantitative analysis methods separate the different types (water, solvent /DMSO/ and other components) with distillation and analyze the efficiency of the separations in laboratory level and also during the manufacturing process prepare sustainability analysis based on technical performance, life-cycle analysis, CAPEX and OPEX in laboratory level and also during the manufacturing process **In Conclusions** - In our ongoing project we executed the preliminary measurements and due to these results we found the two-step vacuum distillation as the best solution. Now we are testing the efficiency of the separations in laboratory level and we started the life-cycle analysis and CAPEX, OPEX calculations. We expected the following results at the end of the project: according to preliminary estimates the amount of hazardous waste water could be reduced from 265,2 ton/year to 5,5 ton/year, so with 98%; and the amount of water used in the manufacturing process could be reduced approximately with 27%.

#### P02

#### **Sustainability assessment of innovative photovoltaic panel treatment to convert waste into resources promoting circular economy. PV-MOREDE device**

L. Puigmal, LEITAT Technological Centre / Sustainability Division; M. Escamilla, Leitat Technological Center / Sustainability Division

Life cycle impacts of photovoltaic (PV) panels have been largely studied; however, the end-of-life phase has been generally excluded from these studies, mainly because of the low amount of panels that have yet reached the disposal and the lack of data about their end of life. It is expected that the disposal of PV panels will become a relevant environmental issue in the next decade[1]. PV-MOREDE project is being developed to solve this future environmental problem offering an innovative process solution based on a mobile device to treat PV panels directly where they are installed, allowing a cost-effective and easily accessible waste treatment for small quantities of PV panels. The device is particularly suitable to treat first generation PV panels, and it allows obtaining at least three types of recoverable waste products: glass, photosensitive metallic material and «light compound» which will be re-introduced in the value chain in order to make a zero-waste ecosystem promoting circularity. Therefore, PV-MOREDE

project fosters a circular economy handling the situation of recycling the PV panels at the end of their life cycle transforming waste to resource, reducing raw materials scarcity while improving also electronics, metallurgy and glass industries. Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) methodologies have been applied within this project in order to quantify the environmental and economic performance of this innovative technology, since LCA provides a standardized methodology to calculate the potential environmental impacts of the new device. Social issues have been also studied in order to have a full sustainability assessment. Moreover, a comparative analysis has been done between the baseline scenario (existing technology) and the PV-MOREDE process in order to determine the environmental benefits of the new recycling PV panel process. The expected results of are: A PV-MOREDE device working in Germany, Spain, France and Italy. 270.000 treated panels and recover up to 4.735 tons of glass; 669 tons of aluminium, 7,6 Tons of copper. To dispose under controlled way, 1 Ton of lead and 400 Tons of other key materials (EVA, Tedlar, Silicon) To reduce treatment panels costs / tons up to 40% <br clear=»all» /> [1] Cynthia E.L. Latunussa et Al. LCA of an innovative recycling process for crystalline silicon photovoltaic panels. 2016

## P03

### **Life Cycle Assessment of power production by using low temperature waste heat from industrial processes**

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Utilization of waste heat by electricity production is an important issue for increasing energy efficiency and reducing greenhouse gases. Producing electricity from industrial waste heat has environmental advantages, especially when the use of fossil fuels elsewhere is reduced. For the entire system, the waste heat recovery means an improvement by avoiding emissions per se. Emissions, which are typically formed during combustion, such as CO, CO<sub>2</sub>, NO<sub>x</sub> or SO<sub>x</sub>, are avoided. Within the project "RaCiA", an innovative water steam flash-cycle is developed for electricity production from industrial waste heat sources from flue gas or exhaust air. The targeted source temperature range of the process is 140-550 °C. Waste heat with this temperature level is often a byproduct of various industrial processes. The developed flash-cycle is meant to operate in fields of applications where e.g. Organic Rankine Cycles (ORC) are used. The expected ecologic advantage is given by a higher energetic efficiency and the use of the harmless process medium water instead of organic process fluids. As there are no emissions for providing energy sources in the case of waste heat recovery, a bigger focus can be drawn on the construction, operation and disposal. The biggest challenge is to find appropriate LCI-data for modelling the new process, but also for modelling a State-of-the-Art process (ORC). To find representative data, which are consistent enough for a comparison, was a special challenge of the project. Especially in the case of water steam flash-cycle processes are big data gabs for single components. The present study is based on ISO 14040 and 14044. To get the necessary data, primary data for the evaluation information from manufacturers, literature or own technical simulation results were collected. For this analyses data form the ecoinvent database v.2 and the softwaretool Gabi 6 were used. The analyses of the new process shows that the production of the components is associated with the highest environmental impacts. The second largest share is covered by the environmental impact of the operation phase. The results are with a share of around 12% (GWP 100) or 15% (PE N. E.) far behind compared to the total contribution. Comparatively negligible are the proportions of disposal and transport. The results of this exploratory project are the basis for further industrial research, which shall lead to industrial implementation of the process.

## P04

### **Renewable energies for Graciosa Island, Azores - Life cycle assessment of electricity generation**

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At present there are a lot of activities to increase the utilization of renewable energies on islands and to reduce their dependency on fossil fuels to support the transformation towards more sustainable energy systems. In this regard, the Regional Government of the Azores (Portugal) has decided to invest more than 85 million € by 2017 in the area of renewable energy, which will increase the rate of penetration of renewable electricity generation in the region to about 53 %. Graciosa Island belongs to the Azores and is located about 1,600 km west of continental Portugal. The island has a length of 10 kilometers and a width of 7 kilometers. The population is approx. 4,400 people. The current electricity generation of approx. 14 GWh/a is completely covered by diesel generators. A new electricity generation system is currently being realized as a hybrid power plant consisting of a lithium ion battery energy storage system (BESS), a wind park and a photovoltaic system. Start of regular operation of the hybrid power plant is scheduled for end of 2016. The BESS consists of 40 battery racks with 19 battery modules each. One battery module consists of 60 cells. The applied lithium ion cell combines a lithium titanate anode with a nickel cobalt oxide cathode. In standard operation it is possible to fully operate the power grid on renewable electricity generation while spinning reserve and other grid services are provided by the BESS. The existing diesel generators are operated during times when the load cannot be covered by renewable generation and serve as a back-up electricity generation system in cases of non-availability of the hybrid power plant. After system commissioning of the hybrid power plant, the useable total renewable electricity production is projected to be 9.1 GWh/a on average. Under the assumption that electricity generation remains constant on the 2015 level, the share of renewable electricity generation can be increased to approx. 65 % from total generation. The remaining diesel generation leads to a consumption of approx. 1.3 million l/a. Compared to the 2015 diesel consumption this results in savings of approx. 2.4 million l/a. This study compares the current electricity generation by diesel generators and the future hybrid power plant with high shares of renewable energies by a life cycle assessment relating to the functional unit of 14 GWh electricity generation per year.

## P05

### **LCA and Cost Analysis of innovative Li-S batteries for electric vehicles**

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Lithium Sulphur Batteries (Li-S batteries) are the most viable candidates for the commercialisation among all posts Li-ion battery technologies due to their high theoretical energy density and cost effectiveness. Despite many efforts, there are remaining issues that need to be solved to boost these batteries technological development. Some of technological aspects, like development of host matrices, interactions of host matrix with polysulphides and interactions between sulphur and electrolyte have been successfully developed in recent and ongoing projects, while now research is focusing on studying the open porosity of the cathode, interactions between host matrices and polysulphides and proper solvation of polysulphides are requirements for the complete utilisation of sulphur. Besides the technological challenges, Li-S batteries need to demonstrate their environmental and economical sustainability, in order to become the preferable alternative to conventional Li-ion ones. For this reason, LCA methodology is applied to study the environmental performance of Li-S cells and battery packs ("cradle to grave" LCA analysis), following ISO 14040-44 standards. This abstract present the LCA study that is being carried out for the above mentioned Li-S battery cells and packs for electric vehicles. The LCA includes a qualitative assessment of safety aspects with regards to the use of Li-S cells in their intended application, the transport of new and used cells, and the treatment at the end of the battery life. In order to accomplish with current EU-directive 66/2006 that defines a minimum recycling efficiency of 50 wt.% of the battery, an innovative recycling process using novel technology for the vacuum fractionated distillation of battery metals is studied under LCA perspective, whose objectives are focused on achieving high recovery efficiency, at low energy consumption and with a minimized environmental impact. Due to the technology used, this recycling process is deemed to generate metal fractions of high purity at a market-orientated processing cost. Further, the work will assess the economic modelling of an up-scaled processing plant and a life cycle assessment (LCA) for the full life cycle of the Li-S batteries. This LCA assessment is included in HELIS "High energy lithium sulphur cells and batteries" project. This project receives funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 666221.

**P06**

**Comparative Life Cycle Exergy Assessment of on-grid hybrid and conventional Base Transceiver Stations**

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Exergy analysis examines the flows of exergy within a system and its objectives are reduction of exergy destruction and improving the efficiency of processes and systems. While LCA focuses on environmental impacts through entire life cycle, exergy analysis considers inefficiencies of a process isolated from other parts of a system. By combining these methods, its strengths are emphasized and its weaknesses are decreased. Life cycle exergy assessment (LCEA) is used to perform the comparative assessment of hybrid and conventional Base Transceiver Stations (BTS). There are around 5 million BTS sites in worldwide telecommunication network, with the number growing every year as the network expands. Alternative power solutions are not commonly used at telecommunication sites. However the public climates change debate, increased corporate social responsibility, expensive maintenance and high energy demand have increased the interest for small scale alternative electrification solutions for BTS-sites. BTS that are powered with alternative energy sources (besides electrical energy from grid) are known as hybrid BTS. According to GSMA foundation, solar and wind power are viable today and other solutions may become suitable in the future for powering BTS sites. In order to choose an appropriate alternative energy source, an adequate analysis of surrounding factors must be performed, e.g. wind speed, solar radiation, climate conditions, etc. BTS sites are consisted from telecommunication, power and auxiliary equipment. Other phases that are included are on-site works (installation), use and maintenance, dismantling and disposal. This research observe solar and wind power as alternative energy source for BTS-sites as they are the most favorable ones to be used. Results show that conventional BTS has more negative impact than hybrid BTS, primarily due to greater electricity consumption (from grid) during use phase. As for particular life cycle phase, the use phase is the most dominant one regarding the negative impact. Such results are very sensitive when comes to choosing the installation site of BTS, since different countries have different electricity mix. Regardless, reducing the electricity consumption during the use phase is primary objective, which is to be achieved by replacing the electricity from grid with solar and wind power sources.

**P07**

**ADEME SOCLE project, Soil Organic Carbon accounting to improve Life cycle Evaluations**

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Soil Organic Carbon (SOC) is a key component of agricultural soils. It is both an indicator of soil properties and related functions, as well as a critical parameter, when looking at soil-related climate issues. Indeed, soil organic carbon is the first global carbon stock, prior to the atmospheric stock, hence playing a potential critical role in climate change mitigation in the agricultural sector. Despite this ambivalent role, SOC is not yet comprehensively accounted for in Life Cycle Assessment of agricultural value chains. It is either accounted for at the life cycle inventory stage, or taken as a proxy within the impact assessment of land use impact. The ADEME SOCLE project gathers partners from the French Cirad research institute and from the French technical institutes, Arvalis, Idele, and Agrotransfert, with the aim to identify key methodological approaches and bottlenecks in accounting for the impact of agricultural practices on SOC and consequent ecosystem services. The project team started with a comprehensive and critical analysis of conceptual approaches and methods, which were developed in order to either account for the change in SOC on climate change impact, including an analytical review of the biogenic carbon accounting within climate change impact characterization factors, or to link land use to a change in soil organic carbon stock as a proxy for change in soil quality. The aim of this review was to identify complementarities in concepts and approaches in order to provide recommendations as to increase the robustness of soil quality accounting within LCA. The project next step will be to test the recommendations on various and contrasted agricultural value chains, including crop and livestock productions in temperate and tropical regions.



## P08

### **A pragmatic approach for the Life Cycle Assessment of industrial systems as a basis for eco-innovation, the example of Fives' products**

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As industries are more and more challenged by environmental concerns and energy efficiency needs, Fives, a designer and supplier of machines, process equipment and production lines for a large industry panel such as cement, steel, sugar, glass, machine tools and logistic industries; developed new solutions. Through its eco-design program, called Engineered Sustainability®, Fives aims at designing solutions with the best possible environmental performance. This innovation process is based on the following principle: after having performed an environmental analysis of the product, a key step to identify hotspots; the product is redesigned through intensive R&D studies with the goal of minimizing the main impacts identified as much as possible. The best economic and environmental compromises are integrated to answer customer needs. The first step is always based on quantification tools such as Life Cycle Assessment, used in order to take into account all direct and indirect impacts of the product during its life cycle and avoid any impact transfer during the redesign of the product. However, carrying full-LCAs can be time-consuming and streamlined LCAs don't always give unexpected results. Through several years of eco-design experience over a wide variety of products, from the small equipment to the entire plant; Fives developed a pragmatic approach to perform reliable Life Cycle Assessments on industrial products minimizing time and environmental expertise needs. Indeed, from one hand, simplified models are used on life cycle phases that appear to be negligible for industrial products (eg. transport phase) or for those where Fives does not have the hand and lacks information (eg. end-of-life phase). On the other hand, for the life cycle phases with high impact (eg. operation, manufacturing phases) an accurate and exhaustive life cycle inventory is performed and dedicated models and environmental factors have been developed to accurately model the Fives technologies performances. During this presentation, two examples: A sorting system from the logistics industry and a coal tar distillation plant; will help Fives illustrate how to successfully apply simplification methods to perform Life Cycle Assessments on industrial products; and how based on those results and restarting from customer needs, the eco-innovation performed at R&D level leads to develop products with high operational and environmental performances on the market.

## P09

### **More sustainable textiles and improved laundry processes for mitigating the microplastics impact in the marine environment. MERMAIDS project**

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European oceans are contaminated by marine litter, mainly by plastics. Microplastics are particularly worrying because water treatment plants do not take them into account in their management processes and they are deposited in waterways and sewage sludge. Microplastic particles of synthetic clothes coming from laundry wastewater have been encountered in marine sediments, ecosystems and runoff and sewage waters. The *Accumulation of Microplastic on Shorelines Worldwide: Sources and sinks* states that *"the source of the microplastic fibres in the sewage treatment plants is most likely to be from washing machine wastewater as the mixture of fibres found in synthetic textiles is similar to the mixture of microplastic fibres found in beaches at disposal sites and in the wastewater of sewage treatment plants."* On average, more than 1900 fibres of microplastics can be released by a synthetic garment during one wash[1]. MERMAIDS project promotes the mitigation of the impact caused by micro and nanoplastic particles resulting from laundry wastewater on European seas' ecosystems, by demonstrating and implementing innovative technologies and additives for laundry processes and textile finishing treatments. A reduction of at least 70% of the total microplastic fibres that is currently discharged in laundry wastewater is sought by means of the improvements achieved. An analysis of existing technologies and products has been done to determine the main factors involved in the release of these fibres during the laundry process to further improve them. The project fosters a more sustainable textile sector exploring innovative textile treatments, formulations and other actions to improve the finishing processes and fini-

shing fibres. MERMAIDS is also encouraging a more sustainable detergent industry, since is working on innovative additives for laundry products to reduce the fibre breakage and avoid garments' microplastic removal during the laundry. Moreover, optimized washing recommendations are being elaborated to be disseminated to general public. The LCA will allow the quantification of the improvement achieved with the use of the innovative solutions. Then it will serve as a tool for demonstrating the environmental performance of the proposed new eco-innovative textiles and laundry system. <br clear="all" /> [1] Science for Environmental policy. EC DG Env, new alerts 272, 9 Feb 2012

### P10

#### **LCA of different Kraft paper mill scenarios to integrate the manufacturing of new eco-designed supercapacitors based on black liquor**

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Kraft paper mills generate high impacts on the environment because of the important use of energy and hazardous emissions to air and water. Nowadays, performance of Kraft paper mills is improved as they can be fully sufficient or almost self-sufficient in energy, thanks to bark and black liquor combustion. However, it is also possible to maximize the added value of black liquor through its valorization in a functional material instead of energy. In this context, it has been recently shown that black liquor can be used to produce the electrodes of supercapacitors. The aims of this study are to (1) compare different scenario of black liquor valorization within a Kraft paper mill and (2) to compare the eco-designed supercapacitor based on black liquor with conventional production from petro-sourced electrodes. For the first objective, we use generic LCI data from the Best Available Techniques for paper production to model three scenarios of Kraft paper mill operation. The first scenario includes the combustion of black liquor that ensures full energy autonomy of the paper mill and an additional generation of electricity. The second scenario includes the valorization of a fraction of black liquor for materials without affecting energy autonomy of the mill. The third scenario includes a full valorization of black liquor as a material, and needs an extra consumption of heat and electricity to run the process. We apply economic allocation to distribute the inventory between pulp paper and black liquor in the second and third scenarios. As for the second objective, the LCI related to the electrode from black liquor is based on lab-scale data. This bio-based porous material is compared to petro-sourced alternatives based on styrene/divinylbenzene. In both objectives, the impacts are calculated using ReCiPe Midpoint (H). The results relative to the comparison of different paper mill scenarios show that the second scenario including energy and material valorization of the black liquor is the most interesting from an environmental point of view. Therefore, this is the best suited scenario to valorize black liquor as a material. Also, the LCA results related to the comparison of different supercapacitors show a clear benefit from the ones based on black liquor. In addition to environmental advantages, real economic benefits are expected comparing with the prices of supercapacitors with the same characteristics readily available on the market.

### P11

#### **Integrating LCA methods in companies' processes via hazardous substance declaration - creation of a tool**

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On the European and even worldwide levels, regulations and standards are pushing industries towards a better accounting of life cycle related information. Most are requiring the use of Life Cycle Assessment (LCA) approaches (ex: EN 15804, PEF/OEF), and others are oriented towards Life Cycle Management (LCM). It is for instance the case of the REACH directive, requiring the declaration and the traceability of numerous hazardous substances that might be present in products. This regulation enhances the communication between manufacturers and their suppliers and clients. Though, many suppliers find it difficult to gather and exchange this information. In addition, collecting it can be redundant with already existing LCA or LCM policies. This is especially true in the electrical and electronic equipment sector as products can include thousands of substances in a complex, globalized supply chain. Considering those stakes,

this study aims at developing a methodology and a tool allowing the simultaneous collection of hazardous substance and materials and LCA information along the supply chain, and their communication within the product supply chain and towards regulatory authorities and clients. Ultimately, it aims both at reducing the amount of resources needed to perform regulatory declarations, and to widespread the LCA use by integrating it in the industrial processes. This will help companies generating value on a task that is often considered as generating no positive outcome for the industries. As a starting point, the tool is in the framework of IEC 62 474 standard. This standard has developed both a list of hazardous substances covered by various regulations worldwide in the electronic and electrical sector, as well as a common exchange format for all stakeholders. This standard is already in common use in Japan. Though, hazardous substance and material declaration alone is not enough to perform an LCA, and additional information is to be added, such as energy consumptions, wastes, water uses, etc. Therefore, their inclusion to the tool is also considered in order to reduce the diversity of entry points and to give a common framework for collecting LCM information on a product. In the future, the final step would be the coupling of this data collection tool with existing LCA tools in order to further reduce the resources needed when performing LCA.

## P12

### **Consumer perceptions of the environmental sustainability of liquid food packaging: a survey among Danish consumers**

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As consumers in general put greater emphasis on environmental issues, and FMCG (Fast Moving Consumer Goods) companies invest in developing new sustainable packaging in order to position themselves as responsible brands, knowledge on what consumers perceive as environmentally sustainable as well as on their understanding of product labels, becomes key enabler of the strategic decision making. In this study we investigated how Danish consumers perceive the environmental sustainability of liquid food packaging and tested their knowledge of common packaging eco/labels. Five different product categories were considered: milk, beer, soft drink, olive oil and skinned tomatoes, with different packaging alternatives in each. Empirical data were collected using both quantitative (web survey) and qualitative methods (interviews). The survey was structured in four main parts: 1) investigation of consumer attitudes to sustainability consisting of general questions about sustainability and a series of statements related to packaging and packaging sustainability where the respondent had to indicate the level of agreement; 2) list of a number of pictures of alternative packaging types containing the same product, where the respondent had to indicate how sustainable they perceive the alternatives on a 1-7 scale; 3) test of the knowledge about product labels related to sustainability (e.g. the green dot, plastics resin identification codes, the Cradle to Cradle certification label), where the respondent had to select among different plausible meanings; 4) background questions (e.g. age, gender, education level). The survey was answered by 197 Danish consumers, and the results showed that consumers assess packaging sustainability based on the material type and on what they can personally do at the disposal stage. New bio-based packaging types and glass packaging are perceived as the most sustainable and plastics in general are perceived as the least sustainable option, meanwhile laminated cartons have a more mixed standing. The general knowledge of environmental packaging labels is quite low for most of the tested labels, and no significant correlation was found with the number of years of education of the respondents. These findings can be used to inform packaging designers, purchasers, marketing professionals and decision makers to steer their decisions, but they need to be complemented with information on the actual environmental impacts of the packaging alternatives.

## P13

**Analysis of the variability and reliability of Environmental Product Declarations for the comparison of environmental performances of construction products**

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The significance of Environmental Product Declarations (EPD) grew fast on the market of construction materials and products during the last decade. Indeed EPD provide environmental performances of construction products according to a standardised and harmonised methodology and form; aiming to communicate verifiable and accurate information in order for the manufacturers to achieve competitive advantage on the market. In order to support the marketing challenges, EPD content must therefore provide objective statements of environmental performances of products, and Life Cycle Assessment (LCA) is recognised as one of scientifically based methodologies to support environmental communication through EPD. The ISO standard 14025:2006 establishes the generic principles and specifies the generic procedures for developing EPD; and Product Category Rules (PCR) provide the specific rules and requirements to be considered regarding the Life Cycle Inventory (LCI) and the Life Cycle Impact Assessment (LCIA) stages. For construction and building products, specific standards are available, aiming to harmonize PCR production and application for this products' category. Despite the transparency and level of harmonisation obtained from the standardisation efforts, comparison of products based on EPD in order to support decision-making remains sensitive because of variable LCI parameters, and also due to the uncertainty induced for LCIA results, which is not considered in EPD. The LIST in collaboration with Tarkett, worldwide leader of innovative and sustainable flooring and sports surface solutions, performed a detailed comparison of two EPD for Tarkett products in order to show the limits of EPD comparison, induced by the application of the PCR requirements regarding modelling assumptions, detailed information provided for data quality and LCI modelling differences. It contributed to demonstrate the variability of LCIA results. It has been completed with an uncertainty analysis regarding some of the identified variable LCI parameters. The presentation aims at discussing the results and conclusions of this case-study.

## P14

**Feedback from a collaborative LCA network: SCORE LCA's four first years**

J. Garcia, P. OSSET, SCORE LCA; s. morel, Mines Paristech & Renault / Engineering

SCORE LCA is an association created to promote and organize cooperation between companies, institutional and scientific community in order to support the evolution of LCA methods and their practical implementation at European and international level. This structure is the result of an initiative of some industrials (TOTAL, EDF, ENGIE, RENAULT, VEOLIA R&I, SAINT GOBAIN), supported by ADEME and fostered by the Association RECORD (see [www.record-net.org](http://www.record-net.org)) After presenting the operating mode of the Association, we will explain the different obstacles encountered and the keys to success for such a collaborative structure. The specificities of SCORE LCA: - The governance of industrials: The scientific program is defined and selected by the members according to their real needs in LCA practice. All decisions concerning the Association is taken by the members. - Numerous topics related to LCA, outside the competitive scope: 23 ended studies (since 2012) covering a large number of subject concerning LCA and LCT: Circular Economy, Monetization, Resources, GIS and LCA, Biodiversity, End of Life... - A place for sharing eco-innovation practices: The meetings organized along the year provide opportunities to have privileged exchanges with other experienced members, and with the teams of consultants or researchers who conducted the studies. Bridging the gap between research and practice: The main objectives are to develop LCA practices, to communicate their progress and to answer current and future needs of companies in a more effective and efficient way. Each project is time-bounded and provides practical results with recommendations approved by all members. This aspect is an argument towards decision makers to use these more credible and relevant recommendations. Moreover, studies are more and more integrating case studies directly related to members' activities to illustrate the recommendations. Continuous improvement: After 4 years of existence, SCORELCA conducted a self-assessment of the shared benefits (Morel 2014) created for each members. The focus is made on 4 issues: financial, image, decision, skills. Interviews were conducted in May 2016 and provided two key results. In one hand it allows to better express

the contributions of the structure for the members and in the other hand it sheds light on the progress areas to consider. These results could help us to improve the operating mode and the type of work in order to better meet the members' needs.

## P15

### Glucose production: influence of the datasets choice on LCA results

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The aim of this study is to have a good understanding of the environmental impact of glucose production. Glucose is generally produced from corn or wheat. Since agricultural processes are known to be difficult to evaluate by LCA, the results obtained with two different LCA databases, GaBi and Ecoinvent, are compared in this work. The production of glucose from raw materials can be divided in two steps: the agricultural step allowing the plant production, and the conversion step including the extraction of the starch from the plant and its hydrolysis into glucose. Preliminary results underline the high impact of the agricultural steps, so a special attention has been paid to these data. Specific Belgian data collected by the Walloon Agricultural Research Centre (CRA-W) (2014) [1] have been used as primary data (yield, amount of fertilizers, etc.), either using Ecoinvent or GaBi datasets background data to model fertilizers, diesel consumption, etc. A third model was built using only data available in Ecoinvent for corn and wheat cultures. For the conversion steps, literature data have been used along with some industrial data. As few studies are available in the literature concerning starch hydrolysis, the focus has been placed on data validation (mass balance checks, cross-reference information, etc.). Based on these multiple sources, it is possible to compare the LCA results for the production of 1 kg of glucose for three different cases, summarized in the following table. Table 1: Summary of modelled cases

Agricultural step	Conversion steps	Primary data	Dataset	Case 1	Case 2
Belgian	Literature + Industry	GaBi	Literature + Industry	GaBi	Ecoinvent
Belgian	Literature + Industry	Ecoinvent	Literature + Industry	Ecoinvent	Ecoinvent

The results obtained using these three models will be presented, at both the inventory and impact assessment steps. They show significant differences and highlight the need to understand in depth the involved assumptions when developing the datasets, in addition to the ones adopted for the inventory. 1. Walloon Agricultural Research Centre (CRA-W), ALT4CER project. 2014.

## P16

### Using LCA and integrate quality evaluation for a new eco-design approach in viticulture

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The French wine sector is subject to increasing regulatory and social pressures concerning environmental issues along with a strong imperative about wine quality and its typicality. Winegrowers need to address both environmental and quality issues. They need information about the environmental impacts of their practices in order to prioritize technical options to be changed and identify alternative options. Renaud-Gentié (2015) recently proposed a methodology to assess environmental impacts of Technical Management Routes (TMR) at plot scale, based on LCA. TMR is defined as a logical succession of technical options designed by the farmers (Sébillote, 1974). As a decision support and eco-design tool, LCA can help building new TMRs integrating both environmental and grape quality issues. This PhD work aims to create and test a new approach (named "eco-quali-conception<sup>®</sup>") which integrates quality and environmental evaluations in the innovation process, conducted jointly with the winegrowers. Several eco-quali-conception<sup>®</sup> workshops will be organized with 2 different groups of winegrowers from different PDO (Protected Designation of Origin) areas. The first group will be composed of independent winegrowers (making their own wines) whereas the second will be composed of winegrowers members of a cooperative (wine is made by the cooperative). The first group is already in an environmental approach about reducing pesticides use whereas the second is in a multi-issue approach integrating all aspects of sustainability. These workshops will be based on a co-design approach. LCA results will serve as a basis to foster discussions between winegrowers during the first workshop. The objective will be to share scientific

knowledge and empirical “know-how” to explore various ways reducing the impact of current practices. The second workshop will focus on the most impacting practices and their influence on grape quality. A final workshop will enable building a set of innovative TMRs. This new approach aims to help winegrowers integrate life cycle thinking and the link between their practices and grape quality in the design of TMRs. Two objectives will have to be achieved for the new TMRs: improving environmental performances and achieving the desired grape quality. Eco-quali-conception® approach could be extended to design agri-environmental measures to be implemented labelling regulations to enhance a collective transition toward more ecological agriculture.

### P17

#### **Energy returns on investment (EROI) of four agricultural biomasses for bioenergy generation**

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The country’s development, economic stability and the welfare of its people depends on the independence of its energy supply. Whereby, the incorporation of renewable energies to national energy matrix is an important goal at short term. Where biomass and bioenergy seem to be a solution or a great fallacy. In this framework, each biomass or bioenergy source should be analyzed with a broad scope to define if is a solution or not. Uruguay, a country whose 50% of energy supply is foreign fossil fuel, come seeking how increase its energy independence with biomass and bioenergy. For this reason, this study estimated the EROI of first highlighted uruguayan feedstocks: eucalyptus wood for biomass production; grain sorghum, sweet sorghum and sweet potato for ethanol production. An assessment since field preparation until thermoelectric power plant generation or the dehydrated bio-ethanol produced. Our results are a first proxy to EROI, which shown an EROI per hectare per year of 0.56, 1.2, 3.5 and 7.2 for eucalyptus culture for cellulose, sweet potato crop, grain sorghum crop and sweet sorghum crop, respectively. According to these results the sorghums could be a potential bioenergy source, if can prove its environmental sustainability.

### P18

#### **The best options for Eucalyptus energy crops according to EROI values**

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Uruguay started the promotion of commercial forest crops in 1990 on specific soils, with only 20000 ha approximately. This agricultural activity has developed until now focusing on *Eucalyptus* spp for ECF-bleached pulp mills and *Eucalyptus* spp. and with *Pinus* spp for solid wood. In 2015 the area under commercial forest plantations reached 1,4 million ha. This productive scenario along with the use of forest residues (i.e. black liquor or rest of plywood) for bioenergy production carried out to the question whether or not it is possible to increase bioenergy use from this crop. However, the current national experience and technology has not focused on energy crops, therefore the most appropriate tree species, densities and type of soils for forest energy crops remain uncertain. For answering those questions we assessed the energy balance through EROI (energy returned on energy invested) analysis of two energy forest trials in Uruguay. Both trials were aimed to compare four species (*Eucalyptus benthamii*, *Eucalyptus dunii*, *Eucalyptus grandis*, *Eucalyptus tereticornis*) growing at four different densities (2220, 3330, 4440 and 6660 trees per hectare) with three replicate on two major forest soils of the country (Acrisols from Tacuarembó and Argiudols from Paysandú). We assessed the energy return on investment to identify the tree species, density, and soils with best performance when both trials were 2 years old. This evaluation included the energy involved from field preparation to the electric energy production considering a 10Mwh-thermoelectric-power plant. For these estimations the calorific power of the wood from each replicate of specie-density-soil was determined. Our results showed EROI values from 5 to 17 and are the highest EROI values obtained for a feedstock in Uruguay, and they are also high values compared to other biomass pro-

ductions. *Eucalyptus benthamii* and *Eucalyptus dunnii* showed the highest EROI with 17 and 15 respectively in Paysandú soil, with densities of 4440 or 6660 trees per hectare. Therefore, given the current technological development and the availability of industrial nursering of *Eucalyptus dunnii*, plantations with densities higher than 4440 of this species located in Paysandú represent the best option.

## P19

### **Carbon Footprint of Italian Natural Mineral Water: an empirical research**

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**Abstract** Water is the most diffused substance on the earth and covers the 7/10 of the whole surface. Its total volume wanders on the 1.450 million km<sup>3</sup>. It is the predominant component of the human organism: the 60% of the weight of an adult individual. Water scarcity is already for many, and is set to increase such as population increase, climate change, urbanization and changing lifestyles. In the last years mineral water has had a fundamental role as substitute of the drinkable water. This derives from the scarce trust of the population towards the traditional water of the faucet, considered easily subject to pollution. It is evident in many studies of sector the increase of the consumptions of the mineral waters, which has been supported by the technological innovation, that has invested the effective tools of marketing. During the research process several key-factors of the industry have been defined and analyzed. Sustainability, Carbon Footprint and Water Footprint are the most important topics that have been discussed, in order to be able to evaluate this industry. The aim of this study concerns the Carbon Footprint (CF) application of the production and distribution of an Italian Natural Mineral Water. The functional unit used was a 1,5 litre bottle and applying the standard method PAS 2050. The Life Cycle Inventory Analysis allowed the consumption of raw materials and energy, as well as the formation of effluents and solid wastes, to be estimated (derived from the databases of the SimaPro 7.2 software according to the method IPCC 2007). Finally, a few actions were recommended to reduce the product CF and to improve its environmental performance. **Key words:** Carbon Footprint (CF), Life Cycle Assessment (LCA), Standard Method PAS 2050, Water Industry, Environmental Performance

## P20

### **Carbon footprint in fertilizer production as a tool for reduction of GHG emissions**

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Mineral fertilizers are an essential component of agricultural production but during their production significant amounts of energy are consumed and carbon dioxide (CO<sub>2</sub>) and other greenhouse gases (GHGs) are emitted adding to the concentration of GHG in the atmosphere. However, the fertilizers industry can implement actions directed at the reduction of the GHG emissions per unit of their products, that is the carbon footprint of products. In this paper the results of carbon footprint calculations for selected nitrate and urea fertilizers (ammonium nitrate, urea, ammonium sulphate, urea-ammonium nitrate solution) produced in "ZA PULAWY" company - leading producer of nitrogen fertilisers and chemicals in Poland, are presented. Moreover, the assessment of the potential to reduce the emissions during their manufacturing is also presented. The carbon footprints of selected fertilizers were calculated according to standard ISO 14067:2013 *Greenhouse gases – Carbon footprint of products: Requirements and guidelines for quantification and communication*. The "gate-to-gate" approach was used, where only inputs and outputs associated with the processes within the company site were included. Upstream activities and downstream activities were not part of the study. Total carbon footprint of the company covers a broad range of emission sources. Proposed methodology covers: - actual wear indicators for all components - a breakdown by the emission source - utilization of heat produced by ammonia installations, what reduces the usage of fossil fuels - calculations connected only to process of production (excluding sewage treatment) The carbon footprints were calculated for the processes of ammonia production, nitrogen and sulphur acid production, and finished fertilizers production taking into account the emissions from energy production (of site and onsite) for the years 2007 – 2014. The decrease in the carbon footprints during period 2007 – 2014 for all the fertilizers produced in the "ZA PULAWY" company was observed. The decrease is due to the improvement to the production processes implemented in the company.

**P21****LCI of food products sectors: from field data collection to the big picture**

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The ACYDU project, co-funded by the French National Research Agency (ANR), investigates the environmental, social, economic and territorial impacts of the production system of three emblematic French products under official quality marks: *foie gras* from the South-West area (Protected Geographical Indication), Burgundia and Beaujolais wine (Protected Designation of Origin) and Comté cheese (Protected Designation of Origin). Environmental impacts were assessed through the LCA methodology. The study looks at the agrifood sectors with a broad perspective, i.e. encompassing all steps linked with the products themselves (from agricultural stages to final consumption) but also complementary activities that belong to the sector (research, promotion, etc...). To build the LCI, a methodology deriving from both product and organizational LCA was thus developed and applied. The so-called "functional unit and reference flow" in product LCA was translated as the activity of the food product sector over a production cycle (e.g. a year). The LCI was built using a bottom-up approach in the sense that sub-inventories were first built for each life cycle step and then scaled-up to complete the global LCI at the sector level. Emphasis was put on collection of site-specific primary data to obtain sub-inventories. To be able to scale-up the sub-inventories, it is necessary to establish a mass balance featuring inputs and outputs flows at the sector level and these data are used to put together the global sector model. Primary data sources used for this task are statistics of trade associations and Customs trade data to be the most accurate. Assumptions were made to deal with unavoidable data gaps. This work has therefore led to the development of a methodology that can provide a useful framework for LCA practitioners that would like to study the potential environmental impacts of other agrifood sectors. This type of assessment at the sector level can be used to better understand the environmental significance of agrifood sectors and be a basis to explore the consequences of possible changes to the sectors. The thorough inventory analysis also provides valuable insights for sector stakeholders.

**P22****LCA of urban development projects: coupling LCA and transport simulation tools**

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A life cycle simulation tool was developed to model urban projects including various buildings, streets, green and other public spaces, and networks. This tool, developed in an object oriented approach, associates dynamic building energy simulation and LCA, complemented with modules for open spaces and networks. A set of environmental indicators is evaluated, e.g. resource depletion, energy and water consumption, global warming, waste generation, toxicity. A new urban project brings additional transportation demand. Design choices (buildings program, density and spatial organisation), made in a given urban context, influence mobility characteristics both quantitatively and qualitatively. Transport simulation tools forecast this demand and study its interaction with available offer, drawing consequences on transportation level of service. Coupled with emission models, they allow evaluating local pollution accounting for traffic conditions and vehicles fleet composition. A transportation simulation model was coupled to an LCA tool for district evaluation. The added value of the coupling is to make mobility impact evaluation more specific to local conditions: by using transport model outputs, fuel consumption and direct emissions of private cars cover congestion effects while per-passenger impacts of public modes are adjusted to local ridership and fleet composition. This integrated approach was compared to a reference situation using mobility statistics and ecoinvent v3 generic database. For instance, buses in the studied zone have a carbon footprint per km around twice as high as the generic bus of the ecoinvent v3 database. This multidisciplinary approach allows comprehensive assessment of districts, constituting a decision support in early phases of urban projects. The mobility assessment of a project in the Greater Paris Area is presented to illustrate this integrated approach and the magnitude of impacts per user is compared with impacts related to buildings construction and use. Daily transportation accounts for more than 30 % of the



carbon footprint of the district project. The transport simulation tool allows evaluating effects of urban morphology choices on both energy performance and mobility behaviour. Attributional and consequential LCA modelling is discussed relatively to the objectives of the study and data accessibility.

## P23

### **LCA case study: Tertiary treatment process options for wastewater reuse**

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In the aim to obtain a water quality suited for high-quality reuse from wastewater treatment, a tertiary treatment process (including filtration and/or disinfection) is often necessary. To make a choice between different treatment processes following the conventional secondary treatment of a wastewater treatment plant in the South of France, life cycle analysis (LCA) methodology is used to evaluate their comparative environmental impacts. Five options are studied: 1) sand filtration + storage followed by ultraviolet (UV) disinfection, 2) sand filtration + storage with UV disinfection, 3) ultrafiltration, 4) ultrafiltration and storage with UV disinfection, 5) microfiltration and storage followed by UV disinfection. The chosen functional unit is: "To produce 1 m<sup>3</sup> of water with a quality in compliance with the highest standard of the French reuse directive." ReCiPe method is used to determine environmental impact indicators, combining intermediate approach and damage evaluation. Models for impact evaluation of each option are built by using Gabi software, and two databases: PE international database, and Ecoinvent v2.2. The different options studied can be ranked according to their environmental impact (from the lowest to the highest): ultrafiltration, sand filtration combined with UV disinfection, microfiltration combined with UV disinfection, and ultrafiltration combined with UV disinfection. These results are hardly generalizable, because the study was conducted at pilot scale. In real scale, other materials would be used, that may change the overall environmental impacts of the processes. Hence, further adjustments are to be done to generalise this first approach comparison.

## P24

### **How is carbon footprint of SIAM configuration affected by methane management?**

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Anaerobic systems are used in warm climates to treat municipal wastewaters. A fraction of the generated methane (CH<sub>4</sub>) is present in the effluent and could be emitted into the air by stripping. The novel SIAM technology was studied in terms of Carbon Footprint (CF) (ISO, 2013). SIAM consists of an UASB followed by a preanoxic MBR system, in which the CH<sub>4</sub> of the effluent is used as carbon source for denitrification (Sánchez et al., 2016). Experimental results showed that UASB produced 21.9±1.8 g CH<sub>4</sub> d<sup>-1</sup>, of which 12±1.5% remained in the effluent. Part of dissolved CH<sub>4</sub> not consumed for denitrification was emitted to air in the aerobic MBR compartment. This emission (*stream 2*) as well as the generation of biogas in UASB (*stream 1*) were identified as main contributors to CF. Energy production from *stream 1* and burning of *stream 2* in a torch were analysed. The advantages based on 1 m<sup>3</sup> of treated water as Functional Unit (FU) were demonstrated: 0.21 kg CO<sub>2</sub> eq vs 0.28-0.44 kg CO<sub>2</sub> eq for full-scale aerated MBR and 80% lower than burdens for pilot-scale MBR (Rodriguez-Garcia et al., 2013). Even if *stream 2* was released to air, benefits obtained from energy production from *stream 1* (0.12 kg CO<sub>2</sub> eq) balanced out CH<sub>4</sub> desorption (0.09 kg CO<sub>2</sub> eq per FU), with a CF of 0.30 kg CO<sub>2</sub> eq. Without energy recovery from *stream 1*, CF is doubled up to 0.43 kg CO<sub>2</sub> eq per FU when *stream 2* is directly released to air. Effects of SIAM at the endpoint level complete the picture. Since Human Health Damage (HHD) and Ecosystem Diversity Loss (EDL) were dependent on energy, the optimal aeration and the trade-off between energy use and recovery favoured SIAM. In fact, energy recovery led to remarkable benefits, HHD decreasing from 1.90 to 0.32 DALY per FU while a marked drop in EDL was noticed (248.78 vs 19.98 PDF m<sup>3</sup> d per FU). Reductions up to 80% were found when compared to other MBR, demanding systems in terms of energy and chemicals. Finally, it is important to highlight that the nitrate content of SIAM permeate makes it suitable for irrigation purposes. The option of wastewater reuse together with the low burdens

when compared to conventional aerobic MBR configurations raises SIAM as an environmentally friendly technology. **Acknowledgements** To the Holsia project (CTM2013-46750-R) **References** ISO (2013) ISO TS 14067 Rodriguez-Garcia G. et al. 2013 Cost benefit and environmental Life Cycle Assessment p. 223-261. IWA Sánchez A. et al. 2016 J Chem Technol Biot DOI: 10.1002/jctb.4913

## P25

### **Sustainability assessment of integrated innovative wastewater technologies in Mediterranean tourist facilities (demEAUmed project)**

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The aim of demEAUmed is to demonstrate and promote the integration of innovative water treatment technologies to achieve an optimal and safe closed water cycle in Mediterranean tourist facilities. Water resources are limited and unequally distributed geographically and among the year seasons in Mediterranean regions, with higher pressure during summer. For instance, water consumption per guest has been estimated at 222 L/day in hotels in Spain<sup>1</sup>. So, it is of great importance to achieve a holistic water resource management. DemEAUmed affords the reuse of greywater and wastewater generated in touristic facilities with an integrated approach bringing environmental benefits such as water savings and management carbon footprint reduction. Eight different innovative technologies together with an advanced monitoring, control and decision support system have been integrated and implemented on the demonstration site: Samba Hotel (Lloret de Mar, Catalunya, Spain). These technologies are being assessed through a comprehensive Life Cycle Assessment (LCA), including the life stages of construction and operation of technologies, assessing the impacts for each individual technology and for the demo-site integration. Besides the LCA, a Life Cycle Costing (LCC) is being performed in order to analyse the economic costs and to promote a global sustainable system. A social LCA is also conducted in order to assess the social impacts generated by the project. A comparative analysis is being prepared between the baseline scenario and the scenario with the implementation of demEAUmed. Final results will be extrapolated in a hypothetically situation of implementing demEAUmed solution in different touristic facilities of Mediterranean areas. The expected results are to: Obtain a complete sustainability profile of DemEAUmed solution developed and the different WWT technologies (including environmental, social and economic impacts). Calculate sustainability benefits from the reuse of greywater and wastewater in tourist facilities by complying with water quality requirements and regulations. Account the reduction of costs of wastewater treatment assumed by touristic facilities. Account the reduction of environmental impacts of water management in touristic facilities. <sup>1</sup> Gössling, S., Peeters, P., Hall, M.C., Ceron, J.-P., Dubois, G., Lehmann, V., Scott, D., Tourism and water use: Supply, demand, and security. An international review. *Tourism Management* 33, pp. 1-15, 2012

## P26

### **Dynamic Life Cycle Assessment applied to a wastewater treatment plant construction and operation**

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LCA is a widely used methodology to evaluate products and processes. However, nowadays this methodology does not allow time-dependency consideration over the whole life cycle of a process. Considering that real-world processes are highly dynamic and have variable requirements (raw materials, energy, and transport) during time, neglecting time-dependency might represent an important loss of information and an arbitrary approximation. Wastewater treatment is an important example as the performance of a plant is influenced by the anthropogenic activity that generates the wastewater and the seasonal characteristics. Accordingly, requirements of raw materials, energy and emissions (direct and indirect) vary during time. Between the main studied impacts on LCA, one might find climate change (CC) and toxicity. Traditionally, CC is represented by the Global Warming Potential, based on radiative forcing. However, parameters are calculated at arbitrary time horizons without real consideration of the evolution of the gas emissions from the studied system over time and of the gas dynamics in the environmental compartments. Following, a large panel of methods for toxicity evaluation are available nowadays with USEtox®

being the consensus between them. The objective of this work is to study the influence of using a dynamic LCA methodology applied to a wastewater treatment plant (WWTP). The dynamic LCI was modelled following the method proposed by Tiruta-Barna et al. (2015). It considers the temporal behaviour of the foreground processes emissions (direct emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O in the plant; CO<sub>2</sub>, N<sub>2</sub>O, heavy metals and organic substances from sludge handling), the infrastructure emissions and the supply chain emissions (iron chloride, methanol and electricity). The discussed methodology is then applied to a WWTP with or without anaerobic digestion for sludge with sludge handling by incineration or spreading on farmlands. Comparison between conventional LCA and the dynamic one clearly showed the gain of information when time-dependency is considered. For CC, N<sub>2</sub>O is the most important gas and a highly dynamic behaviour is noticed according to the gas specie. Considering toxicity, heavy metals have the most important impact as they are more persistent (in relation to organic substances that are easier degraded). Finally, results are importantly influenced by the compartment where emissions take place and the following dynamics of the pollutant in the environment.

## P27

### **LCA of energy systems - a comparison of methods**

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Many studies and scientific papers show that life cycle assessment especially for energy supply plays an important role. The environmental impacts of energy consumption are beyond doubt and are further illustrated by the CO<sub>2</sub> emissions trading system. In the literature, different sets of methods, rules or guidelines for determining the environmental effects exist. The guidelines very often have different focus on what to evaluate or what rules to follow. The choice of the best suitable life cycle inventory assessment (LCIA) method for answering a given question is the challenge. There are various problems besides knowing certain methods well enough, not all available methods are known or there is not enough time to examine and compare different methods before starting the actual work on an LCA study. Within this case study various LCIA methods are determined and compared with the focus on using them to perform a LCA study for energy systems. The evaluation has its focus on methods used in LCA studies of energy systems (on technology basis and for the power supply of an entire region). The evaluation is starting with a listing of methods, what is "best practice", what methods are used the most in literature. Next step is a comparison of the methods. Various criteria are defined to provide a systematic in comparison. Therefore requirements for analyzing energy systems are analyzed and defined also drawing special interest in problems, data gaps and weaknesses that can be found in literature. Criteria for the review will be for example: Which impact categories are considered? How to set system borders; lifecycle approach yes / no? How to handle allocation of coproducts (heat and electricity)? Scope; international or regional standard/guideline? How to handle/indicate uncertainties? All this with the focus on applicability to power generation and how the method can be handled and used within the company.

## P28

### **Water utilization of beef supply chain from the Brazilian savannah**

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The increasing demand for animal protein has been raising concerns among consumers, especially, with issues related to the sustainability of production systems. Considering that Brazil is one of the world's leading food producers and exporter, it is necessary to stress the environmental sustainability of its agrifood products. Therefore, it is relevant to know the amount of water used throughout the food supply chain. There are still few studies assessing water usage in beef cattle production comparing biomes and production systems. This study aims to account the water usage to produce one kilo of deboned beef, ready for consumption. The study was conducted with beef cattle reared in the Brazilian savannah biome. The inventory phase included data from water consumed per animals, used for pasture and water used at the slaughterhouse. Results are expected to provide valuable information to stakeholders from the beef supply chain. They could use results to improve beef cattle production and processing at the industry to assure the environmentally friendly production of animal protein. In addition, results are expected to support further studies related to water usage and water footprint in the agrifood sector and the environmental sustainability.

## P29

**A Consistent Framework for Modeling Inorganic Pesticides: Adaptation of Life Cycle Inventory Models to Metal-Base Pesticides**

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Quantifying over the life cycle of a product or service the chemical emissions to the environment in the life cycle inventory (LCI) phase is typically based on generic assumptions. Regarding the LCI application to agricultural systems the estimation of pesticide emissions is often based on standard emission factors (percentages) or dynamic models base on specific application scenarios that describe only the behavior of organic pesticides. Currently fixed emission fractions for pesticides dearth to account for the influence of pesticide-specific function to crop type and application methods. On the other hand the dynamic models need to account for the variability in this interactions in emissions of inorganic pesticides. This lack of appropriate models to estimate emission fractions of inorganic pesticides results in a lower accuracy when accounting for emissions in agriculture, and it will influence the outcomes of the impact profile. The pesticide emission model PestLCI 2.0 is the most advanced currently available inventory model for LCA intended to provide an estimation of organic pesticide emission fractions to the environment. We use this model as starting point for quantifying emission of inorganic pesticides and customize it taking into account the complex chemistry of metals in order to properly reflect the their environmental fate behavior. We identified specific needs for metal-specific pesticides emission modeling looking at the current PestLCI structure and propose an approach for the different metal-related processes and interactions. The proposed framework takes into consideration the speciation of the metals to accurately describe the soil processes (runoff and leaching). The processes involving degradation are assumed not significant for metals and volatilization is only accounted for special cases (i.e. mercury). And finally, a new module of erosion is included in the modified PestLCI model, because the transport of soil particles to which the metals are bound needs to be considered as potential source of emissions to surface water. In conclusion, we provide a starting point to better estimate metal-specific pesticide emission fractions, addressing the issue of inorganic pesticides for inventory analysis in LCA of agricultural systems.

## P30

**Environmental and economic assessment of an eco-innovative Continuous Flow Integrative Sampler (CFIS) for pharmaceutical compounds measurement in waters**

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The increasing concern for the presence of emerging compounds in water bodies has led the European Commission to lay down a strategy that involves the identification and monitoring of priority substances in waters (Directive 2000/60/EC). Water quality is conventionally monitored by spot sampling, although it is a time and workforce consuming approach and no complete information about the concentration of target compounds could be obtained. CFIS-ECOPHARMA is a project co-funded by the European Commission through the Eco-innovation initiative that aims to demonstrate the capability of the Continuous Flow Integrative Sampler (CFIS) for pharmaceuticals continuous monitoring in waters. This device solves the limitations of conventional spot sampling by allowing a time-averaged measurement of target compounds and the improvement of the quantification limits. **Life Cycle Analysis (LCA)** based on **ISO 14040** approach, and **Life Cycle Costing (LCC)** methodologies were used to assess the environmental and economic performance of the CFIS in comparison with conventional spot sampling. The LCA and LCC results were integrated in an eco-efficiency assessment based on the **ISO 14045**. For this study a common scenario for both sampling procedures was defined in terms of site distance, number of spot samples equivalent to CFIS and water body quality. LCA was carried out based on experimental data collected by the CFIS and spot sampling during several field monitoring campaigns. LCC analysis was based on economic data. As an innovative sampling procedure, no previous studies of eco-efficiency have been done for the CFIS and, to the best of our knowledge, neither for conventional sampling. Therefore, this study evaluates the eco-efficiency of both water sampling procedures for the first time.

The transport to the sampling site was considered as a key aspect in the greenhouse gases reduction. From an economic perspective, costs savings were focused on fuel consumption and workforce time.

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## P31

### **Life cycle assessment of steam-thermolysis to recycle carbon fibers from composite waste**

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The global demand for carbon fiber is predicted to rise to 89,000 tons by 2020, therefore an increasing amount of carbon fiber reinforced polymer (CFRP) waste is expected to be generated. Recycling of carbon fibers, a high value added material, from the composite waste offers both environmental and economic incentives for the development of recycling routes. For this purpose, steam-thermolysis has been developed. Steam-thermolysis is a process that combines pyrolysis and superheated steam at atmospheric pressure to decompose the organic matrix of the composite<sup>1</sup>. In order to measure the environmental impacts, a life cycle assessment (LCA) study was carried out to compare a scenario without recycling carbon fiber with a scenario where the carbon fiber is recycled by steam-thermolysis. In this study, the ILCD methodology is used to compare the two systems. Data were collected directly from the pilot process of steam-thermolysis. The chosen functional unit was 2 kg of CFRP. In relation to the system boundaries, only the use phase of the carbon fiber was not taken into account. The results show that the recycled composite with recovery of carbon fibers, brings evident advantages from an environmental point of view. The scenario without recycling generates between 25% and 30% more impact and requires approximately 30% more energy. Carbon fibers production is currently energy intensive<sup>2</sup>, making recycling by steam-thermolysis an attractive waste treatment, which can be avoided with material reuse. Materials necessary for the construction of steam-thermolysis machines are also included in the system boundaries. These materials increase the potential environmental impacts of recycling scenario, especially for the impact categories «Abiotic resource depletion», «human toxicity» and «marine ecotoxicity». The study has shown the comparison of the potential environmental impacts generated by steam-thermolysis against a scenario where the composites are incinerated and landfilled. It has been demonstrated that the recycling of carbon fibers saves raw materials and energy production. The future perspective is to use the approach proposed by the study in the further analysis at an industrial scale. **References** [1] NUNES A. O., *thesis*, Institut National Polytechnique de Toulouse, France, 2015. [2] SONG S. Y., et al., *Applied Science and Manufacturing.*, 2009, **40(8)**, 1257–1265.

## P32

### **Reducing climate impact in steel industry - LCA of a new gasification technology**

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Powder metallurgy is of increasing interest for flexible and efficient manufacturing processes such as additive manufacturing. Pre-processes include annealing at high and controlled temperatures and subsequent reduction processes. Demands for fuel quality and evenness in these processes are high, excluding most solid bio-fuels. Today often natural gas is used as fuel in annealing furnaces whereas coke from hard coal is commonly used as reducing agent. In Swedish steel industry, there is a strong intent to decrease the use of fossil fuels and substitute them with bio-based alternatives. In the project PROBIOSTÅL, a new process for gasification of bio-mass in combination with production of bio coke was studied. The basic idea was that syngas from the gasification process should replace natural gas and that bio coke should replace fossil coal used for reduction in the steel production process. The preconditions for implementing the gasification process to one of the annealing furnaces at a company producing iron powder were examined. To examine if, and under which process conditions this would be beneficial for the environment, an LCA was performed based on model and pilot scale results. The

functional unit was set to 1 tonne iron powder processed in the annealing furnace, and the system was limited to the annealing process. In the study, a number of scenarios for the gasification process, with different degrees of heat integration and bio coke production were studied and compared to a base case. One challenge in this work was how to allocate the environmental impacts from production and processing of the different types of bio-fuels studied. Economic allocation was chosen, but in a future bio-based economy, prices of forestry products will probably change, resulting in a change in allocation factors. To account for this, three different forest-based bio-fuels were studied; bark, pellets and tops and branches. Another challenge was to account for the potential of the technology if it was widely implemented at the steel industry. Scenarios were tested to account for such effects. The results show that for global warming potential, there is a 60% reduction in environmental impact when syngas from gasification is used to fuel the furnace. When also bio coke is produced and the avoided emissions from coal production and use are taken into account, this reduction is more than 90%. The choice of bio-fuel was not of large importance for the outcome.

### P33

#### **Life Cycle Assessment as a tool to assess the sustainability of innovative materials: the case of second generation superconductors tapes**

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A superconductor can be defined as a material which is able to conduct electric current with nearly zero resistance, allowing electrical current flow without any energy loss. Superconductors have several current and potential applications, some examples are: high-speed transports, magnetic-resonance-imagining equipment, ultra-high-speed chips, or alternative energy storage and transmission systems. Current investigations are focused on developing new superconductors materials to allow low cost robust processes, high performance, and reliable manufacturing routes for long length conductors. Besides these goals, concerns about the sustainability of these new materials and processes are increasing, as it happens for all emerging technologies. For this reason Life Cycle Assessment (LCA) should be applied in this promising research field. EUROTAPES is a FP7 European project aimed at the integration of the latest developments into simple conductor architectures for low and medium cost applications with enhanced performance. The EUROTAPES consortium has 20 partners including universities, institutes, technological centers and industrial companies. Within the project, a comprehensive LCA is being developed in order to evaluate the environmental performance of the superconductor tapes and wires developed. The LCA analyses the different substrate metals and the alternative chemicals/physical routes. The final superconductor tapes are complex architectures composed by several layers and buffers, so that the life stages from cradle-to-gate have been defined as: metal substrate preparation, subsequent buffer layers, superconductor layer and top coating. During the first stage of the project, LCA has assessed the different substrates and pilot scale processes in order to provide environmental information for the decision-making process when selecting the best candidates for the final architectures. Preliminary results at pilot scale show environmental benefits from key innovations such as the simplification of substrate preparation processes, the use of chemical deposition techniques as inkjet printing, the use of innovative nanomaterials or the development of sustainable precursor solutions with less hazardous substances. The final LCA calculations will be performed for the up-scale final architectures, with the collaboration of the industrial partners of the project which are currently working in the scaling-up processes.

### P34

#### **Life cycle approach for comparing nano-based textile finishing processes versus conventional textile finishing. ECOTEXNANO project**

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In response to competitive challenges, the textile industry in Europe should improve their competitiveness by ceasing mass production and simple fashion products and concentrating instead on higher value-added sustainable products. The use of nanomaterials is gradually increasing daily due to the new properties addressed by the nanotechnology based products. Such rapid proliferation results in a key

environmental problem due to the lack of knowledge of their health and environmental impacts and subsequent effects on the ecosystem. Within this scope, the overall aim of ECOTEXNANO project is to improve the environmental performance of best innovative solutions that are emerging with regard to technical textiles that incorporates nanoparticles in the textile finishing industry. The project addresses four textile functionalities: soil release, UV protection, antimicrobial and flame retardant; the most representative nanomaterials that are being used in textile finishing processes by functionality have been selected. Environmental, health and safety impacts have been assessed by carrying out a comprehensive Life Cycle Assessment of the manufacturing operations and Risk Assessment of the selected nanomaterials. The analysis has allowed to quantify the environmental impacts of the use of nanomaterials in substitution of bulk substances, and to guarantee that these nanomaterials do not pose risk on workers and environment. Demonstration has been developed into two pilot scale trials (Spain and Italy) in order to provide evidence of best practice in the application of nano-based techniques comparing with the conventional finishing chemicals. The project results provide the textile finishing industry with a user-friendly tool to support the chemical safety assessment of nanomaterials along their life cycle and to bridge knowledge gaps on nanomaterials properties, hazard and exposure. The tool compares nanotextiles and conventional textile finishing products and quantifies the achieved environmental performance and risks improvement. Human health and environmental EU policy such as REACH and CLP Regulation, biocidal products, BREF for textile sector are been analyzed for potential updating coming from the project results.

## P35

### «End of life» treatment environmental impact analysis for a new car back seat

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The End of Life Vehicle (ELV) Directive aims at making dismantling and recycling of ELVs more environmentally friendly. It sets recycling objective 85% of total vehicle weight and 95% for valorisation. In order to reach these objectives is necessary taking to account End of Life impact in new car design and process manufacture. A new process for car back seats was developed and its environmental impact and recyclability were analysed. Two ELV routes were proposed: seats treatment with the entire vehicle or a separate seat treatment after dismantling. A second row back seat from a medium size car was considered in order to analyse ELV environmental impact. This car part is mainly composed by polyurethane foam, fabric and steel. Also some plastic accessories were considered. Two ELV routes were proposed: in first called "business as usual", full vehicle is firstly shredding and then just metal (steel) is recovered. Finally ASR (automotive shredder residue) is incinerated and energy produced should be recovered. In second one, called "seat recycling", a first seat dismantling step is considered, and an independent treatment route for seats is proposed. After seat shredding, steel is recovered. Due to high polyurethane content of ASR, foam recovery and recycling is possible. Remaining ASR is incinerating. Considering 96% recovery rate for steel and 60% for polyurethane, recycling rate for "business as usual" and "seat recycling" route are 65% and 77% respectively, and for 94% and 96% for valorisation. Therefore just valorisation rate for "seat recycling" route fulfil ELV Directive requirements. Environmental life cycle assessment for both ELV routes was performed using SIMAPRO 8.2 and EcoInvent 3.2 database. CLM-IA impact categories were evaluated. Results show an increase of 41% in GHG avoided emissions in End of Life step, considering polyurethane recovery: -7.5 kg CO<sub>2</sub>eq in "seat recycling" route vs. -4.4 kg CO<sub>2</sub>eq in "business as usual" case. In both cases, End of Life step represents around 2-3% of avoided GHG in entire back seat life cycle. Other CLM-IA categories show the same trend, i.e. 21% increase in avoided Ozone layer depletion (ODP), and 56% in Human Toxicity. As a conclusion, a separate seat ELV treatment reduces cars environmental impact and allows fulfilling legislation requirements. Acknowledgments: Special thanks to CDTI for funding DESPEGA project and the partners involved.

## P36

### Application of SLCA in energy generation

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Two pilot studies have been conducted looking into the social impacts along the value chain for

Swedish hydropower and for Nordic wind power trying to apply theoretically developed methods in practice. The aims of the study were to try the methods provided in existing guidelines/handbooks and develop them further to be easier to apply and better suited to identify hotspot areas in the supply chain. Yet, this time focus for deeper investigation was our own operations and 1<sup>st</sup> tier suppliers because of accessibility. To identify hotspots further back in the supply chain material flows were identified and generic data for selected indicators from a database was used. As base for these pilot studies the *Guidelines for Social Life Cycle Assessment of Products* (UNEP/SETAC 2009) and the *Handbook for Product Social Impact Assessment* (Roundtable for Product Social Metrics, 2014) were used. Together with a master thesis work (*Assessing the Social Performance of Products: Developing a Set of Indicators for Vattenfall AB Connected to the International EPD® System*, Welling s., 2013), and discussions with some of the stakeholders, stakeholder groups were selected and due indicators were identified. For the latter the GRI indicators were used as input as well. The challenges we met during the work were a partly immature business in this area - many of the indicators are not measured or extremely difficult to track, also internally. Qualitative material can be collected but quantitative material is more difficult with the selected indicators. In spite of this, more involvement of different stakeholder groups is wanted and needed to be able to elaborate on possible indicators and gain better knowledge of impacts along the value chain. A test was made to use reference values for the chosen indicators, to put the results in a context and the conclusion is that the method for referencing quantitative indicators has to be further developed. Another challenge is how to weigh impact from different streams, where optimally the number of working hours per process is used. This proved to be impossible since this information is not available. There is also a challenge of how to weigh the impact on local communities in the different life cycle stages to reflect the severity of the impact in a good way.

### P37

#### **The work conditions in the Brazilian sugarcane industry: an application of Social Life Cycle Assessment (S-LCA)**

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Brazilian sugarcane production has grown more than 500% in last three decades, setting Brazil as a world leading producer and exporter of sugar and ethanol. Notwithstanding, there are many studies stressing social issues related to working conditions. We used S-LCA in compliance with UNEP guidelines to analyze working conditions in three phases of the sugar cane supply chain in the Mato Grosso do Sul state to the year 2012: Agricultural stage, Ethanol and Sugar production. We use the National Household Sample Survey (PNAD) database and our study covered the production and related processes from the sugar cane supply chain. Results: To the subcategory "Freedom of Association and Collective Bargaining", workers' "rate of unionization" was the indicator adopted. As expected, the lower rate of unionized workers occurred at the agricultural stage (17%). Most of the rural workers enrolled in the cultivation and harvest of sugar cane have a lower education level than those workers working downstream. The higher rate of unionization identified was at the sugar production (40%). In Brazil, the Consolidation of Labor Laws states that the minimum age to work is 14 yrs old, young people up 14 yrs old may work as apprentice under special conditions. Given this, to the subcategory "Child Labour", two range of age was assessed, 5-9 yrs old and 10-13 yrs old. Neither the agricultural nor the industrial sectors studied presented registers of children under 14 working. Concerning the subcategory "Fair salary" we compared the workers mean wage to the national minimum wage to the year 2012, (~ US\$ 338.67), so all three sectors have been paying wages above the national minimum wage. In addition, we were able to observe that the agricultural stage paid lower salaries compared to the industrial stages. To analyze the subcategory "Hours of work" we chose as parameter the national weekly allowance according to the Consolidation of Labor Laws; where the maximum working hours may not exceed 8 h per day or 56 h per week. The sector with the lower weekly working hours was the ethanol production (42 h), followed by sugar production (46 h) and agricultural stage (46 h). Our results showed that the sugarcane supply chain accomplished the Consolidation of Labor Laws regulation to the categories and year studied herein. There are some differences in the same supply chain in relation to



social issues among sectors; e.g. the worst performance of agricultural stage in most subcategories.

## P38

### **Life Cycle Sustainability analysis of municipal solid waste management systems in developing countries. A Brazilian case study.**

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To analyse waste management systems implemented in developing countries, it is need to be able to evaluate them both from a life cycle perspective and from a sustainability perspective, being the Life Cycle Sustainability Assessment (LCSA) methodology the appropriate framework for this purpose. To this end, it is necessary to define a set of indicators able to measure and quantify the sustainable performance of waste management from an economic, environmental and social point of view. In this paper, a set of indicators affecting different stakeholders through the life cycle of a waste management system is proposed and then applied to a case study in the city of João Pessoa, Paraíba (Brasil). João Pessoa is one of the pioneers Brazilian cities in incorporating a door-to-door selective waste collection system. Although this waste collection system has been steadily expanding around the city to nowadays, it has never been analysed from a sustainability perspective. For measuring/quantifying the proposed set of sustainability indicators, different primary sources of information have been considered. On one hand, life cycle inventory data needed for quantifying the environmental and economic indicators have been collected directly from companies and stakeholders involved in the waste management of the city (waste composition, waste collection rates, consumptions of the plants, transports, costs, etc.). On the other hand, information needed for quantifying the social indicators has been obtained from surveys, specifically designed for users and formal/informal workers involved in different stages of the life cycle of the waste management system, and from legislation or national reports.

## P39

### **Resource use assessment of a portable battery recycling system**

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Recycling has been defined as one of the options for sustainable waste portable battery management, which might help to not only prevent the risks of toxics leaching but also achieve raw materials conservation. Therefore, unlike existing studies on waste portable battery management with a main focus on emissions, this case study uses a resource-oriented approach to thoroughly analyze the performance of the waste portable battery collection and recycling system in Belgium, organized by Bebat. The study was conducted at two levels. At the cradle to gate level, the performance of the Bebat collection and sorting system for the mixed waste portable battery in three successive years (2011, 2012 and 2013) was assessed. At the cradle to grave level, the performance of the whole collection and recycling chain of Alkaline and ZnC batteries, representing the two biggest fractions, was analyzed and then benchmarked with an incineration scenario. To gain a comprehensive analysis, three existing life cycle impact assessment (LCIA) methods representing three different aspects of resource consumption were applied i.e., resource accounting (through Cumulative Exergy Extraction from the Natural Environment (CEE-NE)), resource scarcity (through abiotic depletion potential (ADP)) and resource depletion (via impact on the resource cost (RC)). Additionally, a new LCIA method, the criticality-based impact assessment method (CIAM) has been proposed to cover the socio-economic aspects of natural resource consumption. Overall, the results show that in all assessment perspectives, the Bebat collection and sorting system performed best in 2012. Moreover, the collection step mainly accounts for the total burden of the whole system. In the comparison of the two Alkaline and ZnC battery management scenarios, the RC result does not show significant differences. However, the ADP score for the recycling scenario is eight times lower than for the incineration scenario. In accounting for the total resource consumption in

the whole life cycle, the recycling system requires only half of the material criticality, but the CEENE use was 12% higher for the incineration system. These comparisons indicate that the waste portable batteries management system organized by Bebat is less efficient in usage of energy resources but has higher benefits in term of abiotic resource savings, especially metal and minerals saving.

#### P40

##### **Life Cycle Assessment of storm water management systems for Nørrebro, Copenhagen**

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To prevent damages from increasingly severe rain events due to climatic changes, the Copenhagen municipality has developed Cloudburst Management Plans. They specify how runoff can be infiltrated, retained in roads and parks, and discharged above and below the surface. A combination of interacting elements is necessary to attain well-defined flood protection targets. The focus lies on handling water locally, and introducing additional green and blue elements in the city. The environmental impacts of implementing, operating, and decommissioning the Cloudburst Management Plan for the densely populated Nørrebro sub-catchment in central Copenhagen are assessed in this case study. An LCA is performed to compare the plan to a subsurface alternative, using a more conventional approach of discharging and retaining water in underground systems. The functional unit is defined by the flood safety levels, which have to be ensured over a 100 year period, and over the complete catchment of 260ha. This approach is novel, as previous research focuses on single elements of storm water management systems, e.g. the reduction of combined sewer overflows, or the treatment of runoff. The environmental impacts are calculated and normalized in eight different categories using the ILCD method. For the Cloudburst Management Plan, they range between 3 and 18 PE/year, and between 14 and 103 PE/year for the subsurface alternative. The uncertainty analysis highlights opportunities to optimize the system design, but does not change the overall conclusion of the Cloudburst Management Plan being the environmentally preferable alternative.

#### P41

##### **A new method for allocating impacts to products from complex multifunctional processes: An illustration and application to an integrated biorefinery**

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Biorefineries produce multiple marketable products and energy from biomass in the same way petroleum refineries refine crude oil into fuels and chemicals. Biorefineries can contribute to a more sustainable resource supply and to mitigate climate change. To support environmental claims, the impacts of biorefinery products are often quantified by applying life cycle assessment (LCA). The application of LCA requires practitioners to address the allocation problem especially when numerous products are cogenerated. This requires an appropriate method for splitting resource use and environmental impacts among products and coproducts. Substitution can be used to award credits against actual impacts for impacts theoretically avoided, while mass, energy content, and market prices are used as parameters for allocating impacts among the cogenerated products. But neither avoiding allocation, nor the allocation based on physical (or other) relationships works satisfactorily when applied to biorefineries. We developed a hybrid mass and energy (HYMEN) allocation method to computing the share of the environmental impacts of biorefinery products by combining both mass and energy allocation approaches. We used the HYMEN method to allocate the energy use and greenhouse gas emissions within a biorefinery to various biorefining products and coproducts. Finally the results of the HYMEN approach were compared to those obtained from substitution as well as from the mass, energy, and economic-based allocation. The results showed significant differences in the shares of energy use and GHG emissions across biorefinery products. In most cases, the shares of the energy use and GHG emissions estimated

using HYMEN did not differ considerably from those of energy-based allocation. Relative to other allocation methods, the HYMEN approach maintained the ranking of different products within a given biorefinery. This implies it will produce the same prioritization if used to evaluate biorefineries. The HYMEN also revealed some additional energy use and GHG burdens associated with certain biorefining products such as electricity and lime that are otherwise overlooked when mass and energy allocation are used respectively. HYMEN is an attractive and a more reliable method to correctly allocate energy use and GHG burdens to biorefining products in a transparent way. It allows allocating burdens to all products based on their physical properties, thus avoiding risks for litigations.

## P42

### **The Economic and Environmental Assessment in the Design Process: A Decision Support Toolbox conceptualization**

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The research focuses on a Decision Support Toolbox (DST) able to assess the economic and environmental implication during the early stage of the prototype design and development. The Toolbox offers a better support to designers during the development of a product, focusing on both components and full systems. The DST is a set of computer-based tools allowing the assessment of economic and environmental information that are summarized into a calculation sheet. The product's implementation has to be seen as a series of steps. First, each actor involved in the development process (and responsible of a particular component) should be able to use the DST for the definition of best solutions in its area of interest. In the second hand, all the single best solutions should be evaluated both in performance terms (benchmarking and validation step) and in sustainability terms (life cycle optimization step) with the traditional ones, up to define a set of single optimized solutions. Third, single optimized solutions should be put together in a final product configuration. The first method pertaining to the Simulation Toolbox is the functional groups analysis. This procedure allows engineers to better understand the real composition of the final product (or its single components) and how the different elements relate each other. After developed the functional groups diagram, engineers have to acquire all the required data about the product. During this phase the official bill of materials can offer a good starting point, but a direct interview of designers can avoid any sort of misunderstanding. Then, the acquired data can be divided into environmental and economic ones. Environmental data are needed to support the LCA process. Instead, economic data will be inserted into a dedicated spreadsheet for the subsequent LCC analysis. Finally, the data elaboration phase will translate both environmental and economic results into a series of performance indexes that could be useful for a direct comparison of the assessed product (or component) with similar ones in terms of sustainability features. The DST has to be customized in the ELICiT project (ENV-2013-603885, [www.elicit-project.eu](http://www.elicit-project.eu)) for the household refrigeration industry. In particular, the DST has to cope with components and attributes of two different types of technologies: the current one (vapour compression) and the new one (magnetic cooling).

## P43

### **Pragmatic Sustainability Evaluation Tools for Cross-Sector use in the EU Process Industries**

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Many indicators, tools and methods for sustainability assessments exist. However, these vary widely in their sophistication, applicability, maturity and usability thereby limiting broad cross-sectoral implementation. A consistent approach is needed to assess the sustainability impact of products and production processes across the full value chain and enhance the comparability between different available options. This is particularly challenging when it comes to assessing sustainability across industrial sectors sector, or when an innovative technology is assessed and input data are scarce. STYLE (*Sustainability Toolkit for easY Life-cycle Evaluation*) is one of three projects funded through a Horizon2020:SPIRE (*Sustainable Process Industry through Resource and Energy Efficiency*) call to coordinate studies of current approaches. The STYLE project has a specific focus on tools appropriate when an industrial project team

is evaluating options for a resource or energy improvement for their process or product and they need a pragmatic tool to check the broader sustainability implications of each technological solution. Our inventory and classification of existing tools shows that industrialists use a wide variety of tools ranging from in-house spreadsheets through free online tools, to stand-alone, commercially available software packages. An initial screening of the existing tools suggests that the tools currently most appropriate for the STYLE scenario tend to be in-house spreadsheet tools. Our industrial testing of promising tools - *CCaIC, Ecodesign checklist, Ecolizer Ecodesign tool, EPS, Social Hotspot Database, PSILCA, IPIECA Community Grievance Tool, Product Social Impact Assessment Screening Tool, Solvay tools, Tata Steel New Product Development Tool, LafargeHolcim Integrated Value Assessment Tool, and Veolia Water Impact (WiiX) Tool* - highlights strong aspects and limitations in each tool. We assess the rigour and suitability of the tools through scientific validation. Preliminary conclusions includes a mapping of tool types, from qualitative to quantitative, against Technology Readiness Levels, and recommendations for future development of practical tools for sustainability assessment.

#### P44

##### **Tidal Renewable Energy Schemes as Building Blocks in a Low Carbon Society - A Life Cycle Assessment Case Study**

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Large scale tidal renewable energy schemes could play an important role in meeting United Kingdom's CO<sub>2</sub> reduction aims. However, like all hydro power schemes they have a variety of economic impacts and ecological effects on their environment. It is therefore necessary to use models integrating these effects as well as sometimes conflicting requirements of different users and stakeholders in the evaluation and planning process of such projects. In this case study different proposed tidal barrage options on the Severn Estuary have been compared using the LCA software GaBi. While such renewable energy projects could produce the same amount of carbon dioxide neutral electricity as three of the latest type of nuclear power stations, effects of a barrage on water bird and fish habitats and other ecosystem services as well as CO<sub>2</sub> emissions during the building and decommissioning phases have to be taken into account. To evaluate how a tidal barrage could be integrated in a low carbon society scenario all phases of the life cycle have to be taken into consideration. Information from prior input-output studies was used as a base to set up the LCA model. The model implemented then was used to analyze different tidal energy scenarios. With results from this analysis feasible construction and management scenarios can be outlined. The proposed model is likely to assist materially in the understanding and management of tidal energy schemes and their interaction with society and their environment over the whole lifecycle of such projects.

#### P45

##### **System analysis of biogas upgrading using enhanced membrane separation materials**

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Biogas may be upgraded to biomethane, which is a versatile low carbon energy vector with applications in heat, gas grid injection, and transport sectors. An improvement in membrane material separation properties has the potential for reducing fugitive methane emissions, capital investment, and running costs associated with biogas upgrading. This study aims to quantify the scope for improving the environmental and economic life cycle of biomethane production based on improved membrane separation properties. Environmental life cycle of biogas utilisation was measured using global warming potential (GWP) metric, measured in kgCO<sub>2</sub>-equivalent, calculated using UK government carbon factors for electricity, petrol, diesel and natural gas. The GWP of biomethane depends directly on electricity consumption required for gas compression. Improving membrane separation characteristics will reduce the compression required, consequently reducing the electricity requirement of biomethane production. Also considered is the potential for biomethane to displace natural gas or transport fuels (petrol and

and diesel) providing insight into the most affective end-use for biomethane in order to help the UK achieve its 2050 carbon reduction target. Net present value (NPV) was the metric used to quantify system profitability. NPV calculation was based on the difference between production cost and biomethane revenue expected when used as a natural gas replacement (*i.e.* grid injection) in the UK, assuming a 20-year project life. Membrane upgrading mass and energy balances were evaluated assuming the crossflow permeation model for binary gas mixtures with negligible pressure drop. The mass and energy balances allowed calculation of required membrane area used in the costing model, and required electricity supply used in the costing and environmental calculations. The results of the analysis currently being carried out aim to quantify the incremental improvements in membrane separation properties being reported in the literature, in terms of the economic and financial life cycle of biomethane in the UK.

## P46

### Life Cycle Assessment and Net Energy Analysis of Ground-Mounted Photovoltaic Systems, based on the latest inventory data

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Estimates of the current environmental and energy performance of photovoltaic (PV) systems need to be updated in order to reflect the ongoing and constant improvements in terms of their material consumption and energy efficiency systems. This work provides such an update by means of a life cycle (LCA) and net energy (NEA) analysis. PV systems are composed of PV panels and mechanical and electrical balance of systems (BOS) and their life-times include all the manufacturing, installation and operation stages. The examined PV panels are single-crystalline Si (sc-Si), multi-crystalline Si (mc-Si), cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS) – considering each respective production country, adapting the current electricity mix of the grids accordingly, and taking into account each step of the manufacturing chain. The analysed mechanical BOS are fixed-tilt and one-axis tracking. Three irradiation levels are considered in order to provide results applicable to different types of geographical areas (1,000 kWh/(m<sup>2</sup>-yr) as representative of Central-Northern Europe; 1,700 kWh/(m<sup>2</sup>-yr) as representative of Central-Southern Europe; and 2,300 kWh/(m<sup>2</sup>-yr) as representative of South-Western United States). Results show that the environmental profile of photovoltaics continue to improve, and point to CdTe as the best performing technology in every environmental metric, highlighting a remarkable progress of the current generation in comparison with the previous productions (65% over one decade). Global warming potential (GWP) per kWh<sub>el</sub> average out about 30 g(CO<sub>2</sub>-eq), with the lowest values for CdTe at high irradiation (10 g(CO<sub>2</sub>-eq)); acidification potential (AP) shows values between □0.1 and 0.8 g(SO<sub>2</sub>-eq)/kWh<sub>el</sub>; ozone depletion (ODP) ranges from 1 to □7 μg(CFC-11-eq). Cumulative energy demand (CED) per kWh<sub>el</sub> averages 4.0 MJPE/kWh<sub>el</sub>, with the best performance for CdTe (□3.7 MJ<sub>PE</sub>/kWh<sub>el</sub>). The energy pay-back time (EPBT) of PV fixed-tilt installations range from 0.5 years (CdTe at high irradiation) to 2.8 years (sc-Si at low irradiation); and energy return on energy investment values (EROI<sub>PE-eq</sub>) values range □10 up to 60. Finally, one-axis tracking BOS can improve the environmental performance by approximately 10%, depending on the technology and specific local conditions such as irradiation and low ratio of diffuse to total irradiation.

## P47

### Life Cycle Analysis of crystalline silicon photovoltaic (c-Si PV) panels at their end-of-life: energy savings and material recovery

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Given that photovoltaic (PV) system deployment has grown significantly in recent years, with a cumulative global installed capacity of 222 GW at the end of 2015, a large increase in PV waste is projected to emerge globally in the next decade. This means that one of the main future environmental challenges for this sector consists in an effective and efficient process of PV panels decommissioning, in order to reduce waste and waste-related emissions, and in parallel provide advantages in terms of energy use decrease and emission reduction related to virgin material production. At present, the European Union (EU) has adopted PV waste specific regulations and a number of methods and processes to decommission PV panels have been investigated. In this work, we have performed a life cycle analysis of the recovery process of crystalline silicon (c-Si) PV panels at their end-of-life, assuming thermal treatment to separate PV cells from the glass, through the removal of ethylene-vinyl-acetate (EVA). Also, after the latter stage, two alternatives have been investigated:

a) a high-rate recovery scenario, which includes the recovery of glass, silicon, copper (manual separation), and the reuse of the heat produced by the plastic thermal treatment; b) a low-rate scenario, which only includes the recycling of aluminium frames and glass. Both analysed scenarios show environmental improvements in each estimated impact category (especially freshwater eutrophication, human toxicity, terrestrial acidification and fossil depletion indicators). Finally, results highlight as main environmental benefits the recovery of aluminium and silicon, with the consequent decrease in raw silicon extraction.





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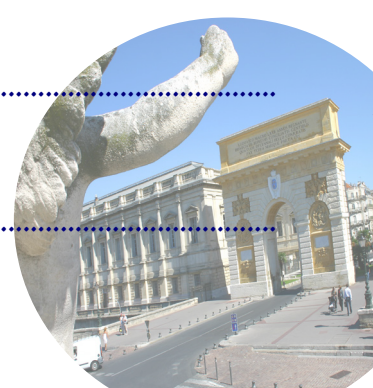
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# NOTES

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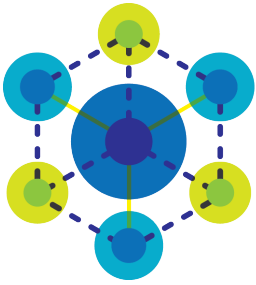
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