POLITECNICO DI MILANO





ACTIVITIES ON LCA: METHODOLOGICAL DEVELOPMENTS AND APPLICATIONS

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Department of Civil and Environmental Engineering
Environmental section - AWARE research group

AWARE

AGENDA

- Politecnico di Milano and DICA
- The "AWARE" research group at DICA
- AWARE research activity
- LCA methodological developments: research in the PEF project and quantification of the avoided materials
- LCA applications: the studies for Regione Lombardia

Politecnico di Milano since 1863

The leading University in Italy for Architecture, Design and Engineering

Politecnico di Milano: enrolled students (a.y. 2017/2018)

Total Students **42,822**

Architecture

Students **7,040**

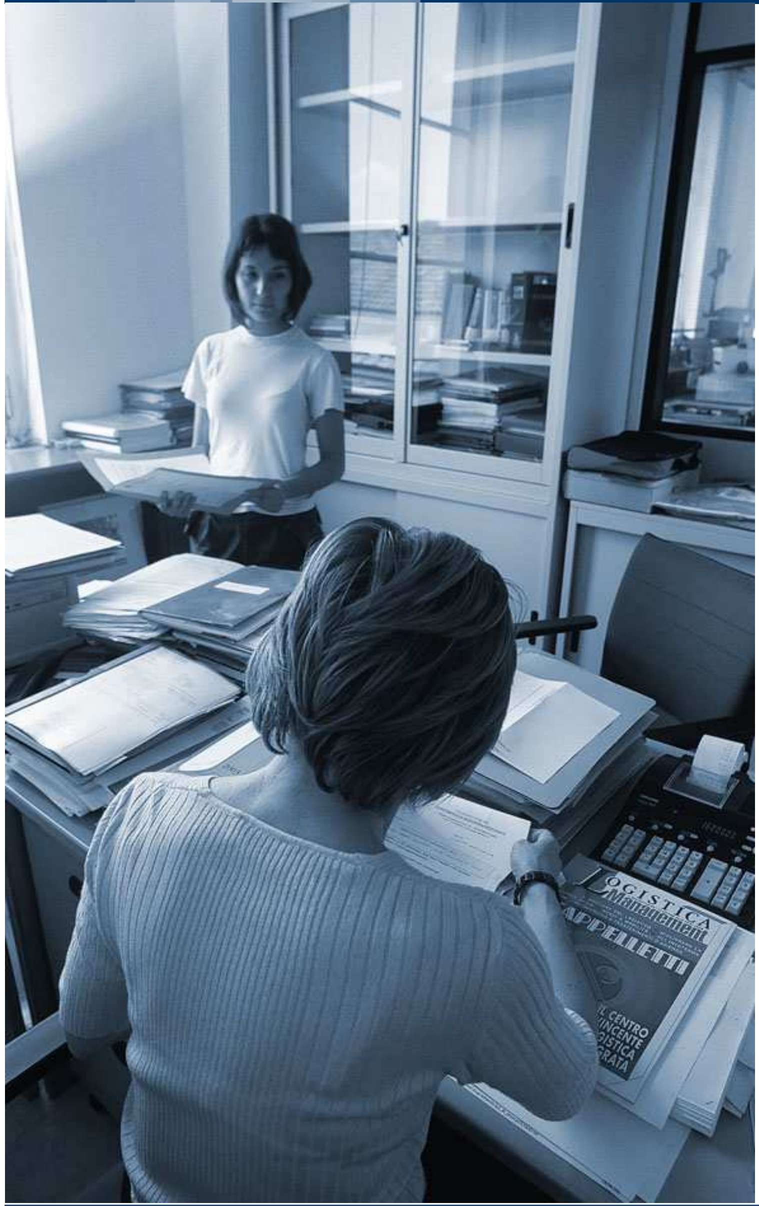
Design

Students **4,156**

Engineering

Students **31,626**

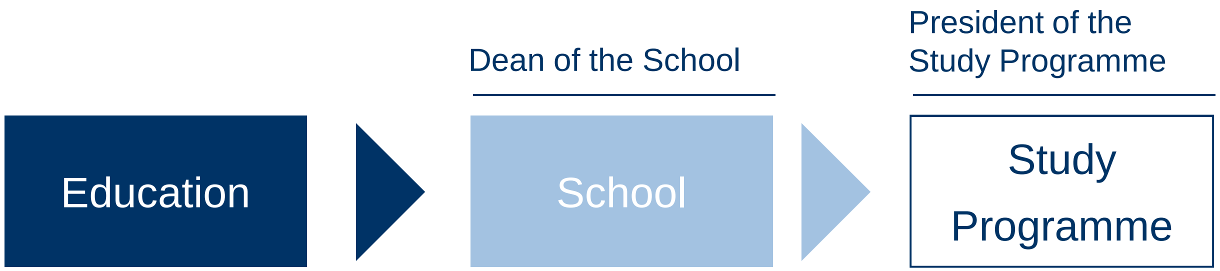
Politecnico di Milano: Human Resources (January 2018)



Professors and Assistant Professors	1,364
Technical and Administrative staff	1,204

For Research:
Each Professor belongs to a Department

For Education:
Each Professor belongs to a Study Course and to a School



Politecnico di Milano: Departments

DEPARTMENTS

- DEPARTMENT OF AEROSPACE SCIENCE AND TECHNOLOGY (DAER)
- DEPARTMENT OF ARCHITECTURE AND URBAN STUDIES (DASTU)
- DEPARTMENT OF ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING (DABC)
- DEPARTMENT OF CHEMISTRY, MATERIALS AND CHEMICAL ENGINEERING "GIULIO NATTA" (DCMC)
- DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING (DICA)
- DEPARTMENT OF DESIGN (DESIGN)
- DEPARTMENT OF ELECTRONICS, INFORMATION AND BIOENGINEERING (DEIB)
- DEPARTMENT OF ENERGY (DENG)
- DEPARTMENT OF MANAGEMENT, ECONOMICS AND INDUSTRIAL ENGINEERING (DIG)
- DEPARTMENT OF MATHEMATICS FRANCESCO BRIOSCHI (DMAT)
- DEPARTMENT OF MECHANICAL ENGINEERING (DMEC)
- DEPARTMENT OF PHYSICS (DFIS)

Sections:

- Structural Design, Diagnostics and Rehabilitation
- Environmental Engineering
- Geodesy and Geomatics
- Hydraulic Engineering
- Mechanics of Materials and Structures
- Structures and Environment
- Transport Infrastructures and Geosciences
- Water Science and Engineering

Air pollution

Monitoring of atmospheric and particulate pollutants (including fine, ultrafine and nano-particulate matter) in ambient air and at the emission sources. Emission inventories for air quality management and planning. Statistical analysis of air quality data. Health risk assessment of toxic and persistent trace pollutants. Control technologies for gaseous and particulate atmospheric pollutants.

Wastewater, drinking water, surface and marine water

Surface water quality management and planning, analysis and evaluation of alternative strategies for reclamation. Monitoring and advanced treatment technologies of both drinking water and urban and industrial wastewater. Enhanced wastewater treatments for industrial and agricultural reuse. Technologies for bioenergy and biofuels production from wastewater, sludge and organic residues.

Solid waste

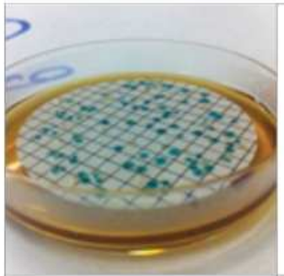
Solid waste characterisation. Strategies for waste prevention and minimisation. Material recycling and biological treatments for the organic fraction. Energy recovery based on dedicated plants and on co-combustion techniques. Analysis and evaluation (according to a Life Cycle Thinking approach) of integrated systems for solid waste management and treatment, with a special focus on material recycling and energy recovery, and to the sustainable disposal of residues.

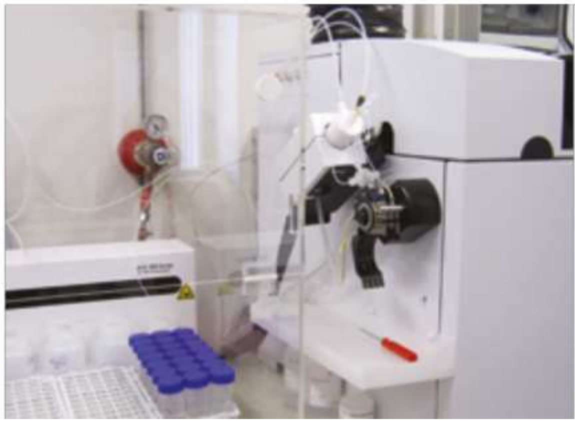
Soil, groundwater and sediments

Experimental studies and modeling of multiphase fate and transport of pollutants in soil and groundwater. Human health and environmental risk assessment of pollutants in soil and groundwater. Relative risk assessment to define priorities among contaminated sites at regional scale. In situ and ex situ treatment technologies for reclamation of contaminated soils and sediments. In situ remediation technologies for groundwater.

Environmental impact assessment

Environmental impact assessment of industrial sites and civil infrastructures. Environmental management and certification systems: management systems (ISO 14001, EMAS), life cycle analysis (LCA), ecological labelling (ISO 14020 - Ecolabel), indicators and indexes (ISO 14031).





THE "AWARE" RESEARCH GROUP AT DICA – POLITECNICO DI MILANO

Assessment on WAste and REsources

Assessment on WAste and REsources

1 associate professor: M. Grosso

1 senior researcher (and lecturer): L. Rigamonti

2 post-doc researchers: L. Biganzoli, S. Pantini

1 PhD student: G. Dolci

5 research collaborators: C. Tua, F. Villa, G. Borghi, E. Leoni. S. Puricelli










Activities are carried out at the Department of Civil and Environmental Engineering (DICA) and at the LEAP laboratory (Piacenza), within the MatER Research Centre, founded in 2011

A strict connection with colleagues from Energy Engineering is established

Assessment on WAste and REsources

www.aware.polimi.it

www.mater.polimi.it

"AWARE" GROUP RESEARCH ACTIVITIES

- Environmental impact of waste treatment plants
  - Macropollutants + toxic micropollutants (heavy metals, organics), especially from incineration plants
- Integrated municipal waste management
  - Material recycling
  - Biological treatments
  - Waste-to-energy plants
- Integration and synergies between material and energy recovery from waste
  - Recovery of waste incineration bottom ash (metals, inert fraction)
- Life Cycle Thinking approach applied to waste management and resource consumption
  - Life Cycle Assessment
  - Life Cycle Costing

Project: Re-use of packaging in Italy (financially supported by the National Packaging Consortium – CONAI)

Aims:

- Identification of the types of reusable packaging
- Qualitative and quantitative characterisation
- LCA of the process of regeneration and single-use vs reusable packaging

Rigamonti L., Biganzoli L., Grosso M. (2016). *"Re-use of packaging in Italy"*. SUM2016 3rd Symposium on urban mining and circular economy, Bergamo, Italy, 23-25 May 2016. Paper n. 16, pp. 1-6.

Biganzoli L., Rigamonti L., Grosso M. (2018). *"Steel drums re-use in the circular economy: an LCA evaluation"*. SUM2018 3rd Symposium on urban mining and circular economy, Bergamo, Italy, 21-23 May 2018

Biganzoli L., Rigamonti L., Grosso M. (2018). *"Intermediate bulk containers re-use in the circular economy: an LCA evaluation"*. 25th CIRP Life Cycle Engineering (LCE) Conference, Copenhagen, Denmark, 30 April – 2 May 2018

"AWARE" GROUP RESEARCH ACTIVITIES: LCA & WASTE PREVENTION ACTIVITIES

- ✓ To verify if (and when) a reduction in waste generation implies also a reduction in the overall environmental impacts
- ✓ To evaluate the environmental convenience of some waste prevention activities included in the National Waste Prevention Programme
- ✓ To evaluate whether the examined waste prevention activities are actually capable of improving, and to which extent, the overall environmental performance of municipal waste management at the regional level

Nessi S., Rigamonti L., Grosso M. (2012). *"LCA of waste prevention activities: a case study for **drinking water** in Italy"*. Journal of Environmental Management, 108, 73-83.

Nessi S., Rigamonti L., Grosso M. (2014). *"Waste prevention in **liquid detergent** distribution: A comparison based on life cycle assessment"*. Science of the Total Environment, 499, 373-383.

Nessi S., Rigamonti L., Grosso M. (2015). *"**Packaging waste prevention activities**: A life cycle assessment of the effects on a regional waste management system"*. Waste Management & Research, 33(9), 833-849.

Dolci G., Nessi S., Rigamonti L., Grosso M. (2016). *"Life cycle assessment of waste prevention in the delivery of **pasta, breakfast cereals and rice**"*. Integrated Environmental Assessment and Management, 12(3), 445-458.

Dolci G., Tua G., Grosso M., Rigamonti L., (2016). *"Life Cycle Assessment of consumption choices: a comparison between disposable and rechargeable **household batteries**"*. International Journal of Life Cycle Assessment, 21, 1691-1705.

LCA & waste prevention activities: conclusions

- ✓ Preventing the generation of waste does not automatically imply a better overall performance (e.g. water from public fountains if car is used)
- ✓ Burden shifting may play a role (e.g. impacts of the tank used in the loose distribution of detergents)
- ✓ Compared to traditional waste management and treatment, the effectiveness of waste prevention activities is strongly dependent on the behaviour of citizens/consumers
- ✓ Prevention activities have different potential to reduce waste and environmental impacts of the overall system

An **LCA-based guidance** is needed to support local authorities wishing to implement waste prevention practices, as well as for citizens to make such practices really effective

LCA METHODOLOGICAL DEVELOPMENTS

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European Commission

ENVIRONMENT

European Commission > Environment > Sustainable Development > Single Market for Green Products

Home | About us | Policies | Funding | Legal compliance | News & outreach

- Single Market for Green Products
- Environmental Footprint pilot phase
  - News
  - The EF pilots
  - Policy background
  - Development of PEF&OEF
- Environmental Footprint transition phase
- Events
- Communicating to consumers
- Questions and Answers

The development of the PEF and OEF methods

DG Environment has worked together with the European Commission's Joint Research Centre (JRC IES) and other European Commission services towards the development of a **harmonised methodology for the calculation of the environmental footprint of products and organisations** (including carbon).

Existing methods and initiatives were taken into account

- For the product angle, the International Reference Life Cycle Data System (ILCD) Handbook as well as other existing methodological standards and guidance documents (ISO 14040-44, PAS 2050, BP X30, WRI/WBCSD GHG protocol, Sustainability Consortium, ISO 14025, Ecological Footprint, etc).
- For the organisation angle, the Reference Life Cycle Data System Handbook (ILCD Handbook), as well as other existing methodological standards and guidance documents (Global Reporting Initiative, WRI GHG Protocol, CDP Water Footprint, ISO 140064, DEFRA guidance on GHG reporting, ADEME Bilan Carbone, etc).

The final methods, called Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF), were published as an Annex to the Commission Recommendation on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. The two methods are tightly interlinked and will have many elements in common.

This version was developed taking into account the results of 2011 road test, the results of the invited expert consultation and of a consultation between Commission services.

LCA METHODOLOGICAL DEVELOPMENTS

Final methodological guide → April 2013

2013-2016 Environmental Footprint (EF) pilot phase

→ three main objectives:

- test the process for developing product- and sector-specific rules
- test different approaches to verification
- test communication vehicles for communicating life cycle environmental performance to business partners, consumers and other company stakeholders

From 27 -> 23 final pilots

- Batteries and accumulators
- Decorative paints
- Hot & cold water pipe systems
- Liquid household detergents
- IT equipment
- Metal sheets
- Non-leather shoes
- Photovoltaic electricity generation
- ~~Stationary~~
- Intermediate paper products
- T-shirts
- Uninterrupted power supplies
- Retailer sector
- Copper sector
- Leather
- Thermal insulation
- Beer
- ~~Coffee~~
- ~~Fish~~
- Dairy products
- Feed
- ~~Meat~~
- Pet food
- Olive oil
- Pasta
- Wine
- Packed water

Deliverables of the pilot phase

European Commission

- A clear Guidance to develop PEFCRs and OEFSRs
- Two updated methods (2013) to carry out PEF and OEF studies
- 21 PEFCRs and 2 OEFSRs covering a variety of sectors and products
- More than 70 models used to define the representative products available for free to any user
- Clear rules to perform PEF/OEF verifications
- About 8000 freely available secondary LCI datasets
- An open source IT tool to perform PEF/OEF calculations for 4 PEFCRs
- E-learning packages in different languages
- Information on the effectiveness of different communication vehicles tested by the pilots and by the Commission

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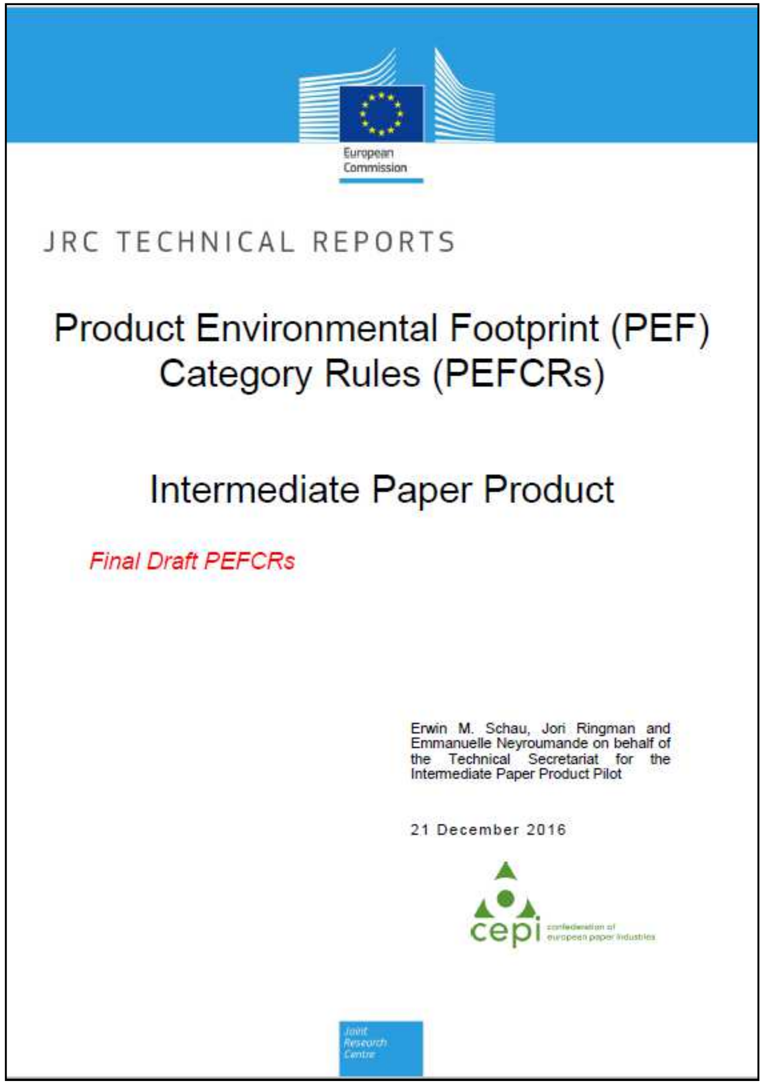
http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

LCA METHODOLOGICAL DEVELOPMENTS: PEF


European Commission

JRC TECHNICAL REPORTS

Product Environmental Footprint (PEF) Category Rules (PEFCRs)

Intermediate Paper Product

Final Draft PEFCRs

Erwin M. Schau, Jori Ringman and Emmanuelle Neyroumande on behalf of the Technical Secretariat for the Intermediate Paper Product Pilot

21 December 2016

cepi confederation of european paper industries

Joint Research Centre

Chair: European Commission, Joint Research Centre (Erwin M. Schau, Rana Pant)
Co-chair: Confederation of European Paper Industries, CEPI (Jori Ringman)
Co-chair: WWF International (Emmanuelle Neyroumande)

- APP (Liz Wilks)
- Cepi ContainerBoard (Gilles Barreyre)
- CEPI Eurokraft (Elin Floresjö)
- China Quality Certification Centre Guangzhou Branch (Hou Jian)
- Chlorine Free Products Association (Archie J. Beaton)
- Copacel (Bénédicte Oudart)
- De Beaufort-Langeveld (Angeline de Beaufort-Langeveld)
- DS Smith (John Swift)
- FEFCO (Krassimira Kazashka-Hristozova)
- Ferrero (Eva Piermario)
- Forest Stewardship Council (John Hontelez)
- Inmetro (Armando Caldeira-Pires)
- Industrial Minerals Association (IMA) - Europe (Roger Doome, Aurela Shtiza)
- Innovhub-SSI (Graziano Elegir)
- Innventia (Malin Kronqvist, Tatjana Karpenja)
- International EPD System (Kristian Jelse)
- International Paper (Marie Claude Ritt)
- Lucart (Sabrina Cosci)
- Lyreco (Nasser Kahil)
- Metsä Group (Eija Saski, Senja Kuokkanen)
- Norwegian University of Science and Technology (NTNU) (Ottar Michelsen)
- PEFC International (Xavier Noyon, Michael Berger)
- Reno De Medici (Lucia Rigamonti (Politechnico di Milano) Thomas Bock, Mino Leo Marucci)
- SCA (Ellen Riise, Pernilla Cederstrand)
- Sequana (Olivier Guichardon)
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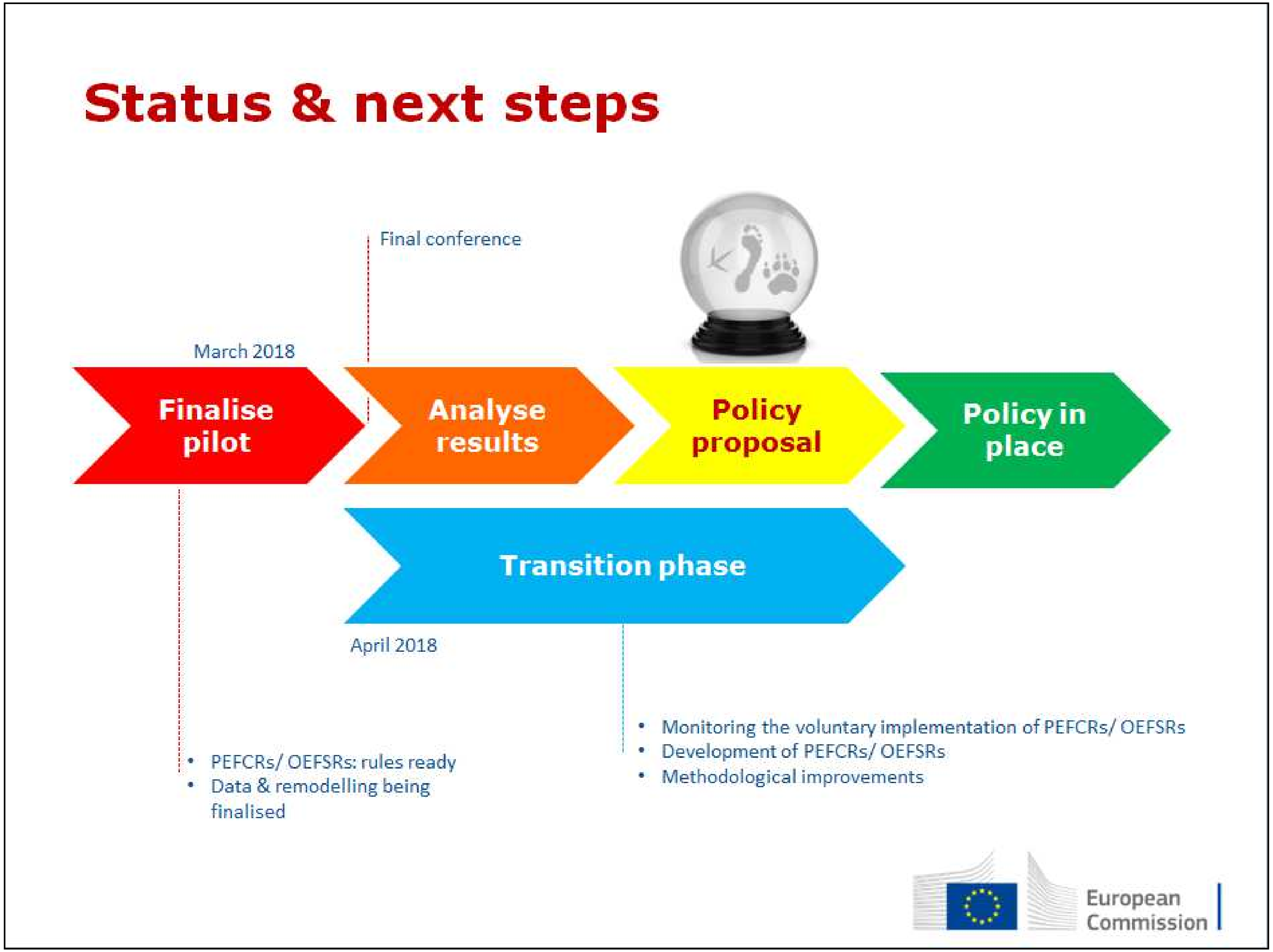
- Solinnen (Philippe Osset, Jad Zoghaïb)
- Steinbeis Papier GmbH (Volker Gehr, Andreas Steenbock)
- Stora Enso (Tuovi Valtonen, Tiina Keskisaari)
- Sustainable value consultancy (Krishna B.M. Manda)
- Swedish Forest Industries Federation (Ingrid Haglind)
- Technische Universität Berlin (Annekatrin Lehmann)
- Tetra Pak (David Cockburn)
- UFIPA (Christophe Girardier)
- UPM (Gabriele Wende)

LCA METHODOLOGICAL DEVELOPMENTS



Dealing with multi-functionality in recycling situations

Dealing with recycling and energy recovery is a challenging aspect. The current PEF/OEF Guides (Recommendation 2013/179/EU) require the use of a formula, commonly known as EoL formula, available in the Annex V of the PEF Guide, to deal with multi-functionality in recycling, re-use and energy recovery situations.

The initial feedbacks received by some pilots participating to the EF pilot phase and the further experience gathered during three years of pilot phase, led the EC to re-consider the EoL formula available in the Annex V and, together with interested stakeholders, to come up with an alternative proposal.

Circular Footprint Formula

Dealing with multi-functionality in recycling situations

a. The Formula

The Circular Footprint Formula is a modified version of formula 2c, as presented in the background document discussed during the 3rd workshop[1].

The final Circular Footprint Formula is:

material $$(1-R_1)E_V + R_1 \times \left(AE_{recycled} + (1-A)E_V \times \frac{Q_{Sin}}{Q_P}\right) + (1-A)R_2 \times \left(E_{recyclingEoL} - E^*_V \times \frac{Q_{Sout}}{Q_P}\right)$$

energy $$(1-B)R_3 \times \left(E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec}\right)$$

disposal $$(1-R_2-R_3)\times E_D$$

Formula 1 – *Circular Footprint Formula (CFF)*

→ Presentation A

Evaluation of the benefits associated with the recycling

Questions:

What is the quality of the waste-derived material compared to the quality of the substituted material?

Is there a real market for the waste-derived material or not?

Waste-management-oriented LCA studies
Secondary material: market and quality

Rigamonti L. – SAM 11 conference – Trondheim – 15 May 2017 7

Waste-management-oriented LCA studies
Secondary material: market and quality



Materials from the recycling of waste = <u>secondary materials</u>

- Is the secondary material really a product or is it a waste?
- If it is a product, what is the secondary material used for? Is it used in substitution of other materials?
- What is the origin of the substituted material?
- What is the quality of the secondary material compared to the quality of the substituted material?

LCA METHODOLOGICAL DEVELOPMENTS

The current practice

Despite such concerns, the vast majority of waste management LCA studies have so far assumed the secondary materials having the same properties as the replaced virgin primary materials (Gala et al., 2015)

→ **1:1 substitution ratio of recycled to virgin materials**

Some researchers and LCA practitioners have introduced a coefficient in order to take into account different characteristics of secondary vs. primary materials at the point of substitution:

- *substitution ratio* (Rigamonti et al., 2009)
- *quality factor* (Gala et al., 2015)
- *quality-correction factor* (Schrijvers et al., 2016a)
- *quality ratios* (Q_S/Q_P) in the Circular Footprint Formula
- *market substitution* (Christensen et al., 2009)

mater
materia & energia da rifiuti
materials & energy from refuse

The replacement coefficient

"replacement coefficient": the coefficient quantifying the amount of primary material that can be replaced by one unit of waste-derived material at a certain point (i.e. the point of substitution) of the recycling chain*

Replacement coefficient R = Q * M

Q = coefficient that takes into the quality of the waste-derived material compared to quality of the primary material, at the point of substitution. Its value varies between 0 and 1. This coefficient represents to what extent the inherent properties of the material are kept in recycling activities.

M = coefficient that takes into account the existence of a market for the waste-derived material, i.e. it is 0 if there is no market, it is e.g. 0.5 if only 50% of the waste-derived material has a market, it is 1 if all the material is used in the market.

*case where the waste-derived material replaces the same virgin material, either in the same application or in a different application, but replacing the same primary production route

LCA METHODOLOGICAL DEVELOPMENTS

The replacement coefficient

Why coefficient M?

Because the existence of a market depends:

- on the quality of the waste-derived material (considered in coefficient Q), e.g. if the quality of the waste-derived material is low, this may be used only in certain applications that alone are not able to absorb all the produced material
- on the diffidence and the lack of knowledge on the quality of the waste-derived material by the potential users: cases may exist where the quality of the waste-derived material is good, but the market is not developed due to the cited reasons

Coefficient M can be calculated considering the percentage of the waste-derived material actually sold by the producer out of the total waste-derived material produced.

The replacement coefficient

Other possible formulation of the replacement coefficient (indeed already present in literature: Schrijvers et al., 2016b):

R = P

P = market-price ratio of the waste-derived material to the superseded primary material. It varies between 0 and 1. In some cases it can be even higher that 1

The replacement coefficient

$R = Q * M$

Approach based on technical consideration (e.g. technical properties, maximum number of recycling cycles), but at the same time it includes the fundamental information about the actual use of the secondary material

Weakness: the calculation of coefficient Q involves subjective choices on which technical property to consider for correction

$R = P$

Approach based on economic considerations but at the same time it implicitly includes information about the quality of the secondary material (in fact, if the quality is really low, the market-price ratio will be near to zero)

Weakness: the market-price ratio can vary over time and therefore the LCA has a limited temporal validity

If data are available, we recommend to calculate the replacement coefficient according to both formulations and then to take the lowest value. The other one might be used in a sensitivity analysis.

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The replacement coefficient

To calculate the amount of displaced primary material, the replacement coefficient shall be multiplied by the amount of waste-derived material at the point of substitution

when the point of substitution is at the end of the recycling chain:

Parameter	Value
Sorting efficiency	90%
Reprocessing efficiency	85%
Q (quality)	0.83
M (market)	1

collected material: **1000 kg**

↓

secondary material:
1000 kg * 0.9 * 0.85 = 765 kg

↓

avoided primary material to be modelled in the LCA =
765 kg * 0.83 * 1 = **635 kg**

LCA METHODOLOGICAL DEVELOPMENTS

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Conclusions and perspectives

- ✓ The replacement coefficient should be considered in any waste-oriented LCA study where the benefits of the recycling have to be evaluated.
- ✓ A consistent quantification of the replacement coefficient allows improving the modelling of the substituted primary materials in recycling processes.
- ✓ In this way the quality and robustness of conclusions and recommendations of waste-management-oriented LCA studies can be improved.

Grosso M., Rigamonti L., Niero M. (2017). “Circular economy, permanent materials and limitations to recycling: Where do we stand and what is the way forward?”. Waste Management & Research, 35(8), 793–794. (Editorial)

Rigamonti L., Niero M., Haupt M., Grosso M., Judl J. (2018). "Recycling processes and quality of secondary materials: Food for thought for waste-management-oriented life cycle assessment studies". Under review in Waste Management

APPLICATIONS:
LCA & REGIONE LOMBARDIA

Italy:

Inhabitants (2016):

60.6 million

Surface: 301,340 km²

201 inhabitants/km^2

Lombardia:

Inhabitants (2016):

10.0 million

Surface: 23,861 km²

419 inhabitants/km^2

GERLA project: GEstione Rifiuti in Lombardia – Analisi del ciclo di vita (Integrated waste management in Lombardia – Life cycle assessment)

Life cycle assessment was selected by Regione Lombardia as a strategic support decision tool in the preparation of its new municipal waste management plan. The goal was to use the life cycle thinking approach to assess the current regional situation and thus to give useful strategic indications for the future waste management.

Duration: October 2010 – December 2012

LCA applied to an integrated municipal solid waste management system

Rigamonti L., Falbo A., Grosso M. (2013). *"Improving integrated waste management at the regional level: the case of Lombardia"*. Waste Management & Research, 31(9), 946-953.
Rigamonti L., Falbo A., Grosso M. (2013). "*Improvement actions in waste management systems at the provincial scale based on a life cycle assessment evaluation".* Waste Management, 33, 2568-2578.

LCA & REGIONE LOMBARDIA

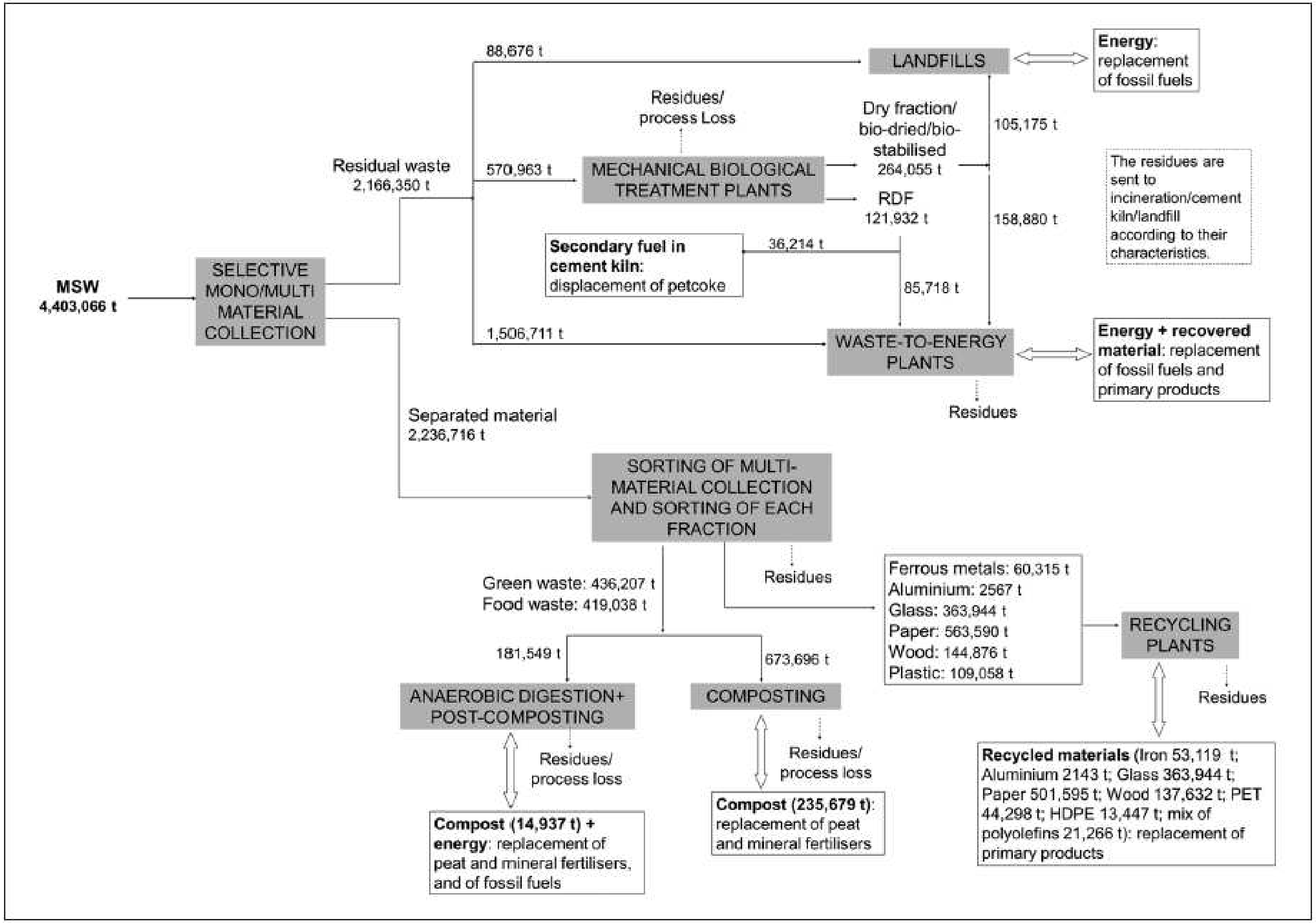

Figure 2. Flow diagram of the municipal waste management system implemented in Lombardia Region in 2009: activities with a positive impact on the environment are in grey boxes, while those that produce avoided impacts are in white boxes. MSW: municipal solid waste; RDF: refuse-derived fuel; PET: polyethylenterephthalate; HDPE: high density polyethylene.

LCA of WEEE (Waste Electrical and Electronic Equipment) management system implemented in Lombardia region

R1: heaters and refrigerators

R2: large household appliances

R3: TV and monitors

R4: small household appliances

R5: lighting equipment

Biganzoli L., Falbo A., Forte F., Grosso M., Rigamonti L. (2015). *"Mass balance and life cycle assessment of the waste electrical and electronic equipment management system implemented in Lombardia Region (Italy)"*. Science of the Total Environment 524–525, 361–375

Rigamonti L., Falbo A., Zampori L., Sala S. (2017). *"Supporting a transition towards sustainable circular economy: sensitivity analysis for the interpretation of LCA for the recovery of electric and electronic waste"*. International Journal of LCA, 22, 1278-1287

LCA OF THE CONSTRUCTION AND DEMOLITION (C&D) WASTE MANAGEMENT SYSTEM IMPLEMENTED IN LOMBARDY REGION

→ Presentation B

THANK YOU FOR YOUR ATTENTION!

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