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Research perspectives in eco-design – Additional material

Harrison Kim¹, François Cluzel², Yann Leroy², Bernard Yannou², Gwenola Yannou-Le Bris^{3,2}

¹ Department of Industrial and Enterprise Systems Engineering (ISE),
University of Illinois at Urbana-Champaign, USA

² Laboratoire Genie Industriel (LGI), CentraleSupélec, Université Paris-Saclay,
Gif-sur-Yvette, France

³ UMR GENIAL, AgroParisTech. INRA, Université Paris-Saclay, Massy,
France

Abstract: This report provides additional material to the authors' publication "Research perspectives in eco-design" (submitted to *Design Science*, April 2019). It gives a detailed description of the ten case studies used in the paper to support the authors' analysis and recommendations.

Keywords: Sustainability, eco-design, economic impact, environmental impact.

Name	Case 1: Aluminium substation
Author	François Cluzel, Bernard Yannou, Yann Leroy
Project description	
PhD thesis of François Cluzel (2009-2012). Collaboration between Alstom Grid (Power Electronics Massy unit) and CentraleSupélec. Supervised by Bernard Yannou, Yann Leroy and Dominique Millet.	
Product/system description	
<p>The diagram illustrates the energy and material flows in an AC/DC conversion substation for an aluminium smelter. It starts with 'High voltage AC energy 900 MW' entering the 'AC/DC conversion substation'. From there, 'DC energy' is sent to the 'Aluminium smelter', which produces 'Aluminium 360,000 t/year'. The process also involves 'Alumina' input to the smelter. On the substation side, 'Initial equipments' (Electrical: 3,000 tons, Civil eng.: 6,000 tons) and 'Additional equipments' (Spare Parts, Transport failures, Maintenance, Updates & Revamping, ...) are shown. 'Electrical losses 8 kW' are noted. 'Exploitation and end-of-life wastes' include 'Metals: 2,500 tons', 'Concrete: 6,000 tons', and 'Transformer oil: 500 tons'. 'Reused equipments' are also indicated.</p>	<p>An AC/DC conversion substation for aluminium smelters is a large electrical system that convert alternative current to direct current usable for aluminium electrolysis. Substations are characterized by:</p> <ul style="list-style-type: none"> • High number of subsystems and components • Operation phase very uncertain (30-40 years) • End-of-life almost unknown • Closely linked to the macro-system (aluminium smelter) • Each substation is unique • The subsystems come from different companies
Pictures	
<p>An aerial photograph of an industrial facility, likely an aluminium smelter or substation. The image shows several large, interconnected buildings with grey roofs and yellow accents. There is extensive piping, walkways, and structural elements visible. The facility is situated in an open area with some greenery in the background.</p>	

Example of an aluminium substation
Stakeholders
<pre> graph LR subgraph Alstom_Grid [Alstom Grid] A[Alstom Grid PEM] B[Other Alstom Grid units] A --> B end S([Suppliers]) --> A S --> B A --> T([Transport]) A --> AP([Aluminium producers]) T --> AP </pre>
Boundaries
<p>Boundaries of the study were limited to the Alstom Grid scope (see on the stakeholders' network above). Unfortunately it was not possible to include suppliers and clients in the study.</p> <p>Concerning LCA, the studied system was the substation from the connection with the HV network to the connection with the plant (busbars), on the entire life cycle.</p>
Objectives
<p>The general objective objective was to develop and implement an adapted framework to eco-design complex industrial systems, through three research questions:</p> <ul style="list-style-type: none"> • How to eco-design complex industrial systems? • How to assess the environmental performance of complex industrial systems? • How to generate and select a powerful eco-innovative R&D projects portfolio for complex industrial systems?
Life cycle thinking
<p>All life cycle phases considered</p>
Sustainable aspects/indicators
<p>Environmental : LCA impacts with Simapro/Ecoinvent/ReCiPe, and qualitative assessment based on the eco-design strategy wheel axes for the eco-innovative projects assessment (scores from 0 to 5 on each of the 8 axes, based on maturity scales)</p> <p>Economic : qualitative assessment (scores from 0 to 5) of the eco-innovative projects through some indicators as Return on Investment for Alstom Grid and Cost reduction for the clients</p> <p>Social : Not taken into account</p> <p>Other : Other qualitative indicators (scores from 0 to 5) were taken into account to assess the eco-innovative projects :</p> <ul style="list-style-type: none"> • Feasibility: ease of implementation in terms of time and resources, technical feasibility in terms of knowledge, internal level of control (is the company able to internally manage the entire project?) • Customers' values: avoidance of risks, improvement of service quality, improvement of image
Results
<p>Research:</p> <ul style="list-style-type: none"> • An adapted methodology to eco-design complex industrial systems


- An adapted model to perform an upstream LCA of a complex industrial system
- Adapted processes and tools to identify a portfolio of eco-innovative R&D projects

For the company:

- LCA results for a substation
- A balanced portfolio of 9 promising eco-innovative R&D projects

References

- Cluzel, F., Yannou, B., Millet, D., Leroy, Y., 2015. Eco-ideation and eco-selection of R&D projects portfolio in complex systems industries. *Journal of Cleaner Production* In press. doi:10.1016/j.jclepro.2015.08.002
- Cluzel F., Yannou B., Millet D., Leroy Y., "Exploitation scenarios in industrial system LCA", *The International Journal of Life Cycle Assessment*, 19, pp 231-245, 2014, DOI: 10.1007/s11367-013-0631-z.
- Cluzel F., Yannou B., Leroy Y., Millet D., "Proposition of an adapted management process to evolve from unsupervised LCA of complex industrial systems towards an eco-designing organization", *Concurrent Engineering: Research and Applications*, 20 (2), pp 111-126, 2012, DOI: 10.1177/1063293X12446663.
- Cluzel F., "Eco-design implementation for complex industrial systems - From scenario-based LCA to the definition of an eco-innovative R&D projects portfolio", thèse de Doctorat, Ecole Centrale Paris, Châtenay-Malabry, France, 2012, <http://tel.archives-ouvertes.fr/tel-00760580>.

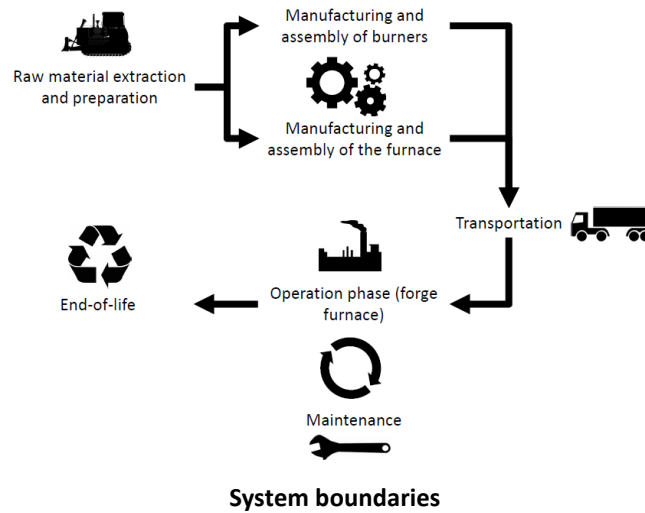
Name	Case 2: Forge Furnace
Author	Yann Leroy, François Cluzel
Project description	
Collaboration between CentraleSupélec and Fives Group.	
Product/system description	
<p>The paper deals with a multi-scale systems including burners for a forge furnace and the forge furnace.</p> <p>3 alternatives solutions of burners for a forge furnace are compared (A cold air system, an oxy-fuel system and a regenerative system)</p> <ul style="list-style-type: none"> (i) A generic LCA is performed to assess environmental performances of the three solutions (ii) An integrated evaluation is then performed including both environmental issues, economic issue and clients' expectations for four different locations across the world: United States, France, Germany and Japan. The economic evaluation is performed through Capital Expenditure (Capex) and Operational Expenditure (Opex). (iii) The different countries were selected because of their specific energy mix and fuel accessibility that impact the environmental and economic performances. (iv) Finally, results are combined with clients' profiles to identify the most promising solution in a specific context. 	
Pictures	
	
Example of a forge furnace	
Stakeholders	
<ul style="list-style-type: none"> - Fives Industries. Provider, designer and installer of forge furnace burners - Operating company (Clients) 	
Boundaries	
<p>Multi-scale approach:</p> <ul style="list-style-type: none"> - Three types of burners - Environmental and economic evaluation - 4 countries with their own energy mix (and fuel prices allocation) <p>Most of data were gathered from industrial case study. Information related to fuel prices were extracted from national statistics.</p>	

Objectives

The main objectives were to evaluate and compare the environmental and economic performances of three different technological solutions for the forge furnace burners.

Identify the best solution according to the plant location and its specific context (energy mix, fuel prices, clients' expectations)

Life cycle thinking



All life-cycle phases considered

Cradle-to-grave perspective

Sustainable aspects/indicators

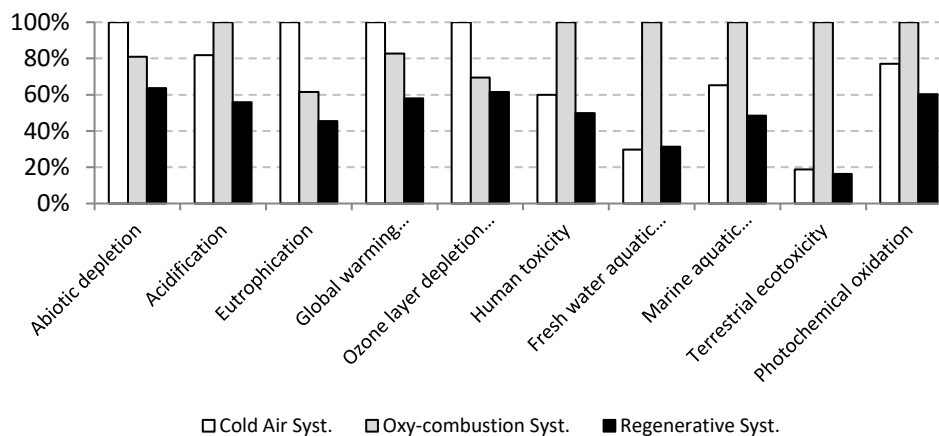
CML 2000 V2 characterization method. The ten following environmental impacts categories are monitored *Abiotic depletion, Acidification, Eutrophication, Global warming, Ozone layer depletion, Human toxicity, Fresh water aquatic ecotoxicity, Marine aquatic ecotoxicity, Terrestrial ecotoxicity and Photochemical oxidation.*

Economic: Capex, Opex and ROI are considered – Opex essentially refer to the price and accessibility of energy resources

Social: N/A

Other: Integration of clients' expectations (including environmental awareness)

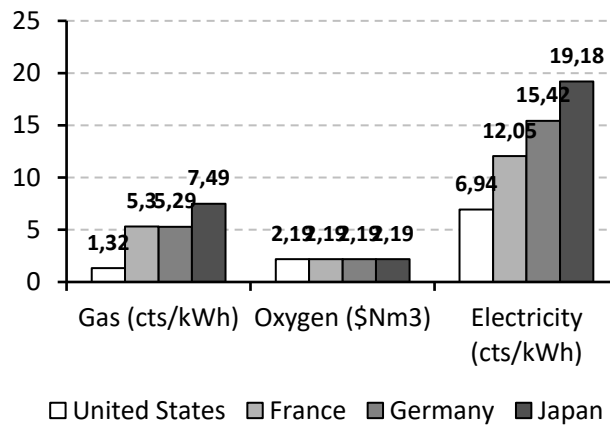
Results



Comparative LCA of three burner technologies for a location in United States

Life cycle Phases	Cold air Syst.	Oxy-combustion Syst.	Regenerative Syst.
Manufacturing	[0.1-15.5%]	[0.2- 4.6%]	[0.2-15.2%]
Transportation	[0.1-0.8%]	[0.1- 1.0%]	[0.1-1.3%]
Operation	[92.4-99.9%]	[97.7-99.8%]	[85.4-99.7%]
EOL	[-8.5- -0.1%]	[-2.7- -0.1%]	[-1.2- -0.1%]

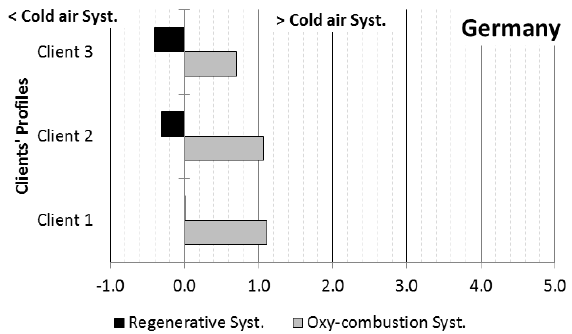
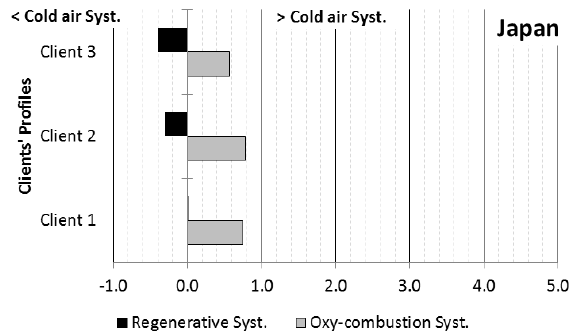
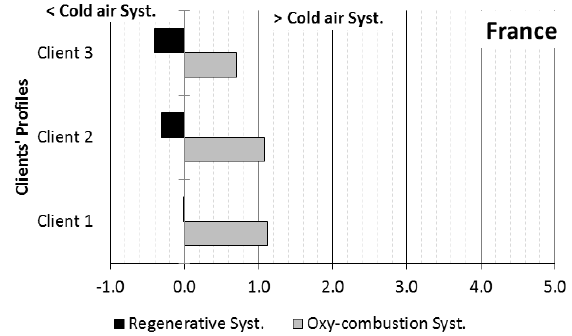
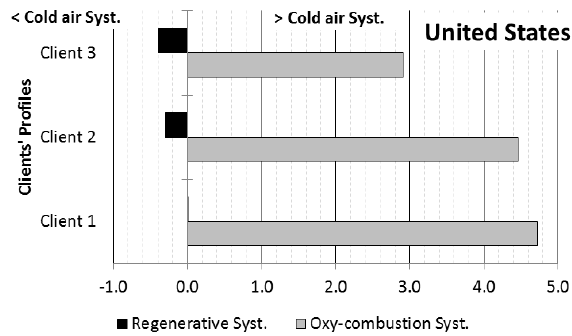
Range of contribution to environmental impacts in respect with the Life Cycle Phase (United States location)



Prices of energy sources according to the operational location

Parameter	Client 1	Client 2	Client 3
Capex	10	10	10
Opex	5	10	10
Global warming potential	2	5	10
Ozone layer depletion	0	2	5
Human toxicity	0	2	5
Fossil depletion	0	2	5
Recycling/reuse	0	5	10

The three clients' profiles considered



Results based on the final single score for the three clients' profiles, the three alternatives systems and the four locations. The Cold Air System is taken as reference.

- Environmental and economic comparison of the three technological solution
- Performance measurement according the plant location
- Integration of resources availability and accessibility
- Inclusion of clients' expectations

References

Yann Leroy, François Cluzel, Guillaume Lamé. Comparing Sustainable Performance of Industrial System Alternatives by Integrating Environment, Costs, Clients and Exploitation Context. *ASME 2014 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference - IDETC/CIE 2014*, Aug 2014, Buffalo, New-York, United States.

Name	Case 3: Automotive axle
Author	Harrison Kim
Project description	
Collaborative research project between Inha University and University of Illinois	
Product/system description	
<p>Background: An emerging market (South Korea) sees a new opportunity for remanufactured automotive part to achieve sustainability and environmental benefit. The government may provide economic incentives to encourage use of remanufactured automotive parts over new ones. The research provides what level of economic incentive is reasonable to insure both economic and environmental benefit.</p>	
<p>A framework to assess both environmental and economic impact of automotive part replacement in an emerging market (South Korea):</p> <ul style="list-style-type: none"> • Automotive part remanufacturing is new and emerging in Korean automotive market. • Part under consideration: constant velocity (CV) joint • Data for number of cars that require part replacement is not known. • Data for number of cars sold is available. • Research question: how much economic incentive (or subsidy by government) should be provided to encourage CV joint replacement with reman part (not new)? 	
<p>Process:</p> <ul style="list-style-type: none"> • Step 1: Analyze the remanufacturing process of CV joint (Figure 1). • Step 2: Estimate demand (i.e., required reman parts) based on vehicle sales data. • Step 3: Assess the environmental impact for new and reman parts. • Step 4: Conduct sensitivity analysis to reflect market preference changes. 	
<pre> graph TD subgraph Remanufacturing_process [Remanufacturing process] A[core collection] --> B[cleaning (external parts)] B --> C[disassembly] C --> D[cleaning (inner parts)] D --> E[inspection / sorting / replacement] E --> F[reconditioning] F --> G[assembly] G --> H[test] H --> I[distribution] E -.-> J[disposal] end </pre>	
Fig. 1 Remanufacturing process of CV joints	
Pictures	
<p>A regular inspection of vehicle is conducted according to the maintenance schedule. Once the damage to the CV joint is identified, the owner has two options for replacing damaged CV joint – new vs. reman. Gamma in the Figure 2 indicates the probability of damaged CV joints identified during regular maintenance inspection. Alpha and beta note preferences for new and reman CV joints.</p>	

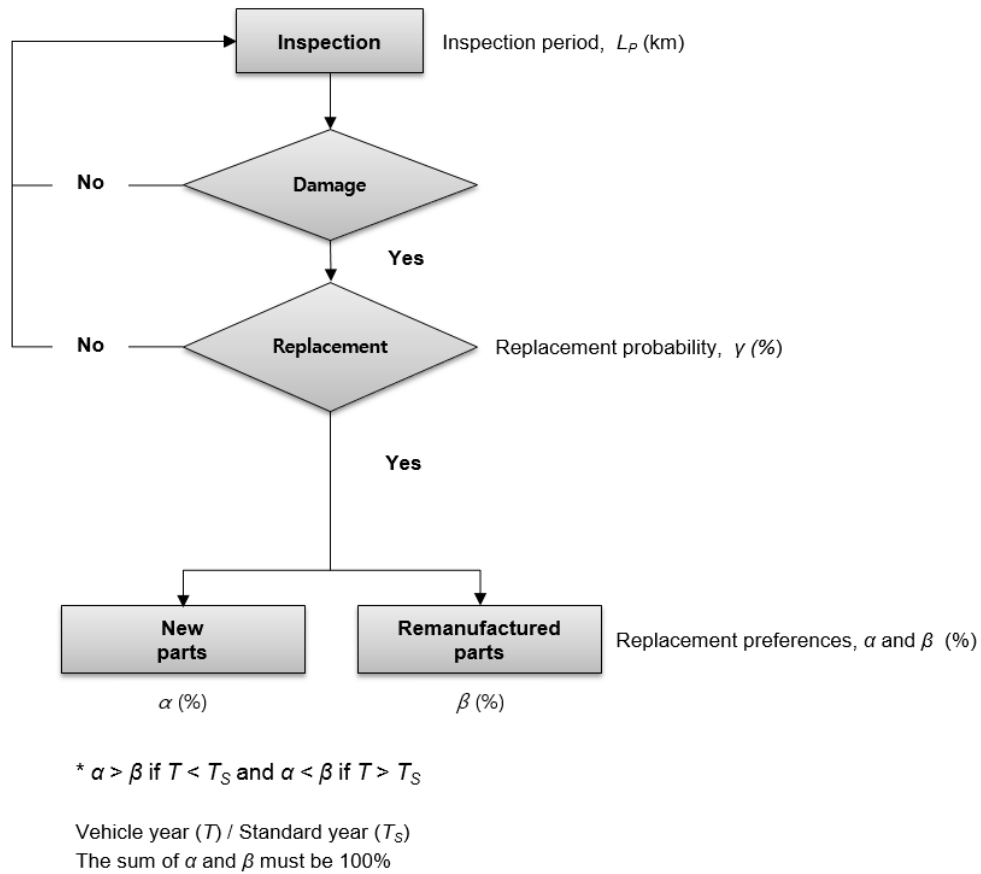


Fig. 2 Framework of CV joint replacement

Stakeholders

- Consumer (owner of vehicle): choice between new and reman CV joint replacement part
- Government: subsidize credit for the reman product
- Manufacturer: evaluate whether reman business is a viable business option under the subsidy scenario; need to estimate correctly how many replacement parts would be needed

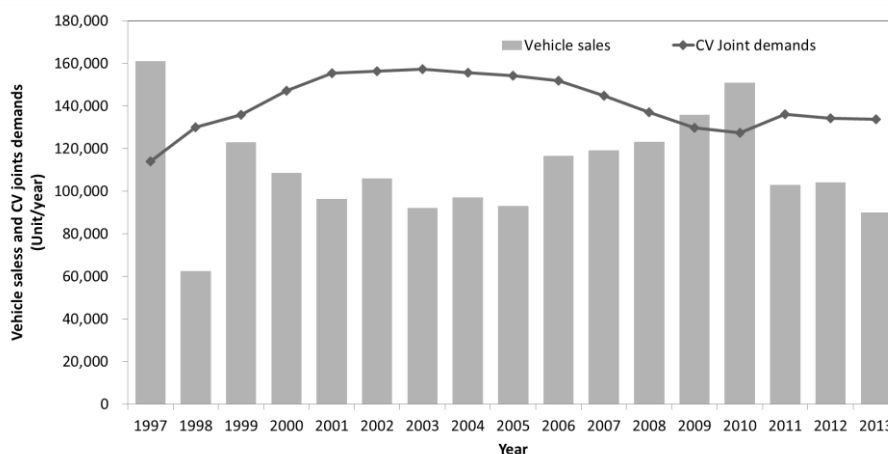


Fig. 3 The demand of CV joint replacements with respect to vehicle sales

Boundaries

- Market data was collected for a specific region/county (South Korea).
- Vehicle type is restricted to a midsize car category that is most popular.

- Critical ownership year (5 years) was introduced to reflect changing preference of new vs. reman. Owners of older vehicles tend to adopt reman CV joints.
- For an automotive vehicle, candidates for reman replacement parts are alternator, starter, CV joint, A/C compressor, injector, brake caliper, shock absorber, lower control arm, turbo charger, and clutch cover.

Objectives

The objective of the project is to develop a framework to assess both economic and environmental impact and their correlation for an automotive part replacement market. The research aims at identifying what level of economic incentive should be provided to encourage remanufactured part use for a regular maintenance and replacement of a major automotive part. The study entails the following tasks:

- Calculation of economic and environmental impact based on estimated demand of replacement parts.
- Pricing of reman part compared to that of a new part to counter any loss of profit due to lower price of reman products.

Life cycle thinking

The replacement part is identified from the regular maintenance of automotive vehicles. For the part itself, all stages of lifecycle were considered.

Sustainable aspects/indicators

Environmental : LCA impact assessment was performed to generate impact scores (EI99 or ReCiPe) for new and reman CV joints.

Economic : Profitability was calculated based on estimated demand of replacement parts from the vehicle sales data.

Social : N/A

Other : N/A

Results

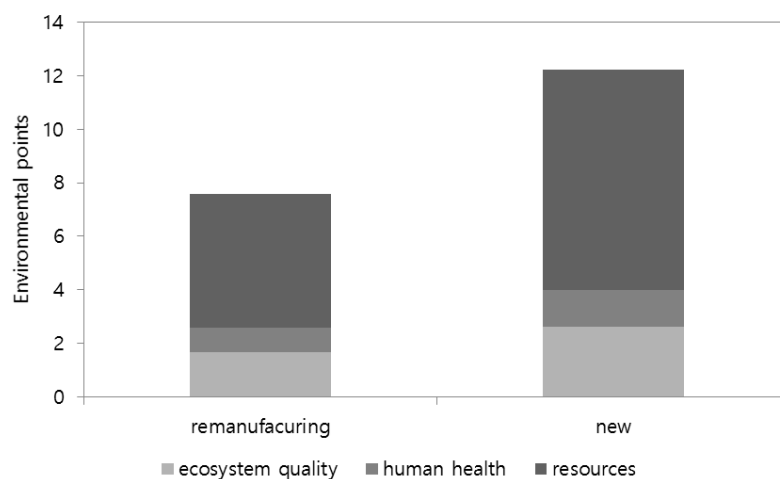


Fig. 4 Environmental impact point of CV joints based on ReCiPe method

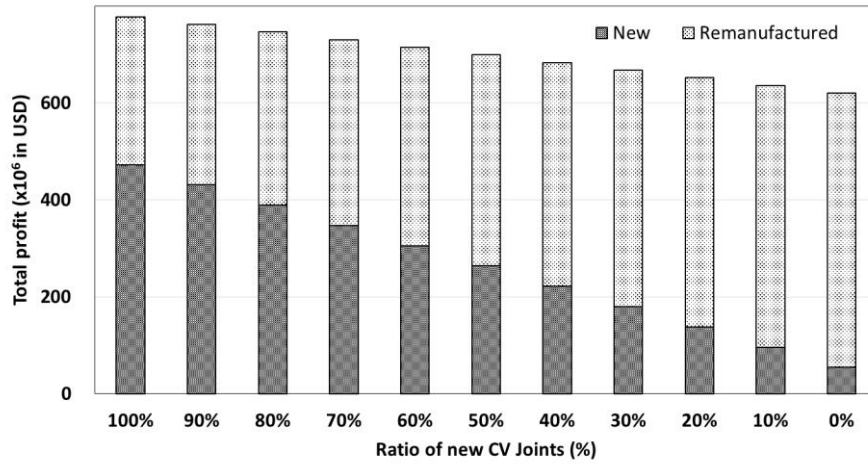
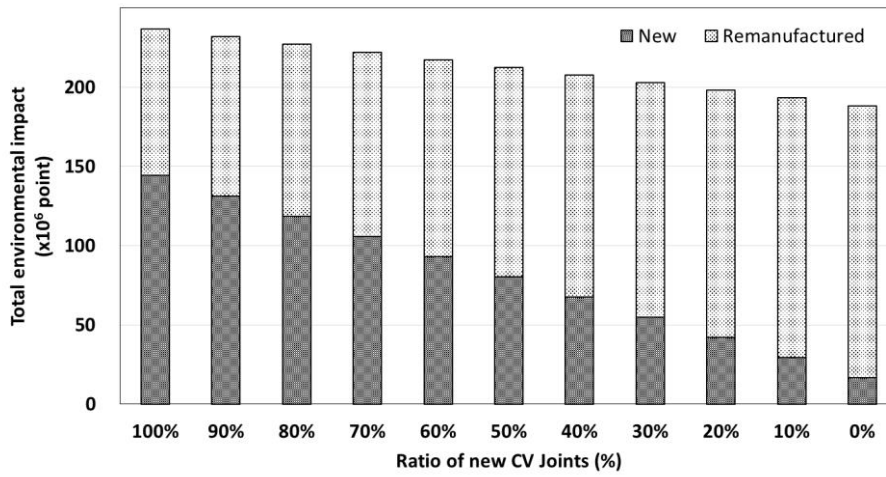


Fig. 5 Total environmental impact point and total profit with the ratio of new CV joints (100-0%)

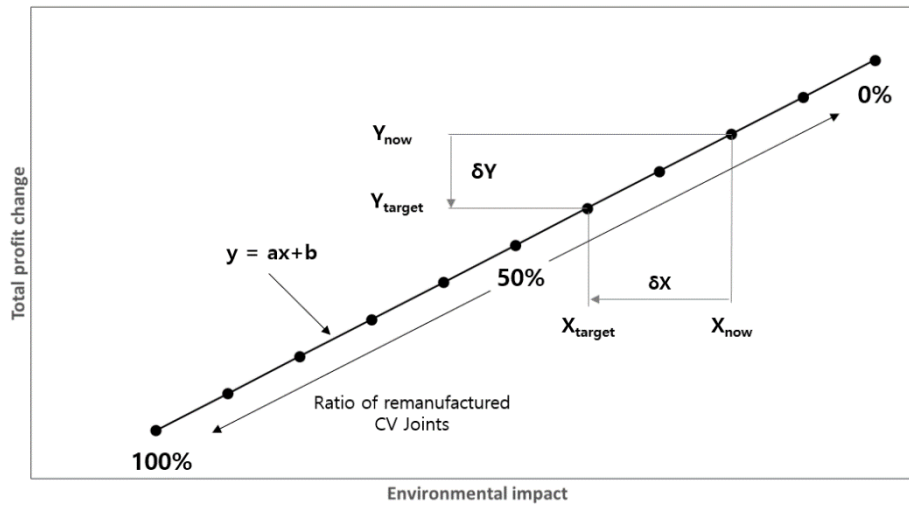


Fig. 6 Relation between economic and environmental impact

Table 1: The amount of subsidy depend on the retail price of remanufactured CV joints

The retail price of remanufactured CV Joint	The retail price of new CV joint	The coefficient of the slope (a)	The number of increased remanufactured CV joints	Preservation of loss rate	Unit subsidy

\$75 (USD)	0.000			\$0.000 (USD)
\$70 (USD)	1.083			\$1.390 (USD)
		\$170 (USD)	376,421	100%
\$65 (USD)	2.166			\$2.166 (USD)
\$60 (USD)	3.249			\$4.170 (USD)

Design insights:

- Pricing of remanufactured CV joint ranges \$60 - \$75 compared to that of a new one \$170 as shown in Table 1. As the price is set lower, profit is reduced in return. The current research identifies the sensitivity coefficient (i.e., how to set subsidy) to compensate profit loss due to the use of reman CV joints (Figure 6). On the other hand, as the reman CV use is increased, the environmental impact is expected to decrease. The current research identifies how much the total impact will be reduced as a net after meeting the total demand of CV joints in the market (Figure 5).
- Calculating individual impact savings (Figure 4) is not of significance, as it is expected clearly in the case of reman product. The contribution is to be able to assess the total impact savings from the entire market (Korea) based on the estimated demand from the sales data.

References

Lee, K., Ahn, H., Kim, H.M. and Lee, C. "Environmental and Economic Impact on Scenario based Constant Velocity (CV) Joint Replacement," under review, 2015.

Name	Case 4: Automotive recycling chain
Author	Bernard Yannou, Yann Leroy
Project description	
<p>Research project VALVER (2010-2013) with Renault, Saint-Gobain and other companies of car recycling value chain. The sponsors have also been ADEME (French Energy Management Agency) and Ile de France region.</p>	
Product/system description	
<p>End of Life Vehicle (ELV) glazing recycling is becoming a legal requirement in France and in all EU countries. At the time of the papers (2003), the non-dismantled glass pieces (e.g. windshield) called the glazing during the dismantling phase is typically shredded with the ELV shell and sent to a landfill. This glass, mixed with other residuals and contaminated with organic substances, is practically unusable and has no market value.</p> <p>Recycling ELV glazing is defined as the process of dismantling, collection, storage and transportation, treatment, and ultimately reuse of recycled glass called cullet. Cullet is regularly used for making glass products, glass wool, or as a substitution for other raw materials. Beyond the price advantage, each 10 % increase in cullet usage in a glass furnace results in a 2-3% energy saving in the melting process: and each ton of cullet used saves 230 kg of CO2 emissions. This has created in certain European countries an increasing demand for high-quality cullet by the glass industry. However, neither the demand for cullet, nor that of post-consumer recycled glass, is satisfied by current supply.</p> <p>The objective of the industrial consortium is to start in France an ELV glazing recycling chain and network for 1) creating value with cullet production 2) avoiding governmental penalties for each non-recycled car glazing beyond a given date. The profitability of such a system must be investigated. The cost and benefit can be stated as follows: the costs arise from dismantling, collection and transportation, treatment, and the penalty paid by the producer in case of non-achievement of the directive target rate. The benefit of the network is from selling the produced cullet in the market, and the cost of not landfilling and shredding residual waste.</p> <p>The objective for ADEME institution is to know the effect of penalty value for starting the recycling process of 70,000 tons/year of automotive glazing for recycling.</p> <p>A first study [Farel et al, 2013a] provides a framework for discussing the alternative scenarios of stakeholder activity in a future glazing recycling network. A mathematical model is proposed to minimize the cost-benefit balance of the future network, providing all the stakeholders behave in a coordinated and rational way. A linear programming model is employed to obtain the optimal material flow of ELV glazing, going through the activity alternatives in dismantling procedure, collection and storage sites, glass treatment units, and the final cullet product. This is a scenario based simulation of optimal recycling networks based on three variables: landfill cost, cullet price on market, penalty per non-recycled car glazing.</p> <p>The impact of this study and the findings on the project stake holders was considerable. First, it provided a quantitative estimation of the impact of future changes on the net balance of ELV glazing recycling. Second, it was communicated to the public state decision maker to give them a realistic picture of the present techno-economic situation and the ideal net balance of a future recycling network at national level. Third, all stakeholders are provided with a configurable model and a traceable data set, in order to give them the possibility of simulation and optimization with new information, and estimate the net balance of ELV glazing recycling.</p> <p>A second study [Farel et al, 2013b] explores the dynamic effects of cullet production and demand in time and the industrial motivation to recycle the totality of glazing stock. Key parameters of future changes, namely glass cullet price, landfill cost, network coverage and transportation costs are identified. A system dynamics approach is then used to simulate the net economic balance of the recycling network under different future scenarios.</p> <p>The simulation reveals an increase in the income and considerable cost savings as a result of the recycling network in some of future scenarios. These simulations have served to estimate ROI times for the different stakeholders and the recycling system in its whole.</p>	

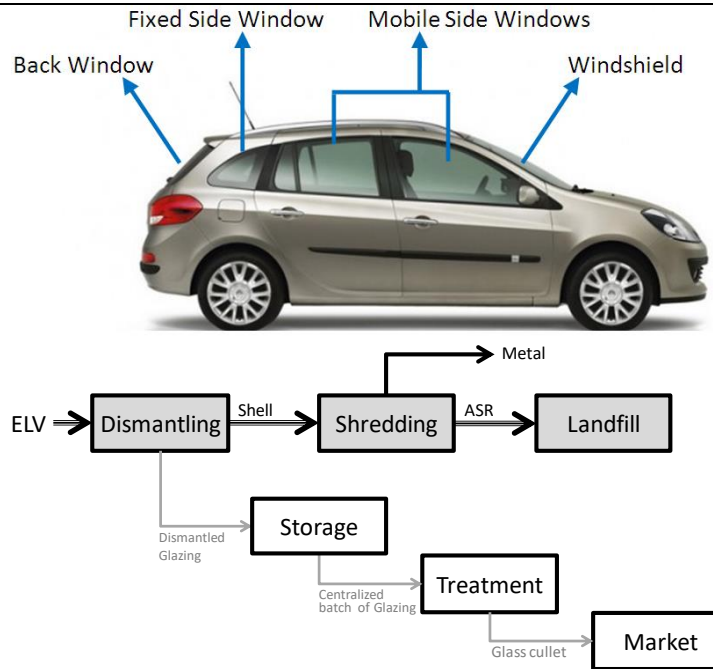
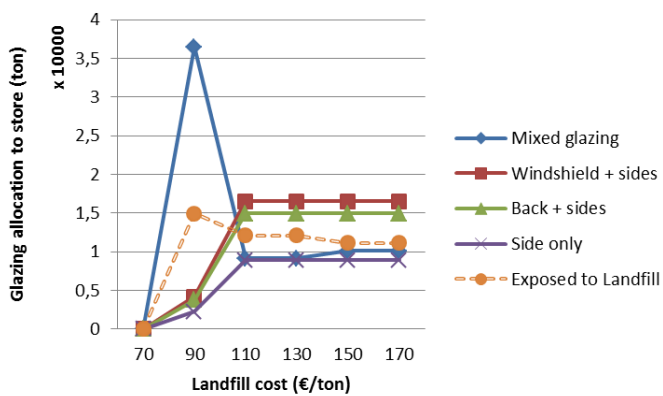


Figure 1. ELV glazing recycling scheme

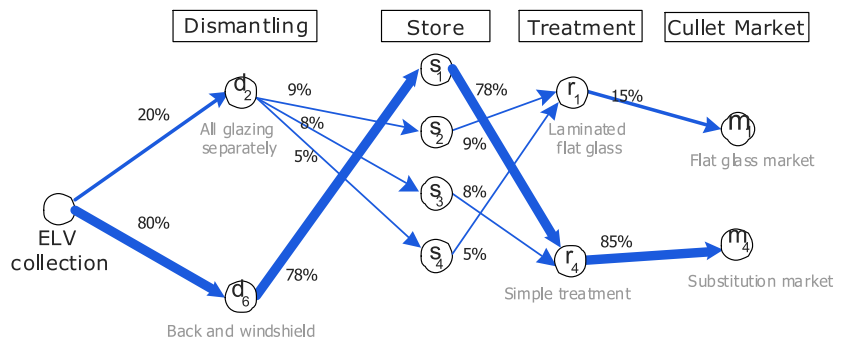
Pictures

Study 1 [Farel et al, 2013a]

The effect of landfill cost on glazing recycling network flows and architecture is simulated.

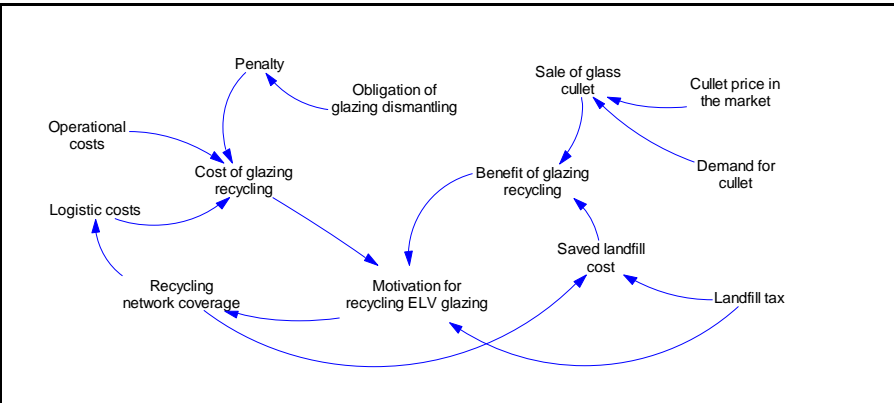


An optimal recycling network corresponding to given hypotheses of landfill cost, cullet price on market, penalty per non-recycled car glazing



Study 2 [Farel et al, 2013b]

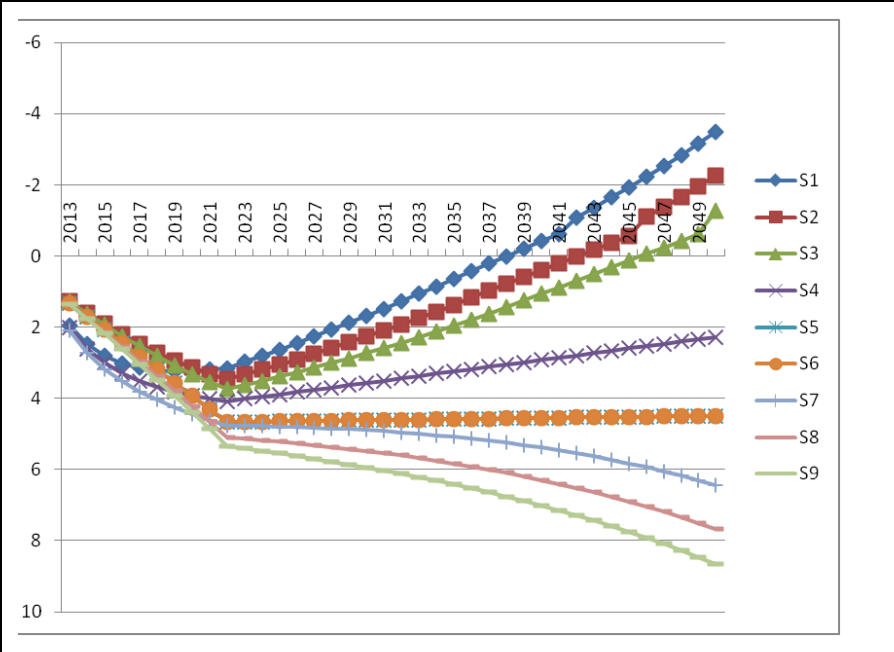
System dynamics model of ELV glazing recycling network



Nine scenarios for the ELV glazing recycling network

		Endogenous			Logistic cost	Network coverage
		Best case	Expected case	Worst case		
	D3.2 (Decrease)	D3.1 (constant)	D3.3 (increase)			
	D4.3 (strong)	D4.1 (linear)	D4.2 (exp)			
Exogenous	Best case	D1.2 (exp)	D2.3 (no ch)	S1	S2	S3
	Expected case	D1.1 (lin)	D2.1 (lin)	S4	S5	S6
	Worst case	D1.3 (no ch)	D2.2 (exp)	S7	S8	S9
		Cullet price	Landfill cost			

Economic balance (income - costs) of glazing recycling in 9 scenarios (Million €)



Stakeholders

Table 1. Individual motivation and disincentives of stakeholders for a future ELV glazing recycling network

	Individual motivation for recycling network	Disincentive for performing activity
Car manufacturer	Meet the 95% target and avoid penalty	None

	Dismantler	Attain a higher dismantling rate and use commercial benefits and potential government subsidies	Extra cost
	Shredder	Less landfill cost	None
	Collection and Transportation	Improve the logistical operation	Volume issues
	Glass treatment	Increase in feed and product flow	None
	Cullet buyer	Satisfy the demand	Quality issues

Boundaries

See “Product/system description” section. The other hypotheses are :

- A new recycling system on the French territory different from the bottles and construction glazing ones
- The recycling system must be installed from scratch on the French territory soil, instead of only collecting glazing and transporting it abroad for transformation into cullet.

Objectives

A **linear programming** model is employed to obtain the optimal material flow of ELV glazing, going through the activity alternatives in dismantling procedure, collection and storage sites, glass treatment units, and the final cullet product. This is a scenario based simulation of optimal recycling networks based on three variables: landfill cost, cullet price on market, penalty per non-recycled car glazing.

A **system dynamics** approach is used to simulate the net economic balance of the recycling network under different future scenarios.

Life cycle thinking

All life cycle phases considered

Sustainable aspects/indicators

Environmental: Lowering of CO2 emissions, material depletion, incenting circular economy.

Economic: optimization of the net balance of a future recycling network at national level, estimate ROI times for the different stakeholders and the recycling system in its whole. Varying parameters are landfill cost, cullet price on market, penalty per non-recycled car glazing, price of CO2 ton.

Other : -

Results

Research:

Linear programming and system dynamics have been satisfactorily used within scenario-based simulation campaigns for designing glazing recycling networks/chains along with net balance of a recycling network configuration and ROI times for the different stakeholders of the network.

For the company:

The impact of this study and the findings on the project stake holders was considerable. First, it provided a quantitative estimation of the impact of future changes on the net balance of ELV glazing recycling. Second, it was communicated to the public state decision maker to give them a realistic picture of the present techno-economic situation and the ideal net balance of a future recycling network at national level. Third, all stakeholders are provided with a configurable model and a traceable data set, in order to give them the possibility of simulation and

optimization with new information, and estimate the net balance of ELV glazing recycling. Four, these simulations have served to estimate ROI times for the different stakeholders and the recycling system in its whole.

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- Farel R., Yannou B., Ghaffari A., Leroy Y. (2013b) 'A cost and benefit analysis of future end-of-life vehicle glazing recycling in France: A systematic approach', Resources Conservation and Recycling, vol. 74, pp. 54-65, doi: 10.1016/j.resconrec.2013.02.013

Name	Case 5: Cotton harvesting
Author	Harrison Kim
Project description	
Collaborative research project between Deere and University of Illinois	
Product/system description	
<p>A comparison framework for two cotton harvesting systems:</p> <ul style="list-style-type: none"> • System A – cotton stripper, cotton module builder, tractor-pulled cart • System B – multi-function cotton stripper, tractor <p>Tasks to be completed:</p> <ul style="list-style-type: none"> • Task 1: Strip the cotton from the rectangular field • Task 2: Move the harvested cotton to a location in the field • Task 3: Package the harvested cotton into modules <p>Background: Deere developed a new cotton harvesting system that is revolutionary in its design in stripping cotton and making modules. The new system (System B) reduces loss of harvested cotton while allowing flexibility in collecting cotton modules.</p> <div style="text-align: center;"> </div>	
Pictures	
<div style="text-align: center;"> </div> <p style="text-align: center;">Field shape and cotton stripper path</p>	<div style="text-align: center;"> <p>Cotton harvester in System A</p> <p>Cotton harvester in System B</p> </div>
Stakeholders	
<ul style="list-style-type: none"> • Manufacturer: Deere needs to evaluate the environmental impact of the products in production for the entire life of the machine. Design engineers need to identify what potential areas of improvement are in product development. 	

- Regulator/Government: Regulators need to impose milestones for environmental sustainability with an objective framework to guide policy enforcement.
- Consumer: Knowledge about the product’s environment enables informed buying decision. Customers need guidance in trade-off between product efficiency vs. environmental impact savings.

Boundaries

Drawing correct system boundaries is critical to assessing the environmental impact in an objective manner. As shown in Systems A and B, the impact comparison is not imposed on individual machine, but on composition of multiple machine and equipment to “get the job done.” Cotton harvesting involves multiple tasks as outlined in the system description. Comparing machine to machine is of no significant value, as the ultimate goal is to compare two “systems” to perform cotton harvesting.

In a typical LCA, four main stages must be considered – manufacturing, usage, maintenance, and end-of-use treatment. In this project, usage of the machine is dominant stage for impact generation, but all four major stages were considered.

Objectives

The objective of the project is to develop a comparative systems LCA framework to assess the environmental impact of multiple heterogeneous systems. The project is to answer the following research questions:

- How can we provide “apple-to-apple” comparison of environmental impact of two heterogeneous systems? A system under consideration has multiple constituent elements that contribute to the environmental impact.
- How can we characterize a common task for two systems so that the output (environmental impact) is assessed for the same amount of jobs done?

Life cycle thinking

All life cycle phases – manufacturing, usage, maintenance, and end-of-use treatment – were considered.

Sustainable aspects/indicators

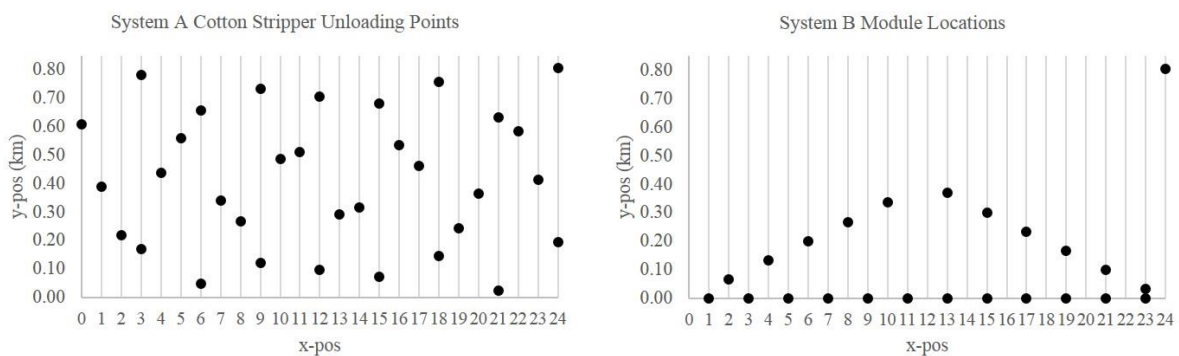
Environmental : LCA impact assessment was performed to generate impact scores (EI99 or ReCiPe) for Systems A and B. The impact was assessed throughout the entire life cycle – manufacturing, usage, maintenance, and end-of-use treatment.

Economic : Lifecycle costing could be adopted to assess total cost of Systems A and B for the entire life. The economic aspect was beyond the scope of the project.

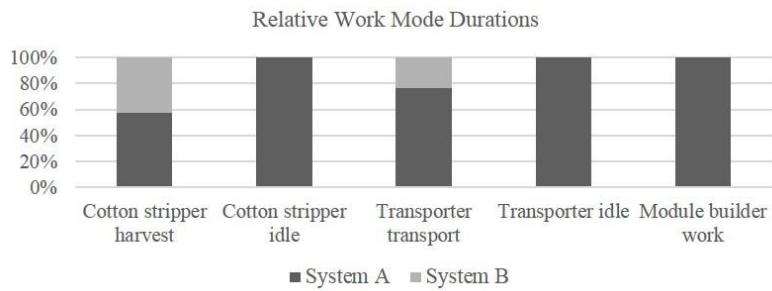
Social : N/A

Other : N/A

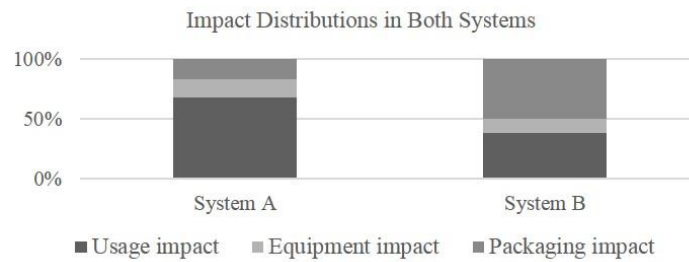
Results



System A unloading points and System B module locations



Relative work mode duration comparison



Impact distribution of both systems

Comparative impact assessment for Systems A and B:


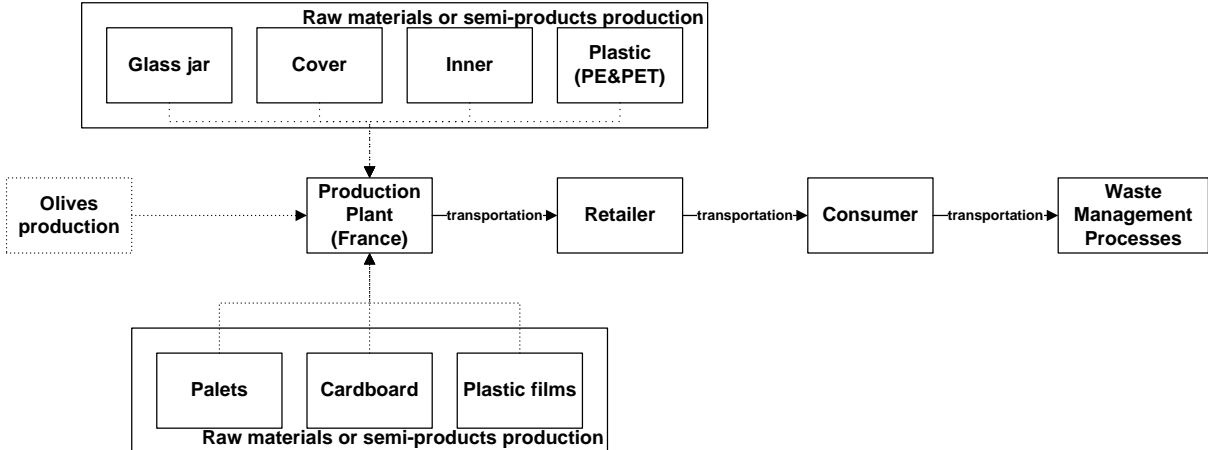
- System B has a capacity to carry a bale, which can be dropped in any location of the field as far as another bale is not completed yet. The figure shows bale locations from Systems A and B separately. System B shows reduction of transportation need.

Design insights:

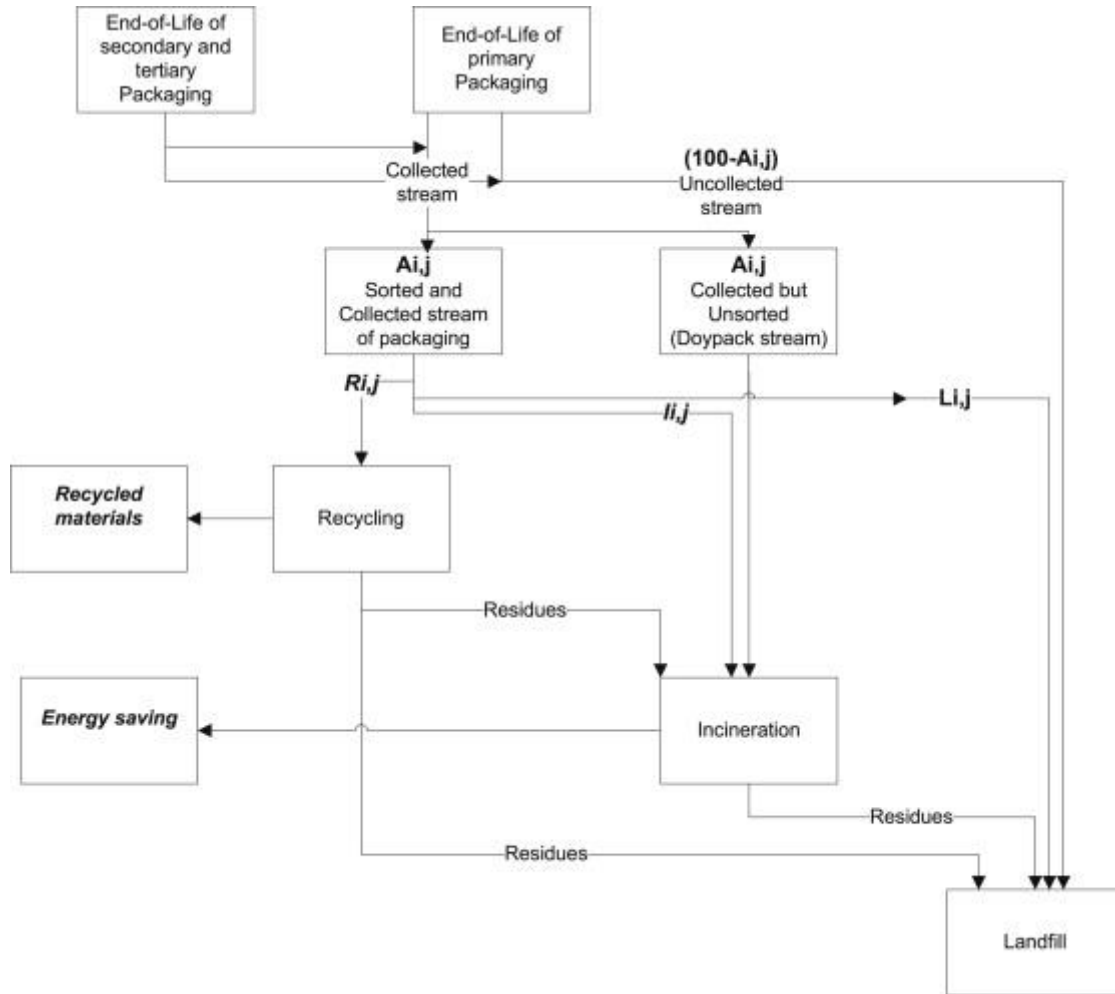
- Increasing bale density can potentially reduce the environmental impact by using less of wrapping material in turn reducing packaging impact.
- Using a different packing material could reduce the environmental impact of use (50% currently). The design option could be to use different wrapping material or to enhance strength of the current wrapping material so that each module can use less of wrapper.

References

Quan, N., Kim, H.M., Knight, E., Nelson, J. and Finamore, P. "Task-Based LCA for Environmental Impact Assessment of Multiple Heterogeneous Systems", ICED 2015, 2015.

Name	Case 6: Olives packaging
Author	Gwenola Bertoluci, Yann Leroy
Project description	
Collaborative research project between AgroParistech, CentraleSupélec and Lund University	
Product/system description	
<p>Reduction of packaging waste has been a European target for more than 40 years. Analysis of European Regulations on packaging EOL effects is performed. Two series of LCA were performed to compare 3 packaging solutions for Olives (i) in a French context and then (ii) in five European countries: France, Germany, Italy, Spain and Sweden.</p> <ul style="list-style-type: none"> - 3 packaging alternatives are considered, the Doypack, the Glass Jar and the Steel can respectively - First comparison only includes raw materials extraction and preparation - Second, integrates the rest of the life cycle in a French context including secondary (cardboards) and tertiary packaging (pallets and films) - The third one compare the life cycles for 5 european countries with their own specific EOL value chain - Finally, consumers habits are investigated to define their preferences regarding functions supported by the product (packaging) but excluded from the Functional Unit. 	
Pictures	
<p>The case study considers the three olives' packaging as depicted in the following picture: The doypack (double layer PE and PET), a Glass Jar and a steel can.</p>	
	
<p>The system boundaries covers the whole life cycle of the packaging, from cradle-to-grave.</p>	
<p>Until the study focuses on the packaging, the production, preparation and conditioning of the olives are excluded from the scope. Mass of olives and brines are considered into the transportation phases and during the use phase (olives consumption).</p>	
 <pre> graph TD subgraph RM1 [Raw materials or semi-products production] GJ[Glass jar] C[Cover] I[Inner] P[Plastic PE&PET] end subgraph RM2 [Raw materials or semi-products production] Pa[Palets] Ca[Cardboard] Pf[Plastic films] end OP[Olives production] PP[Production Plant France] R[Retailer] C[Consumer] WMP[Waste Management Processes] RM1 -.-> PP RM2 -.-> PP OP -.-> PP PP -- transportation --> R R -- transportation --> C C -- transportation --> WMP </pre>	

A generic modeling system is considered to characterize the different EOL value chains as depicted in the following picture.



Stakeholders

- Policy Makers in charge of European regulations and applications in specific European countries
- Olives retailers who define the type of packaging, the conditioning solutions
- Consumers as the end user
- Actors from the EOL value chain (indirect consideration until the integration considers the performance rates of the different process: collection, sorting, recycling and valorization).

Boundaries

Multi-scale approach:

- Three kinds of packaging
- Related data on packaging were obtained from direct measurements (Product dissection – dismantling)
- Five countries and their specific EOL value chain.
- (i) First scenario only considers EOL treatment, the collection is assumed to be constant whatever the country.
- (ii) Data were extracted from European statistics and cover actual collection rates, recycling rates, incineration rates and landfilling rates for each type of material contained in the packaging.

Objectives

The main objective is to measure the effect of the European Regulations on EOL performance for packaging.

- Environmental impact calculation for each couple (product, national EOL perf)
- Control that the ranking between the different solutions is respected in the 5 contexts.

Life cycle thinking

All phases of the life cycle is considered. Additional information are included regarding secondary and tertiary packaging. A specific section is dedicated to EOL treatments and their performances

Sustainable aspects/indicators

LCA: environmental aspects exclusively: LCIA was performed thanks to the ReciPe method.

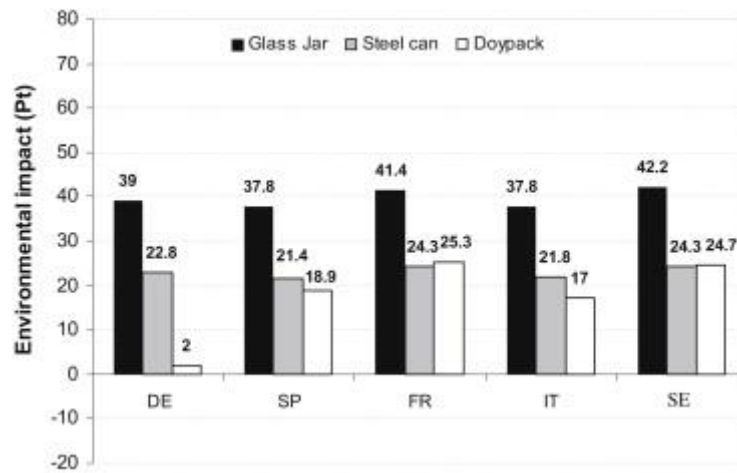
5 indicators were supervised in depth: the climate change, the human toxicity, the particulate matter, the ionizing radiation (due to nuclear energy production and consumption in France and Sweden) and the fossil depletion.

Economic: N/A

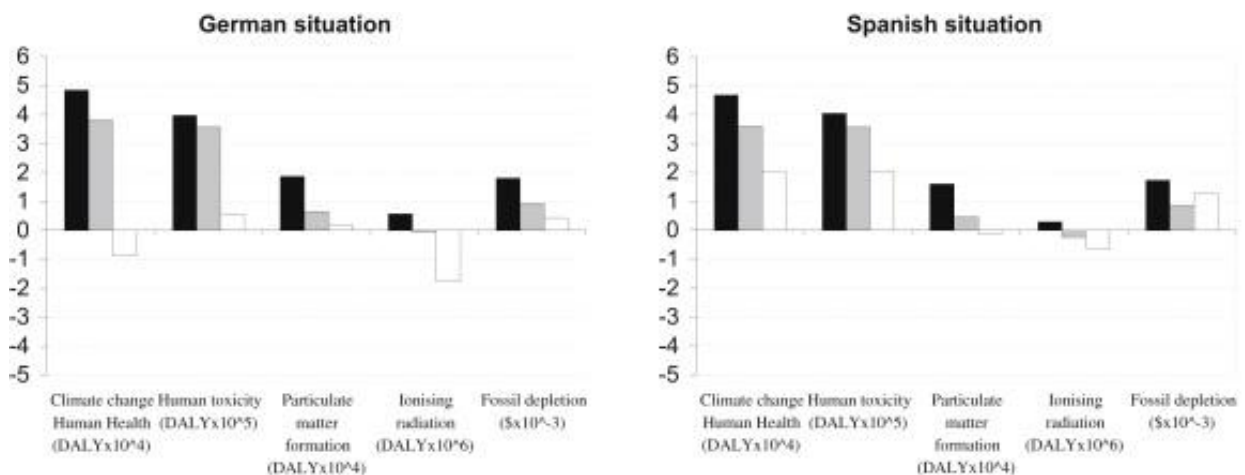
Social: N/A

Other: Inclusion of additional functions supported by the packaging (but excluded from the FU) that may influence the purchasing choice.

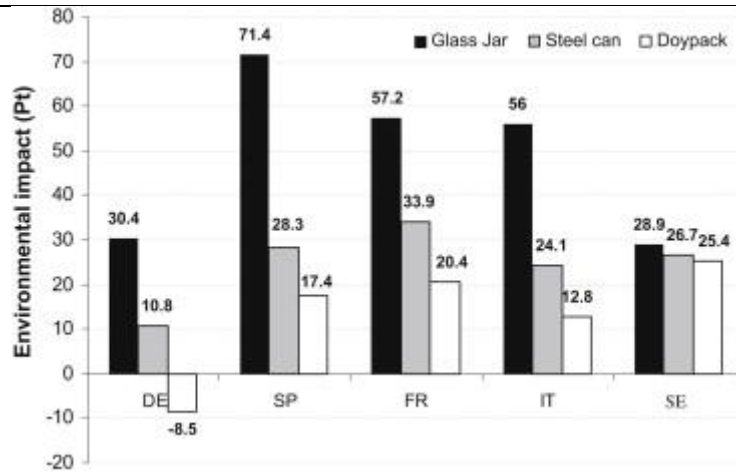
Results



LCAs of three types of packaging according to country where they were treated and valorized. Environmental impact is expressed in point. The representation aggregates impact categories into a single score using their respective weighting factors and allows comparison between the impacts categories traditionally expressed in different units.

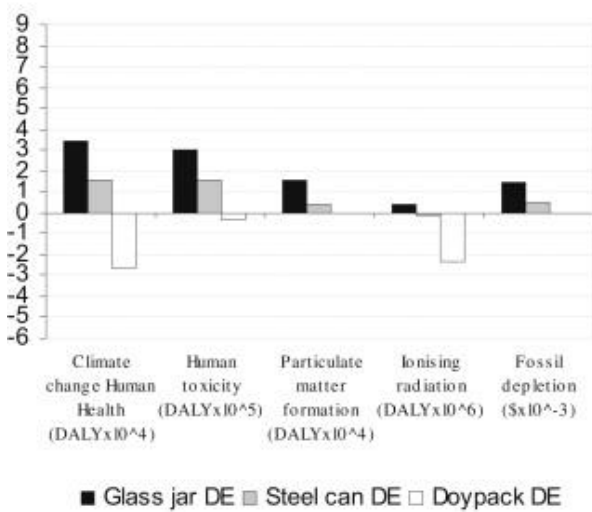


Country specific LCAs for the three packaging solutions (units are reported in the horizontal axis for each impact category).

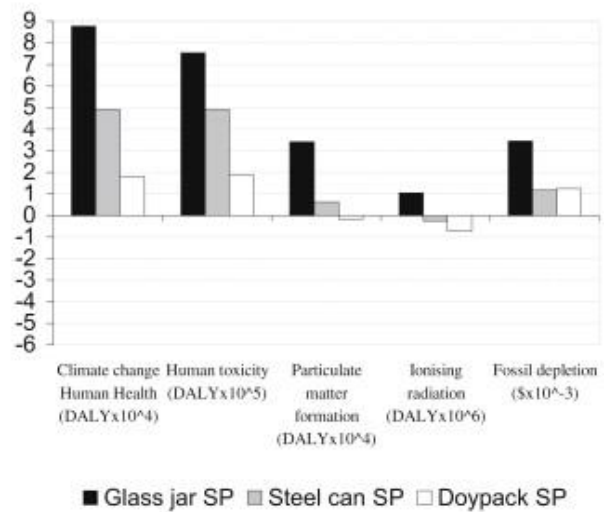


LCAs of the three packaging solutions, current situation.

German situation



Spanish situation



Examples of results of LCAs expressed in characterization values for the three packaging solutions (units are reported in the horizontal axis for each impact category).

		Glass jar			Steel can		Doypack
		Glass	Cover	Label	Box	Cover	
Principal functions							
P	Storage	9			7		4
F	1	Protective but breakable. Can be used after opening.			Protective but cannot be reused after opening.		Volume limited. Not very protective. Not reusable.
P	Protection	10			5		6
F	2	Total protection + able to reclose			Protective, but impossible to reclose.		Protective, but impossibility to reclose.
P	Information	7			10		10
F	3	Label can be removed			Non-removable label		Non-removable label
Constraint functions							
C	Opening	9			6		5
F	1	Easy to open without a tool.			Dirty; may lose some product.		Need scissors; can easily slip.
C	Transport	3			6		8
F	2	Important weight; breakable.			Limited weight; secondary packaging limited.		Very limited weight; important secondary packaging

C	Presentati	10	10	5
F	on	Easy and compact	Easy and compact	Less easy and less compact
3				
Total value		48	44	38

Assessment scores on a scale of 1–10 of the three olive packaging solutions.

(i) 80% collection rate:

The glass jar has the greatest impact whatever the country. The performance are contrasted between the doypack and the steel can. The doypack is preferred in Germany due to the EOL scenario assuming that 100% of the EOL doypack stream is oriented to the incineration.

The main variation from one country to another regarding the doypack performance is due to the specific country energy mix. Sweden and France provide a specific profile because of the importance of nuclear energy in their energy mixes.

(ii) Real collection and recycling rates

The solution ranking is preserved compared to previous analysis. Results are adjusted according to real EOL treatments and value chain performances.

(iii) Qualitative questionnaire

Even if doypack and steel can appear as greener than the glass jar, this last provides additional functions (protection, open + reclose – conservation) that may highly influence the purchasing choice. Those functions are sometimes difficult to be integrated in the FU. Moreover, this functions refer to the use phase (consumption) which highly depends on consumer’s habits. Knowledge on user’s habits is essential to design real environmentally-friendly packaging for food.

References

Bertoluci, G., Leroy, Y., Olsson, A., 2014. Exploring the environmental impacts of olive packaging solutions for the European food market. *Journal of Cleaner Production* 64, 234–243. doi:10.1016/j.jclepro.2013.09.029

Name	Case 7: Pork value chain
Authors	Gwenola Bertoluci
Project description	
Gaelle Petit PhD thesis (2014- 2017) in AgroParisTech associated with the Chaire Sustainable Demand Supply Chain.	
Product/system description	
<p>Analysis of sustainable issues associated with a meat Pork Value Chain illustrating the French context. The impacts of a value chain delivering pork meat on the French market are analyzed under the three dimensions of the sustainability. Major issues associated with the value chain activities and their consequences on the product, its actors and value chain itself are defined. The aim of this first research work is to link the sustainable product performance and the value chain organization performance. This representation will be a mean to define a set of requirements for an informational system dedicated to the sustainability assessment along the value chain and the product life cycle. A next step will be dedicated to the analyze of the sustainability propagation along the value chain.</p>	
Pictures	
<p>The system boundaries covers the whole life cycle of the production of feed for pig until the final shop.</p>	
Stakeholders	
<ul style="list-style-type: none"> • animal feed provider, • farmer, • slaughterhouse • distributor 	

<ul style="list-style-type: none"> • consumer
Boundaries
<p>Multi-scale approach:</p> <ul style="list-style-type: none"> - Product life cycle - actors of the value chain (since feed production until consumer) - major stakeholders of each actors - politics publics expectations
Objectives
<p>The main objective is to produce a set and architecture of indicators able to control the sustainability of the value chain with data that could be shared by the actors and used to certify this sustainability and to increase the sustainable management of the value chain under a global point of view.</p>
Life cycle thinking
<p>Objective is to model a ideal value chain in assembling the point of view of each actors and to define global the sustainable performance of the global chain. For that it must clarify the indicators used to assess the sustainable performance.</p>
Sustainable aspects/indicators
<p>Reduction of resources consumption (energy and water). Protection of biodiversity (deforestation, intensive agriculture and soil depletion, excess of nitrogen associated with manure) Reduction of CO2 associated with the feed transportation (coming from Brazilian for example)</p> <p>Satisfaction at work for the farmer, Animal welfare.</p>
Results
<p>Done : analysis of the value chain issue (organization/product)</p> <p>In work: methodologies differentiated of sustainable indicators selection for the social or environmental issues.</p> <p>Next step: environmental and social assessments of the value chain under the impact of technical and organizational changes.</p>
References
<ol style="list-style-type: none"> 1. Petit, G.; Bertoluci, G.; Trystram, G.; Lecomte, C.; Chapdaniel, A., Traceability system evolution's need for food labelling. In <i>28th EFFoST International Conference 7th International Food Factory for the Future Conference</i>, Uppsala Konsert and Kongress, Uppsala, Sweden, 2014. 2. Monastyrnaya, E.; Bertoluci, G.; Yannou, B., Visualisation of sustainability in food industry as a lever of change. . In <i>International Forum From Science to Business Saint Petresbourg</i>, 2015. 3. Bertoluci, G.; Gomy, C.; Masset, G.; Darmon, N., Developing environmental standard food databases for nutritional epidemiology studies. In <i>Life Cycle management</i>, Bordeaux, 2015. 4. Romdhana, H.; Decloux, M.; Bertoluci, G., Optimization methodology for reducing resource and emissions of drying process. In <i>SFGP2013 - Congrès de la Société Française de Génie des Procédés</i>: Lyon, 2014. 5. Lassalle de Salins, M.; Chapdaniel, A.; Bertoluci, G., Managing sustainability in supply chains: the sustainable Demand-Supply chain approach, a proposal for a pragmatic approach in the food sector. In <i>Wageningen International Conference on Chain and Network Management</i>, Wageningen University: Capri, 2014. 6. Bertoluci, G.; Leroy, Y.; Olsson, A., Exploring the environmental impacts of olive packaging solutions for the European Food Market. <i>Journal of Cleaner Production</i> 2014, (0).

7. Bertoluci G.; G., T., Spécificités de l'éco-conception alimentaire. In *Marché et Organisation*, Harmattan: 2013; Vol. 17, pp 123-135.
8. Mottet, J.; Bertoluci, G.; Trezzani, I.; Trystram, G., Introducing environmental concern in the design of food product and processes. In *Food Factory*, Laval, France, 2012.
9. Mottet, J.; Trystram, G.; Bertoluci, G.; Trezzani, I. In *Define a specific sustainable assessment methodology for the food industry*, EFFOST, Montpellier, Elsevier, Ed. Montpellier, 2012.

Name	Case 8: Consumer electronics
Author	Harrison Kim

Project description

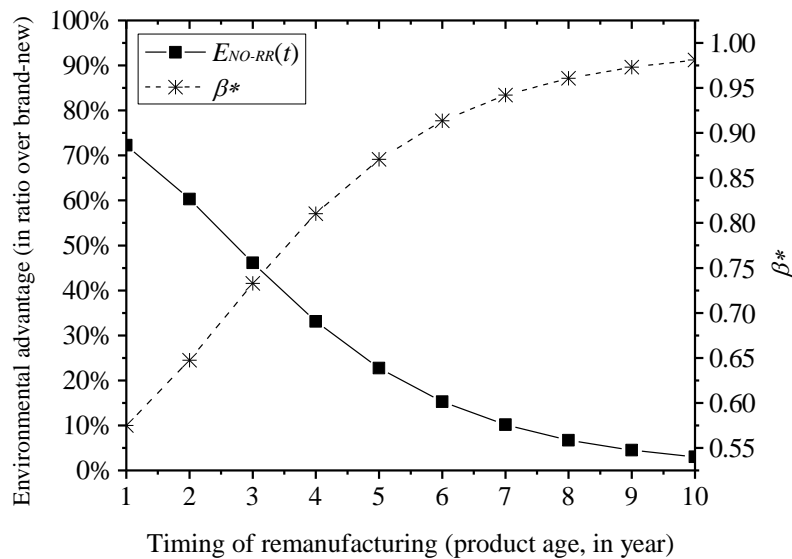
The project is to determine when it is better to remanufacture than to manufacture brand-new.

Product/system description

The research project provides economic and environmental justifications for remanufacturing. Depending on the timing of remanufacturing (or product age, physical conditions, technological obsolescence), one can identify optimal manufacturing strategies, which in turn lead to optimal design of product for economic profitability and environmental sustainability. The approach can be applied to a broad range of products – consumer electronics, automotive parts, etc. – where remanufactured product market is active and widely accepted.



Pictures



β^* Where the Remanufactured and Brand-New PCs are Equally Profitable

β^* depending on the timing of remanufacturing t

t (year)	β^*	t (year)	β^*	t (year)	β^*
1.00	0.5751	4.25	0.8272	7.50	0.9525
1.25	0.5909	4.50	0.8429	7.75	0.9569
1.50	0.6084	4.75	0.8574	8.00	0.9608
1.75	0.6274	5.00	0.8707	8.25	0.9644
2.00	0.6476	5.25	0.8829	8.50	0.9676
2.25	0.6686	5.50	0.8941	8.75	0.9705
2.50	0.6900	5.75	0.9042	9.00	0.9731
2.75	0.7115	6.00	0.9134	9.25	0.9754
3.00	0.7328	6.25	0.9217	9.50	0.9775

	3.25	0.7535	6.50	0.9292	9.75	0.9794	
	3.50	0.7734	6.75	0.9360	10.00	0.9811	
	3.75	0.7924	7.00	0.9421			
	4.00	0.8104	7.25	0.9475			
Stakeholders							
<ul style="list-style-type: none"> • Remanufacturer: The model helps remanufacturers to make informed and effective decisions concerning product planning. The model also guides setting price for remanufactured products, β coefficient, i.e., the remanufacturing is profitable only when the customers are willing to pay more than β ratio of the brand-new product's price. Otherwise, remanufacturing is not profitable. • Customers: Customers can understand how purchasing remanufactured products can be not only environmentally friendly but also economically profitable for the manufacturer. As a result, consumers can gauge whether the remanufactured product's price is reasonable or too high/low for the benefit of environmental impact savings. • Regulators: If the remanufacturers are hesitant to pursue remanufacturing as a viable business, the regulators can provide tax incentive or credit to make up for the economic loss if the remanufactured product's price is set too low in the market. 							
Boundaries							
<p>The research is associated with two out of the triple bottom line – profit (economic aspect) and planet (environmental aspect). Previous research has focused on the environmental aspect only which in turn appealed to a specific consumer group (green customers). Green customers tend to choose environmentally friendly products even if they have to sacrifice economic aspect. The research identifies where the line should be drawn – i.e., by setting price of remanufactured products that are both economically profitable for the manufacturers and environmentally friendly.</p> <p>A wide range of products – automotive to consumer electronics – could be evaluated under the framework.</p>							
Objectives							
<p>The research validates and answers the following questions for two types of cases – products with physical deterioration only and products with physical deterioration and technological obsolescence together:</p> <ul style="list-style-type: none"> • What is the cost advantage of remanufactured products over producing the equivalent brand-new product? • What is the environmental advantage of remanufactured products over producing the equivalent brand-new product? • What is the β coefficient (i.e., price of reman product compared to that of brand-new) from the net-profit perspective? • What is the minimum allowable β coefficient for remanufacturing to be economically viable? 							
Life cycle thinking							
All life cycle phases were considered.							
Sustainable aspects/indicators							
<p>Environmental : LCA impact assessment was performed to generate impact scores (EI99 or ReCiPe) for various products. The impact was assessed throughout the entire life cycle – manufacturing, usage, maintenance, and end-of-use treatment.</p> <p>Economic : Economic profit was calculated based on market size and remanufactured product's price in the market.</p> <p>Social : N/A</p> <p>Other : N/A</p>							
Results							
Pricing of remanufactured product in the time horizon:							

- As product ages (i.e., physical deterioration), environmental advantages of remanufacturing diminishes, while the price of reman product should be set higher to make it profitable. If the pricing ratio is too high, manufacturing brand-new is more profitable, as there will be less demand.


Design insights:

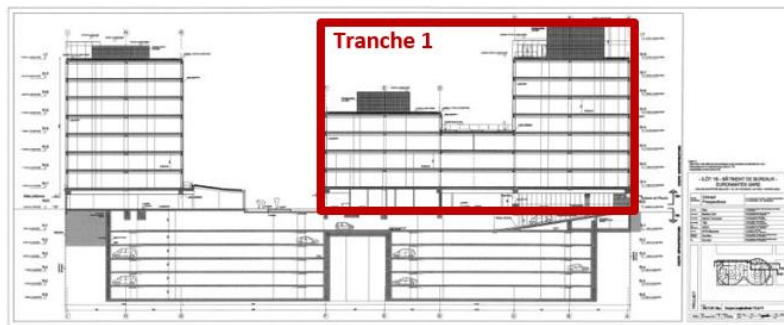
- Product characteristics affect how fast/slow a product loses environmental impact savings and residual values. By use of the framework, designers should be able to identify what types of products are more suitable for remanufacturing and when it the right time to do so.

References

Kwak, M. and Kim, H.M., "Modeling Time-Varying Advantages of a Remanufactured Products: Is a 'Reman' Better than a 'Brand New'?" Journal of Mechanical Design, under review, 2015.

Kwak, M. and Kim, H., 2015, "Assessing time-varying advantages of remanufacturing: A model for products with physical and technological obsolescence," Proceedings of the 20th International Conference on Engineering Design (ICED15), Milan, Italy, 2015.

Name	Case 9: Building and externalities
Author	François Cluzel, Bernard Yannou
Project description	
<p>DECADIESE is an ANR (French research agency) project, with EDF R&D, Vinci Construction, Bouygues Construction, Foncière des Régions, CentraleSupélec, Mines ParisTech and University Paris VII. The project started in 2012 and is currently ending, with perspectives to starts a new project to implement the methodology in the French construction sector.</p>	
Product/system description	
<p>The system studied in DECADIESE is one building (mainly office buildings or schools for the moment).</p>	
Pictures	
<p>Building “Skyline” in Nantes, designed, built, managed and partially used by Bouygues Construction. This building is the main case study for DECADIESE, because all life cycle data and stakeholders are available. It was built in 2011, with a BBC Effinergie label. It is an office building with also shops.</p>	
	
Stakeholders	
<p>We consider all the stakeholders of a building project. The main ones are:</p> <ul style="list-style-type: none"> • Building owner (maître d’ouvrage in French) • Engineering contractor/architect (maître d’oeuvre in French) • Building owner consultant • Constructors • Users • Funders • Local authorities • Neighbourhood • ... 	
Boundaries	
<p>The idea of the project in to enlarge the perimeter of classical stakeholders for a building project, in order to allow more ambitious sustainable building construction or retrofits. So the stakeholders perimeter is moving.</p> <p>DECADIESE only considers single buildings (in their urban ecosystem), and not quarters or towns.</p> <p>Physical boundaries are easily defined (see the picture of the physical perimeter for Skyline building)</p>	



Objectives

Ambitious building retrofits to improve energy performance are often hardly justified by energy savings only. Indeed the return on investment to divide energy consumption of a building by two is more than 25 years, which often discourage investors. Energy efficiency thus needs to be considered differently to be economically justified. That is why a new methodology called DECADIESE has been developed by a consortium of major companies from the French building sector and academic partners. Broader than an energy efficiency focus only, DECADIESE aims at capturing the sustainable value of a building with an original focus beyond the scope of classical analytic methods, by extending the perimeter of associated stakeholders in order to allow ambitious building projects.

Life cycle thinking

All life cycle phases considered.

Sustainable aspects/indicators

Environmental: taken into account through environmental externalities (LCA, but also biodiversity, noise, light pollution...) and one function associated to environmental aspects (integration into the preexisting site)

Economic: DECADIESE is mainly a new economic vision of a building projects. The following economic aspects are taken into account:

- Design and construction costs, but with a new breakdown by usage functions instead of a classical analytical approach;
- Exploitation costs;
- EoL costs;
- Externalities costs (for some externalities)

Social: taken into account through social externalities (for example concerning health and well-being at work, security around the building, productivity, and so on)

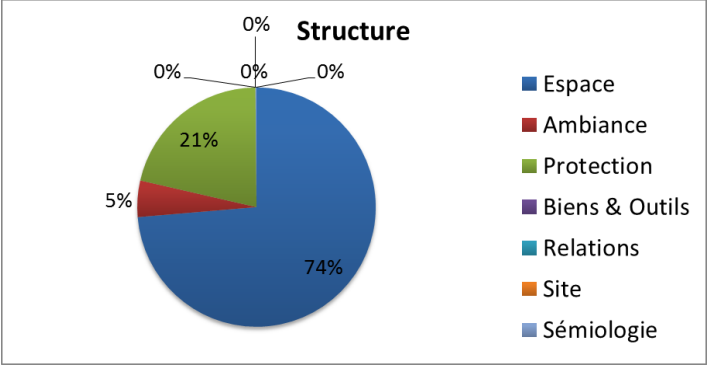
Other: another point quantitatively assessed by DECADIESE is the usage performance of a building. The building is evaluated on about 100 qualitative and quantitative indicators (temperature, protection against storms, image...) aggregated in 7 usage functions. It aims at estimating the value created for the users, which permits to build cost/benefits indicators to help decision-makers.

Results

DECADIESE considers an extended value of a building by incorporating economic, social and environmental aspects through externalities elicitation and integration with a multi-stakeholders point of view, but also by recentering the value created by a building around the benefits brought to its users through a functional approach. The methodology is built around a structured process involving multiple stakeholders (such as building owner, building owner assistant, engineering contractor, potential users and neighbours...) that contribute to feed the different modules of an experimental tool, finally aggregated in cost-benefits indicators.

Concerning the functional part of this model. On the one hand, buildings costs are first broken down into usage functions following a process inspired from value engineering standards. Usage functions costs offer a new vision of costs breakdown for a building, which highlights possible mismatches between functional objectives for users and associated amounts of money. On the other hand, the functional performance of the building is assessed thanks to a grid composed of 95 qualitative and quantitative criteria. Those elementary scores are then aggregated in 7 usage

functions scores thanks to a fuzzy logic model based on building experts rules. Once those elements identified, DECADIESE proposes to a project owner a new vision of its project and the ability to compare building variants. DECADIESE has been experimentally applied on several case studies. Results show a good relevance of results and reveal a high interest of building sector actors. Next steps are underway to make the methodology more reliable and usable by building sector actors.

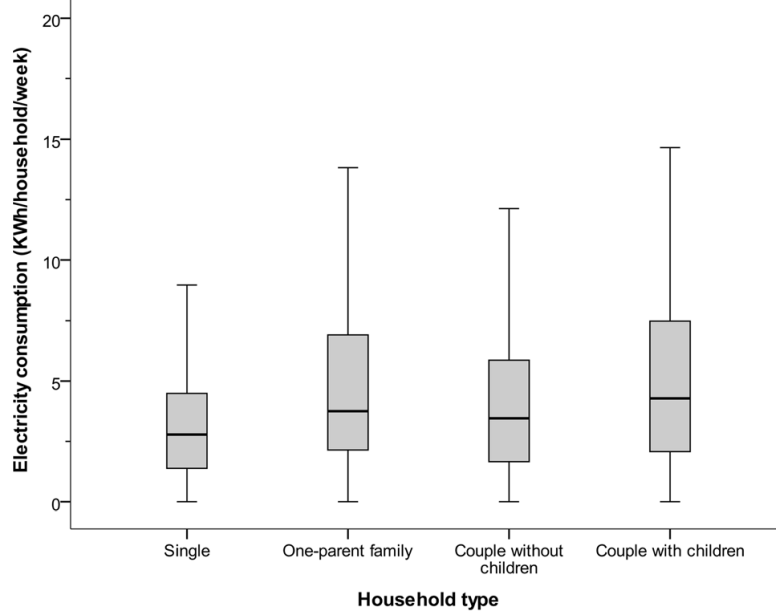


Example of costs breakdown of structural building elements on the seven usage functions

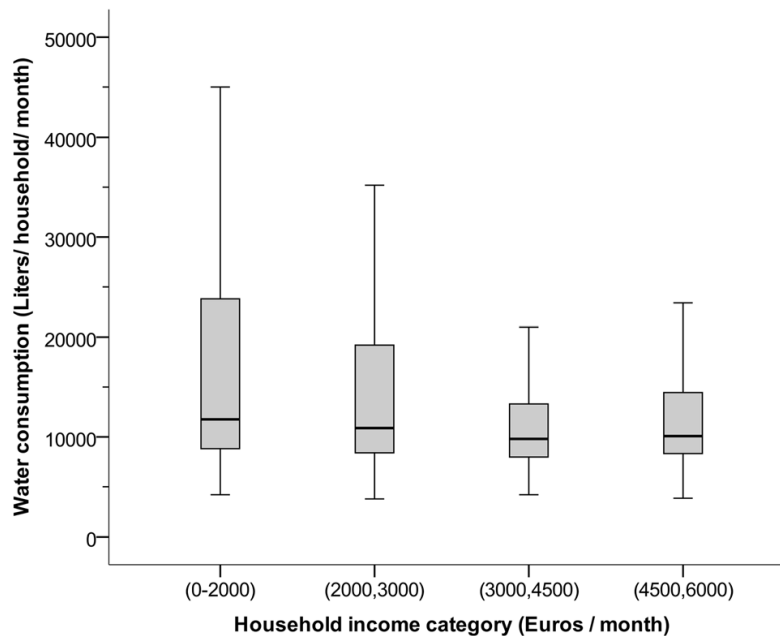
References

Cluzel F., Yannou B., Da Costa P., "DECADIESE: a new method to assess buildings' sustainable value through functional performance and externalities integration", Life Cycle Management LCM 2015, Bordeaux, France, 2015.

Name	Case 10: Building and usage
Author	Bernard Yannou, Yann Leroy
Project description	
Research chair supported by Bouygues Construction	
Product/system description	
<p>Influence of user's behaviors on energy performance of residential buildings</p> <p>The Sabec model includes electrodomestic energy consumption and water consumption.</p> <p>Energy consumed by heating and cooling systems are excluded from the scope.</p> <p>User's behaviors are declined according to activities.</p> <p>29 activities are depicted and modelled</p> <p>An activity is characterized by: user's needs, the service unit (per activity) to be achieved, their behaviors derived from the characterization of social and economic attributes of inhabitants, building characteristics and appliance availability and performance.</p> <p>Experimentation focused on social residential building.</p>	
Pictures	
<p>The diagram, titled "Architecture of Sabec Model", illustrates the relationships between various components. A central dashed box labeled "For each activity" contains the following elements and their interactions:</p> <ul style="list-style-type: none"> Need (1) is satisfied by Activity (s) (n). Activity (s) (n) is done by Action (s) (n). Service unit (1) quantifies Activity (s) (n). Service unit (1) quantifies Action (s) (n). Appliance (1) uses Action (s) (n). Appliance (1) consumes Energy and water flow. HH profile (Individual (s)) characterizes Service unit (1). Building characteristics characterize Service unit (1). External environment characterizes Service unit (1). HH profile (Individual (s)), Building characteristics, and External environment all influence Need (n). HH profile (Individual (s)) and Building characteristics influence Appliance (1) through "influence ownership & quality". <p>Below the dashed box, an arrow labeled Σ of activities points to a box labeled "Energy and water flows for all activities".</p>	



Simulation results of electricity consumption for the activity "watching TV": comparison between five household-type clusters of the French population



Simulation results of electricity consumption for the activity "washing laundry": variability of consumption as a function of the income cluster

Stakeholders

Buildings owners, buildings renter, building user's (owner or tenant)

Boundaries

The main structure of the model considers three major parts: (i) the external environment (weather, orientation, solar exposition...), (ii) the dwelling (building characteristics) and the (iii) household (household type, number of occupants, socio-professional category...)

The model account for electrodomestic energy and water consumption. Energy used for heating and cooling are excluded from the scope.

Objectives

The main objective is to forecast the energy and water consumption in residential building according to the occupant's attributes and the characterization of their daily activities.
Life cycle thinking
Usage phase essentially
Sustainable aspects/indicators
Social aspects (occupants ' attributes) Environmental aspects through energy and water consumption The economic aspect is not directly introduced (taking part of occupants' attributes such as Incomes)
Results
Proposal for a Stochastic Activity-Based Model for Energy Consumption Activity breakdown structure for 29 daily activities Forecasting of energy and water consumptions from occupants' attributes and appliances performances
References
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