

Análise de Sustentabilidade Ambiental (ASA) incluindo perspectiva de ciclo de vida de diferentes fontes energéticas



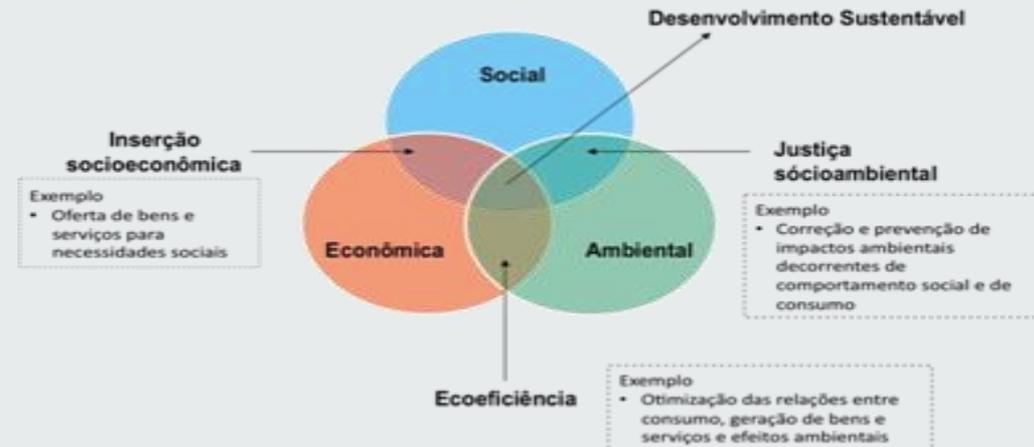
Patrícia Baptista

IN+ Center for Innovation, Technology and Policy Research of
Instituto Superior Técnico

patricia.baptista@tecnico.ulisboa.pt

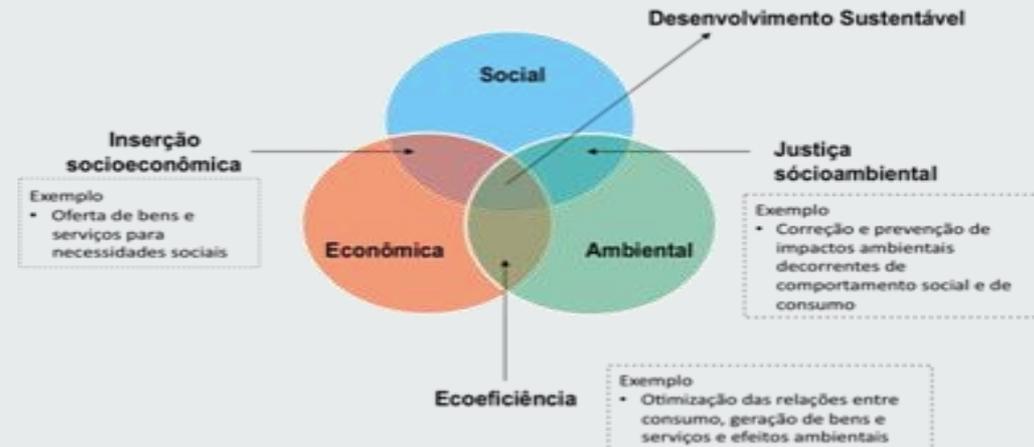
O conceito de sustentabilidade é complexo, pois incorpora variáveis interdependentes, incluindo:

- **Questão ambiental:** com o meio ambiente degradado, o ser humano abrevia o seu tempo de vida; a economia não se desenvolve; o futuro fica insustentável



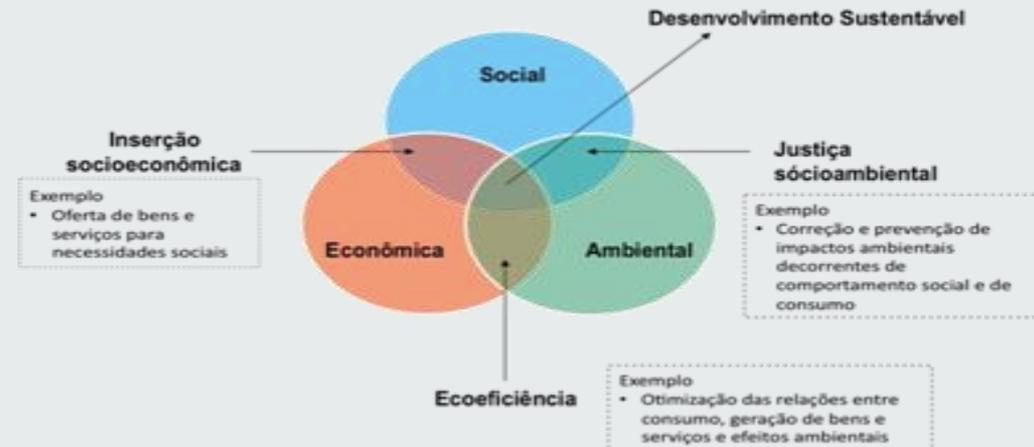
O conceito de sustentabilidade é complexo, pois incorpora variáveis interdependentes, incluindo:

- **Questão ambiental:** com o meio ambiente degradado, o ser humano abrevia o seu tempo de vida; a economia não se desenvolve; o futuro fica insustentável
- **Questão energética:** sem energia a economia não se desenvolve. E se a economia não se desenvolve, as condições de vida das populações deterioram-se



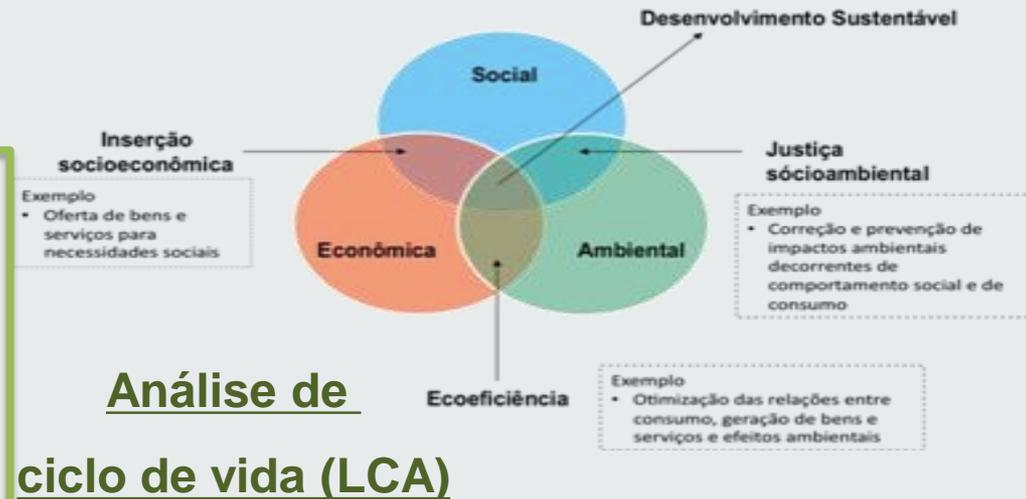
O conceito de sustentabilidade é complexo, pois incorpora variáveis interdependentes, incluindo:

- **Questão ambiental:** com o meio ambiente degradado, o ser humano abrevia o seu tempo de vida; a economia não se desenvolve; o futuro fica insustentável
- **Questão energética:** sem energia a economia não se desenvolve. E se a economia não se desenvolve, as condições de vida das populações deterioram-se
- **Questão social:** Respeitar o ser humano, para que este possa respeitar a natureza



O conceito de sustentabilidade é complexo, pois incorpora variáveis interdependentes, incluindo:

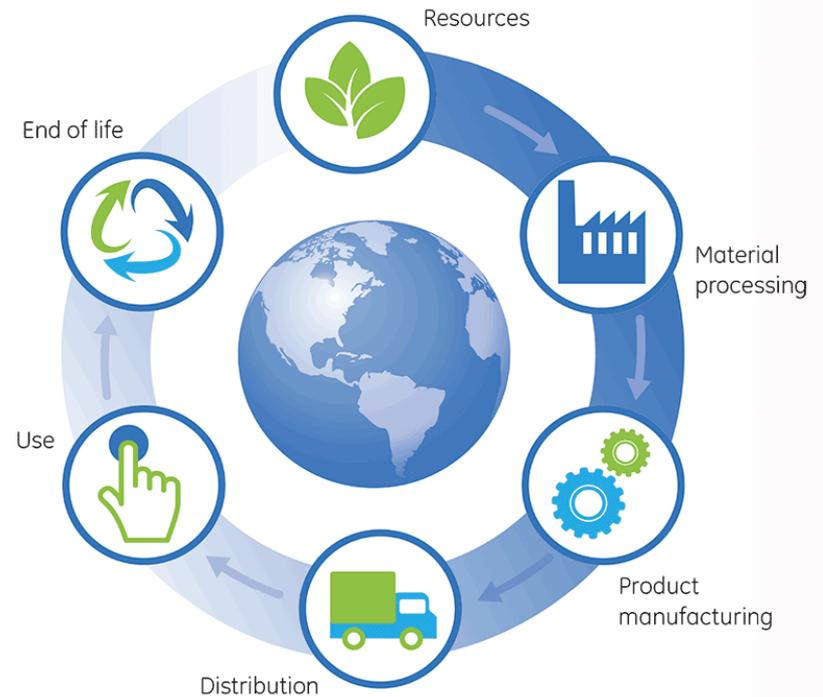
- **Questão ambiental:** com o meio ambiente degradado, o ser humano abrevia o seu tempo de vida; a economia não se desenvolve; o futuro fica insustentável
- **Questão energética:** sem energia a economia não se desenvolve. E se a economia não se desenvolve, as condições de vida das populações deterioram-se
- **Questão social:** Respeitar o ser humano, para que este possa respeitar a natureza



Análise de ciclo de vida (LCA)

- Técnica para avaliar o impacto ambiental associado a todas as fases da vida de um produto desde a sua produção ao seu fim de vida

- Permite construir um inventário de inputs materiais e energéticos e de outputs ambientais



Análise de ciclo de vida (LCA)

- Permite avaliar os impactes potenciais associados a diferentes inputs e outputs
- Permite a comparação de processos o que ajuda na tomada de decisões mais informadas
- Metodologias reguladas pelas ISO 14040:2006 e 14044:2006.

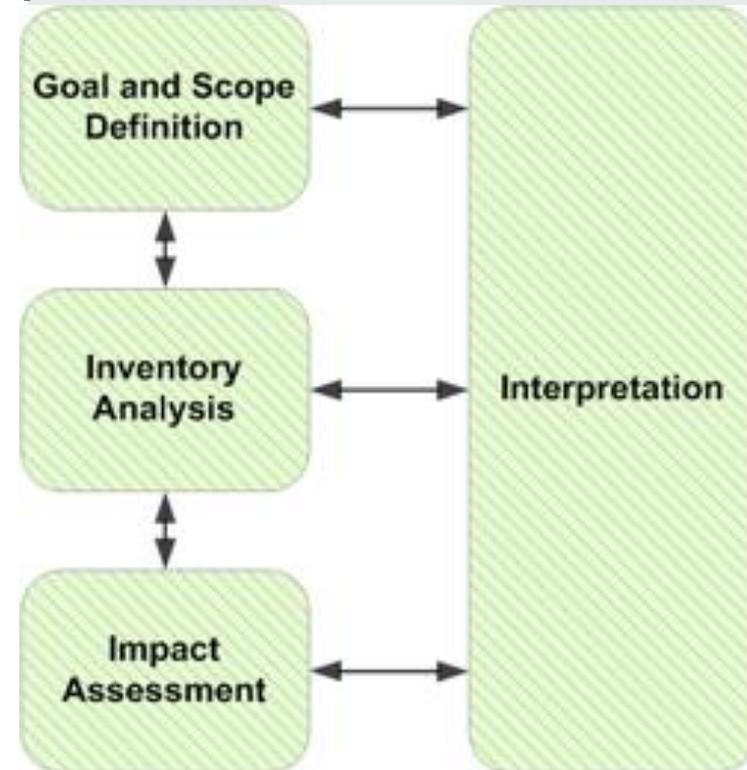
Análise de ciclo de vida (LCA)

- Permite avaliar os impactes potenciais associados a diferentes inputs e outputs
- Permite a comparação de processos o que ajuda na tomada de decisões mais informadas
- Metodologias reguladas pelas ISO 14040:2006 e 14044:2006.



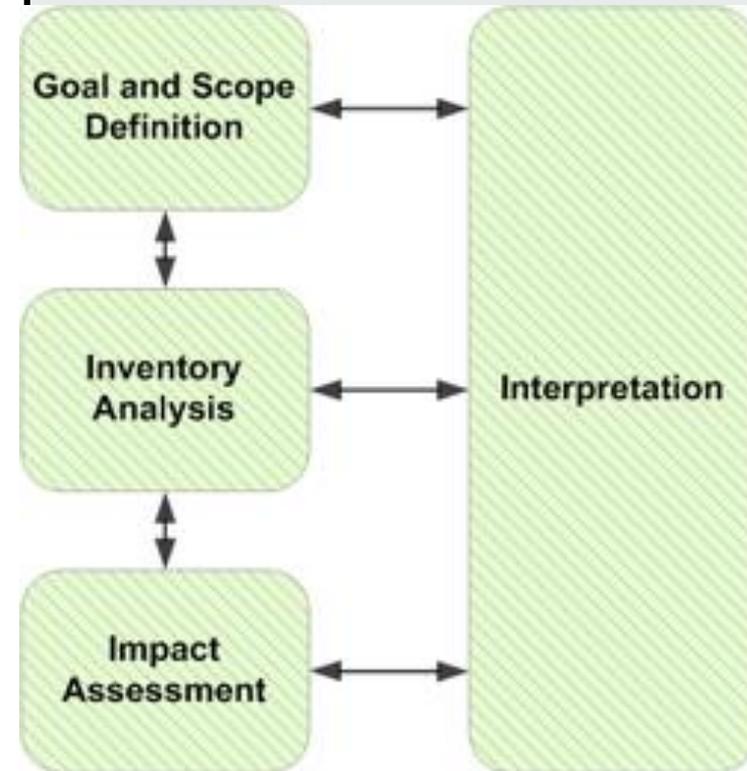
Passos para definição de LCA:

- **Definição da unidade funcional**, define o que está a ser estudado e quantifica o serviço a ser disponibilizado, sendo a referência à qual inputs e outputs se relacionam (**1 unidade?, 1kg, 1L???**)
- **Definição das fronteiras do Sistema**, define quais os processos que devem ou não ser incluídos na análise (**país, EU, mundo?**)
- **Outros pressupostos ou limitações**



Passos para definição de LCA:

- **Definição de método de alocação**, usado para alocar diversos produtos dentro do mesmo processo (**co-produtos: massa, volume, energia?**)
- **Definição das categorias de impacto**, por exemplo toxicidade humana, smog, aquecimento global, eutrofização (**o que queremos avaliar?**)



Ferramentas de quantificação de impactes



About SimaPro ▾ SimaPro Customers

Energy Systems



Enabling fact-based sustainability

SimaPro has been the world's leading LCA software package for 25 years. It is [trusted by industry and academics](#) in more than 80 countries. SimaPro was developed to help you effectively apply your LCA expertise to drive change – to provide the facts needed to create sustainable value.

RESEARCH
FACILITIES
PUBLICATIONS
NEWS

Home
Versions
Features
Documents
APIs
Modules
Contact us

GREET

- [Publications](#)
- [GREET.net Model](#)
- [Fuel-Cycle Model](#)
- [Vehicle-Cycle Model](#)
- [GREET WTW Calculator](#)
- [AFLEET Tool](#)
- [Fleet Footprint Calculator](#)

A fresh design for GREET life cycle analysis tool

GREET 2016 provides the user with an easy to use and fully graphical toolbox to perform life cycle analysis simulations of alternative transportation fuels and vehicle technologies in a matter of a few clicks. This new tool includes the data of the GREET model, a fast algorithm for processing it and an interactive user interface. The interface allows faster development using graphical representation of each element in the model, and drag & drop editing approach to add and modify data.

DOWNLOAD the new GREET 2016 software

If you have questions, please refer to our [Frequently Asked Questions and Answers](#).

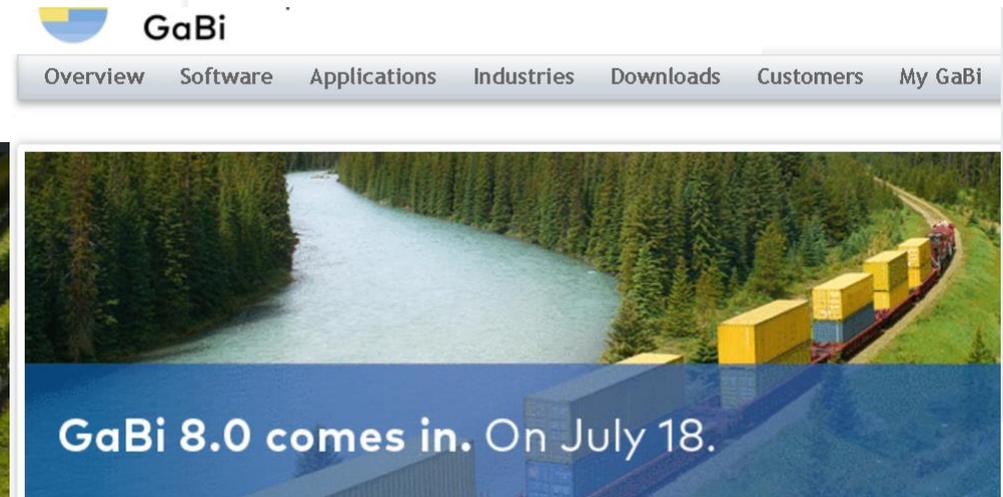


OpenLCA

Software ▾ LCA data ▾ Use cases ▾ Learning & Support ▾ Network ▾ About ▾ Download

The open source Life Cycle and Sustainability Assessment software

Free. Rich. Powerful. Reliable.



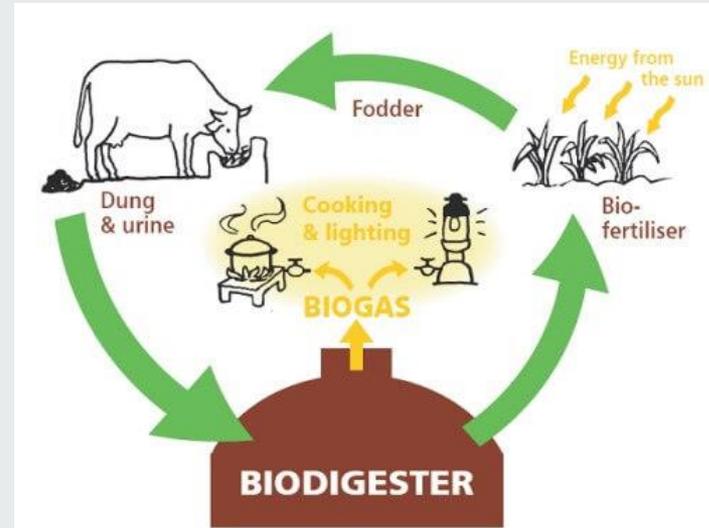
GaBi

Overview Software Applications Industries Downloads Customers My GaBi

GaBi 8.0 comes in. On July 18.

Fontes energéticas alternativas

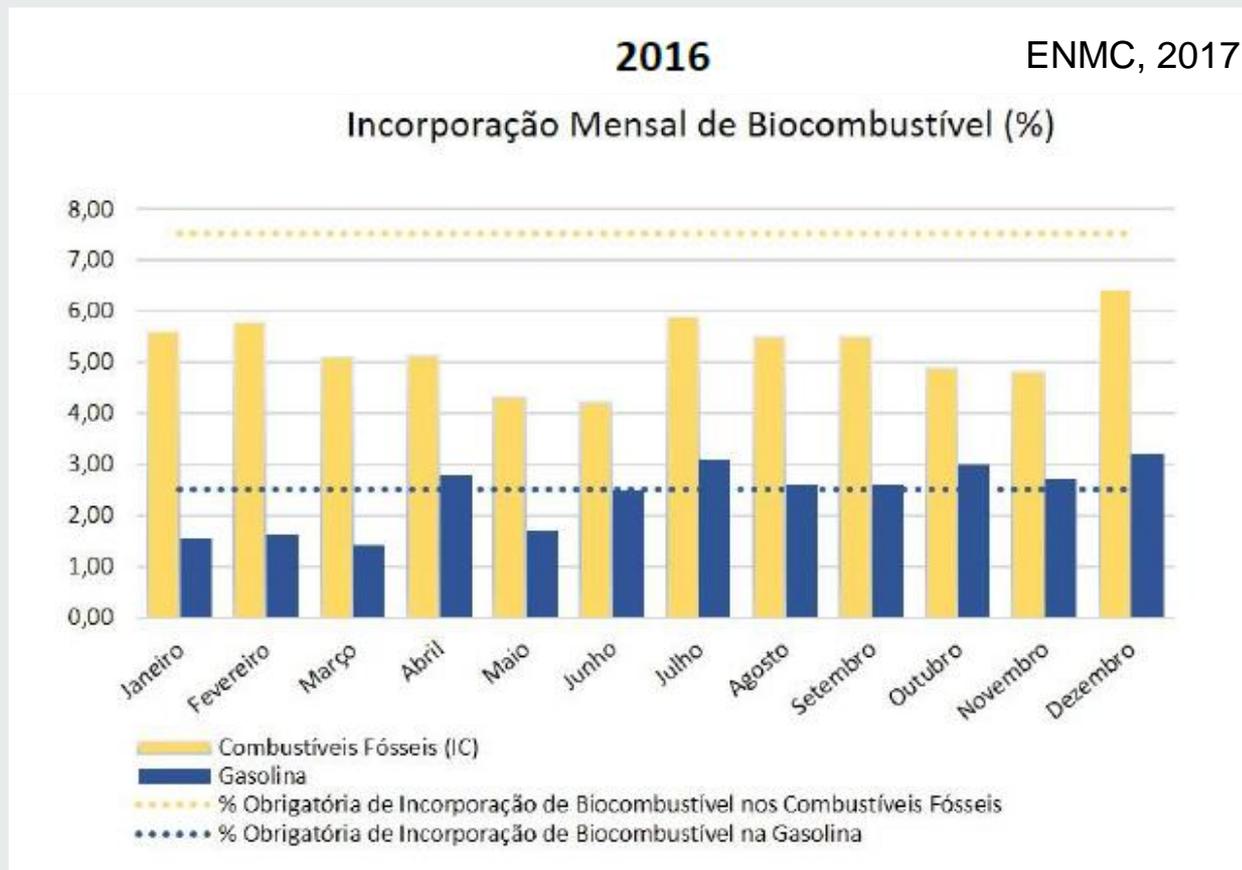
Fontes energéticas alternativas



Fontes energéticas alternativas

Que fontes energéticas alternativas já utilizamos?

Que fontes energéticas alternativas já utilizamos?



Que fontes energéticas alternativas já utilizamos?

		Portugal														
		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Transport																
Ren. electricity in road transport		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Ren. electricity in rail transport		10.9	11.1	12.0	11.9	12.7	13.4	13.9	12.6	13.5	11.5	12.0	12.7	19.0	21.6	0.0
Ren. electricity in all other transport modes		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.5	0.4	0.3	0.3	0.3	0.3	0.0
Compliant biofuels*		0.0	0.0	71.6	121.9	125.6	208.1	309.1	4.0	4.2	9.4	151.5	327.7	259.7	242.1	0.0
	Annex IX	x	x	x	x	x	x	x	4.0	4.2	9.4	10.1	35.7	107.2	139.5	0.0
	3(4)d first paragraph	x	x	x	x	x	x	x	0.0	0.0	0.0	0.0	249.4	137.9	101.5	0.0
	3(4)d third paragraph subsection (i) and (ii)	x	x	x	x	x	x	x	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	other compliant biofuels	x	x	x	x	x	x	x	0.0	0.0	0.0	141.4	42.5	14.7	1.1	0.0
Non-compliant biofuels		0.0	0.0	0.0	0.0	0.0	0.0	0.0	289.1	269.1	252.0	109.7	0.0	0.0	0.0	0.0
Other renewable energies		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (RES-T numerator with multipliers)		27.3	27.8	101.5	151.5	157.2	241.6	343.9	40.0	42.6	47.8	192.1	395.6	414.9	436.3	0.0
* In period 2004-2010 all consumed biofuels are included in this category; as of 2011 only those compliant with Articles 17 and 18 of Directive 2009/28/EC.																
Fuel used in transport (as defined in Article 3)																
Total (RES-T denominator with multipliers)		6,448.7	6,170.3	6,225.7	6,228.7	6,250.4	6,219.4	6,198.3	5,752.1	5,277.4	5,172.7	5,238.2	5,323.5	5,415.4	5,499.9	0.0
Note: All calculation provisions set out in Directive 2009/28/EC are applied to the total numerator and the total denominator																
RES-T [%]		0.42%	0.45%	1.63%	2.43%	2.51%	3.88%	5.55%	0.69%	0.81%	0.93%	3.67%	7.43%	7.66%	7.93%	

Fontes energéticas alternativas

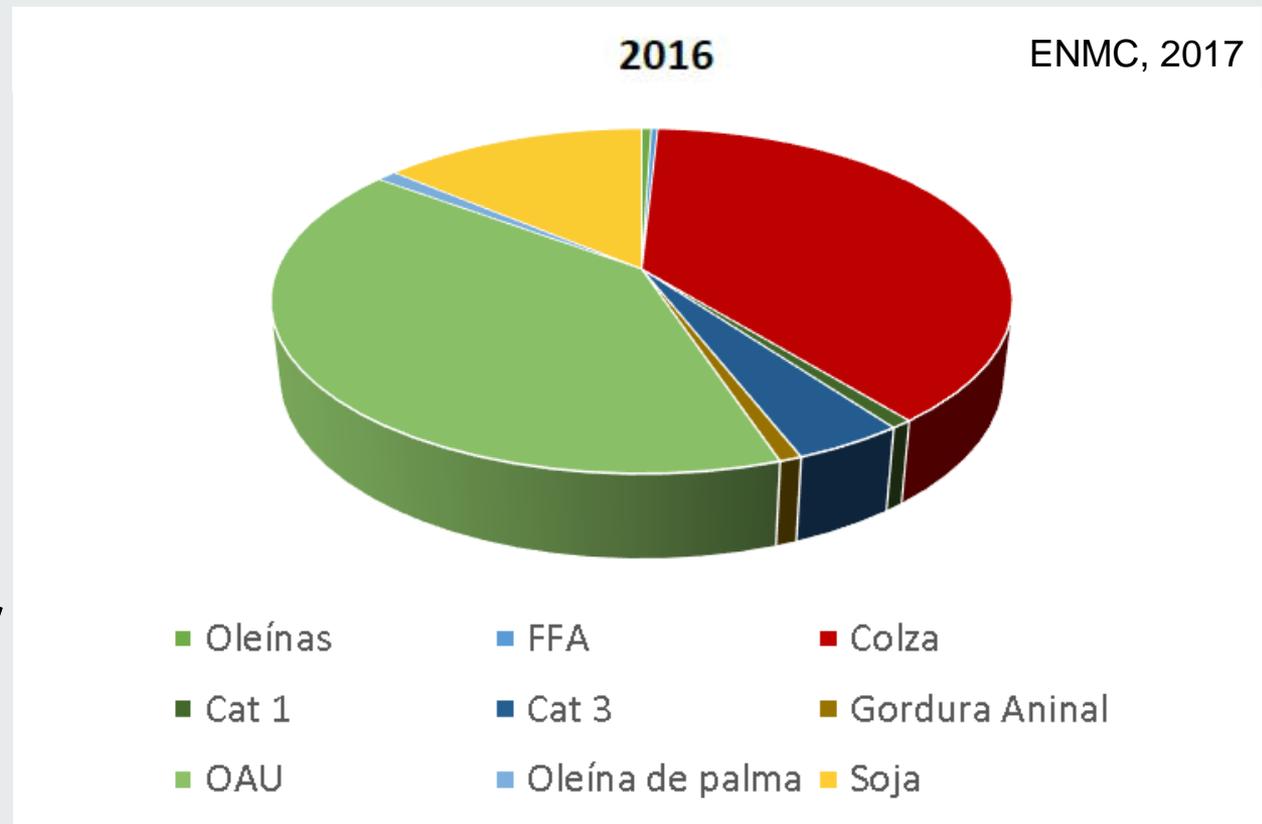
Que matérias primas são utilizadas para produzir essas fontes energéticas alternativas?

Que matérias primas são utilizadas para produzir essas fontes energéticas alternativas?

- Origem?
- Processos?
- Critérios de sustentabilidade?



Economia circular



Qual a utilização das fontes energéticas alternativas?

LCA of vehicle technologies and energy sources

1. Tank-to-Wheel (TTW) - vehicle utilization stage related to driving the vehicle.



2. Well-to-Tank (WTT) - fuel production stage.



3. Materials Cradle-to-Grave (CTG) - the vehicle manufacturing, maintenance and recycling.

Ciclo de vida aplicado aos transportes

1. Tank-to-Wheel (TTW) - vehicle utilization stage related to driving the vehicle.

Fleet

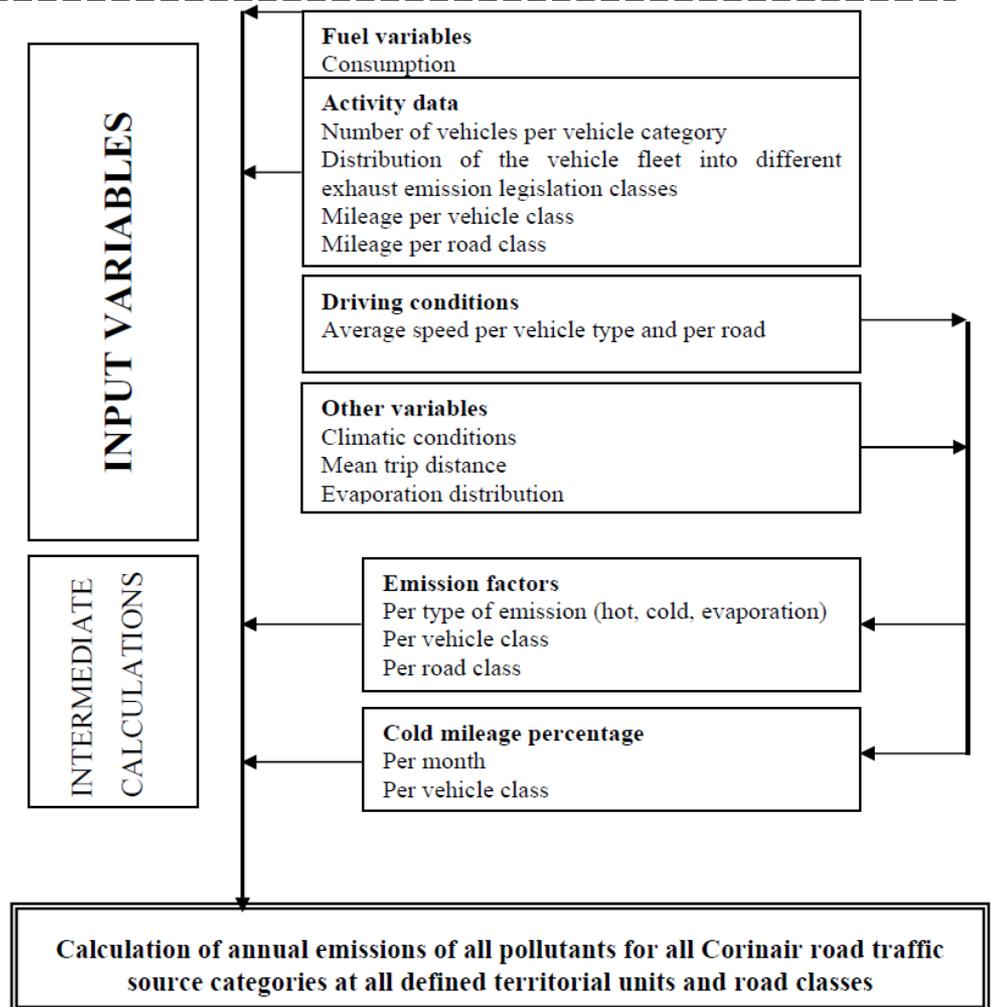
Fleet macro-simulation




version 9.1

Fuel, VOC, NO_x, PM, CO, zinc, selenium, Ni, chromium, copper, cadmium, lead, Sulphur, NH₃, N₂O

1985-2007 - March 2010 financed by the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre on Air and Climate Change.



Ciclo de vida aplicado aos transportes

1. Tank-to-Wheel (TTW) - vehicle utilization stage related to driving the vehicle.

Emissions:

$$E_{\text{TOTAL}} = E_{\text{HOT}} + E_{\text{COLD}} + E_{\text{EVAP}}$$

$$E_{\text{TOTAL}} = E_{\text{URBAN}} + E_{\text{RURAL}} + E_{\text{HIGHWAY}}$$

Table 4.1: Typical average speed ranges for the application of the methodology in different driving situations

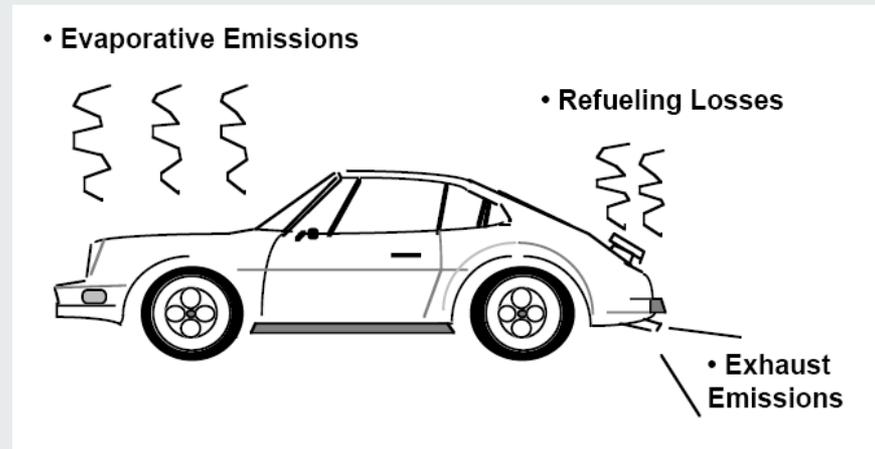
Driving Situation	Typical Speed Range (km/h)
Urban	10 - 50
Rural	40 - 80
Highway	70 - 130

Calculations:

$$E_{\text{HOT}(i,j,k)} = N_j \times M_{j,k} \times e_{\text{HOT}(i,j,k)}$$

$$E_{\text{COLD}(i,j)} = \beta_{i,j} \times N_j \times M_j \times e_{\text{HOT}(i,j)} \times (e_{\text{COLD}(i,j)} / e_{\text{HOT}(i,j)} - 1)$$

$$E_{\text{EVA}(j)} = 365 \times N_j \times (e^d + S^c + S^{\text{fi}}) + R$$



Ciclo de vida aplicado aos transportes

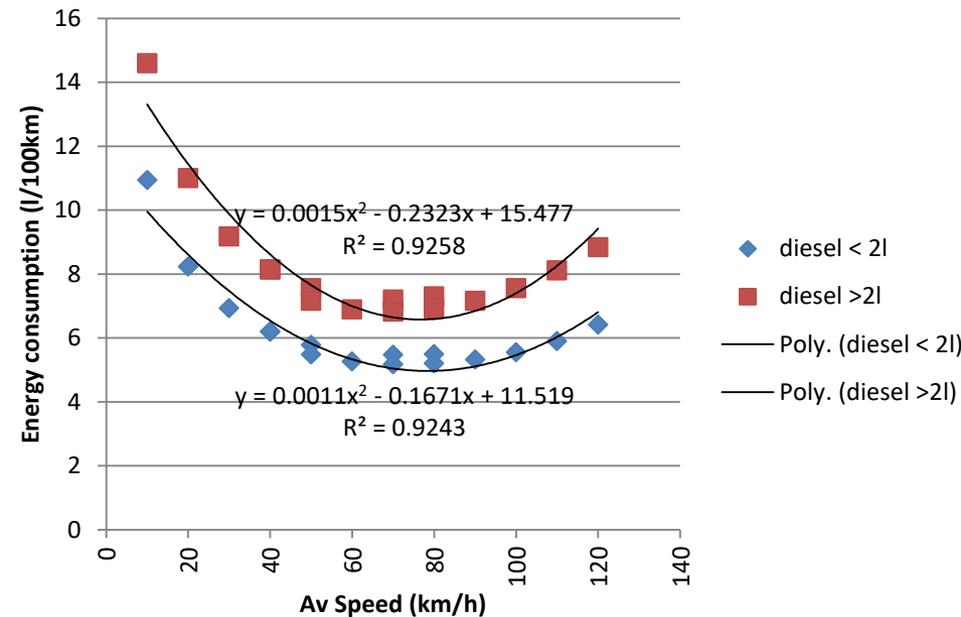
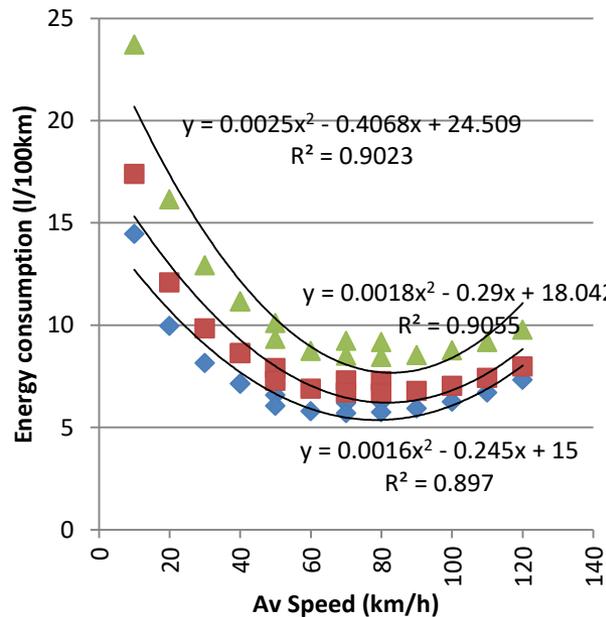
1. Tank-to-Wheel (TTW) - vehicle utilization stage related to driving the vehicle.

FC versus Speed: average Portuguese fleet

Ciclo de vida aplicado aos transportes

1. Tank-to-Wheel (TTW) - vehicle utilization stage related to driving the vehicle.

FC versus Speed: average Portuguese fleet



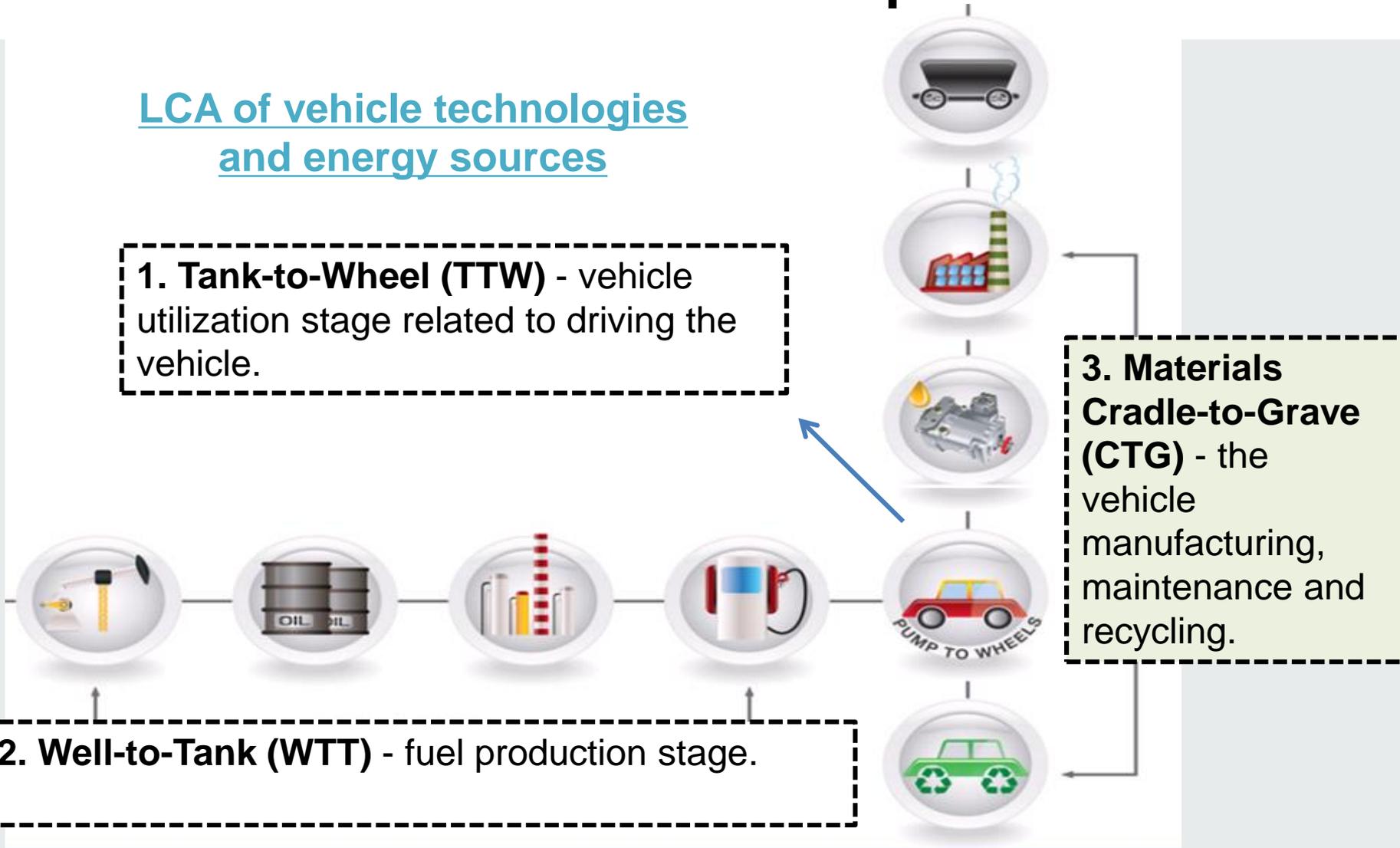
Ciclo de vida aplicado aos transportes

LCA of vehicle technologies and energy sources

1. Tank-to-Wheel (TTW) - vehicle utilization stage related to driving the vehicle.

2. Well-to-Tank (WTT) - fuel production stage.

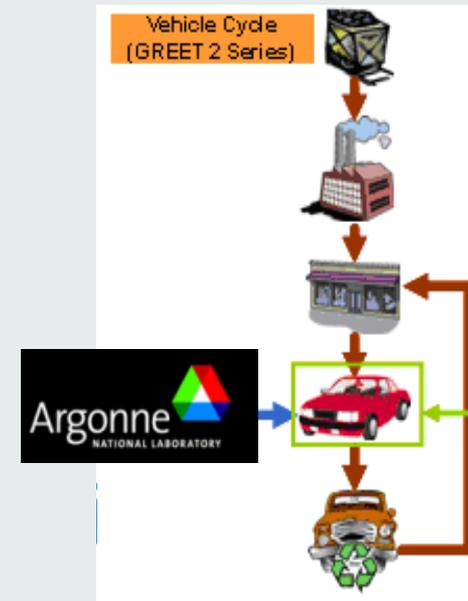
3. Materials Cradle-to-Grave (CTG) - the vehicle manufacturing, maintenance and recycling.



Ciclo de vida aplicado aos transportes

3. Materials Cradle-to-Grave (CTG)

- Includes the vehicle **assembling**, the **maintenance** during its lifetime and finally the **dismantling** and **recycling** processes of the vehicle;
- The materials life-cycle energy consumption and emissions are spread along the **vehicle expected lifetime**; and
- Due to significant import rates of the different constituents of the vehicle, the **European** electricity generation mix is appropriate.



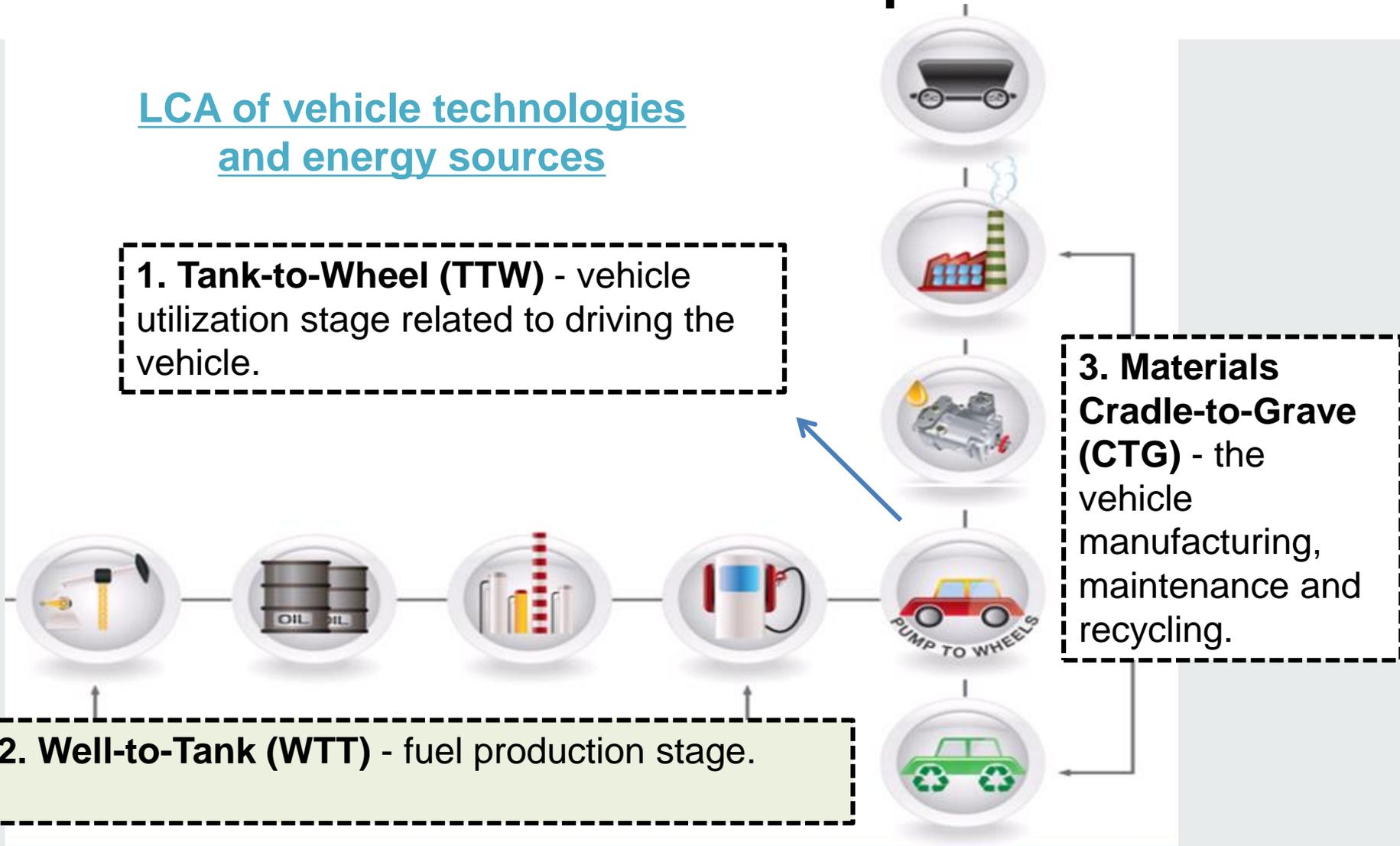
Ciclo de vida aplicado aos transportes

LCA of vehicle technologies and energy sources

1. Tank-to-Wheel (TTW) - vehicle utilization stage related to driving the vehicle.

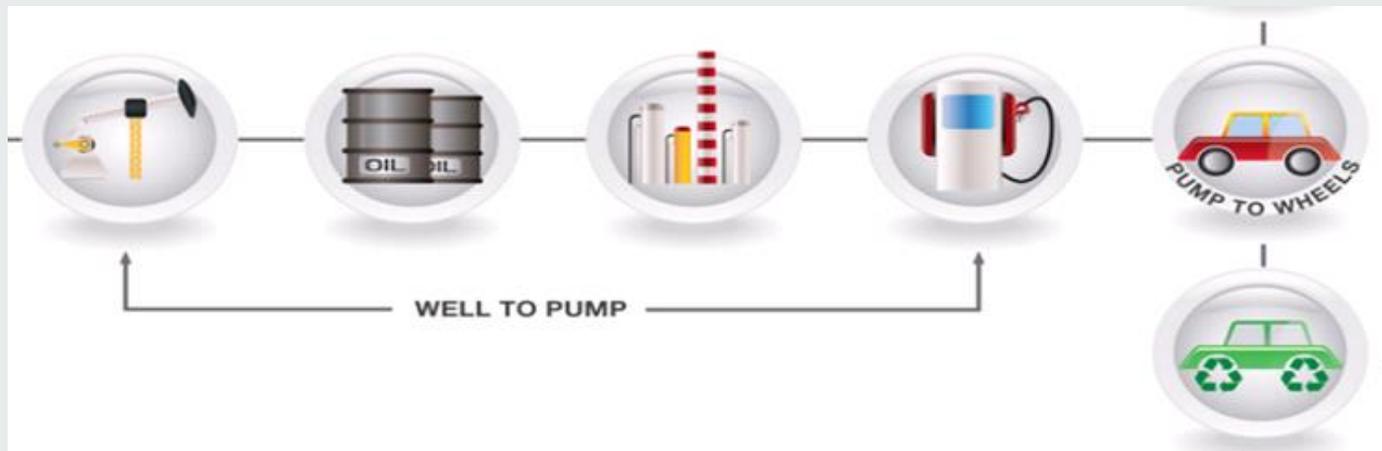
2. Well-to-Tank (WTT) - fuel production stage.

3. Materials Cradle-to-Grave (CTG) - the vehicle manufacturing, maintenance and recycling.



2. Well-to-Tank (WTT) - fuel production stage.

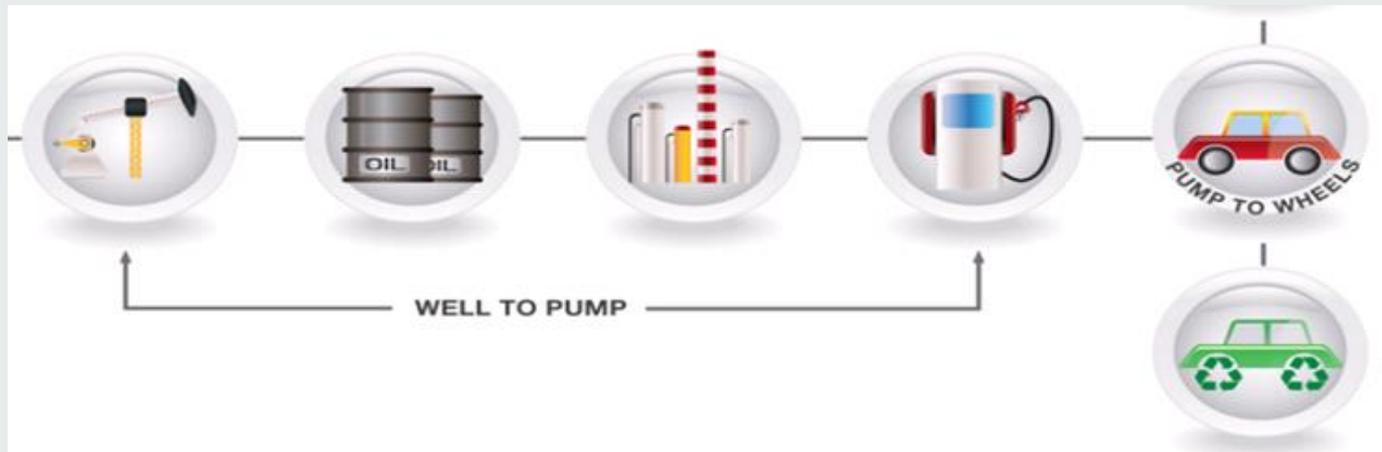
The total energy of the WTT pathways (MJ_{ex}) is the **WTT expended energy** so it does not include the energy content of the produced fuel.



2. Well-to-Tank (WTT) - fuel production stage.

The total energy of the WTT pathways (MJ_{ex}) is the **WTT expended energy** so it does not include the energy content of the produced fuel.

To obtain 1 MJ of fuel to be used by the vehicle...

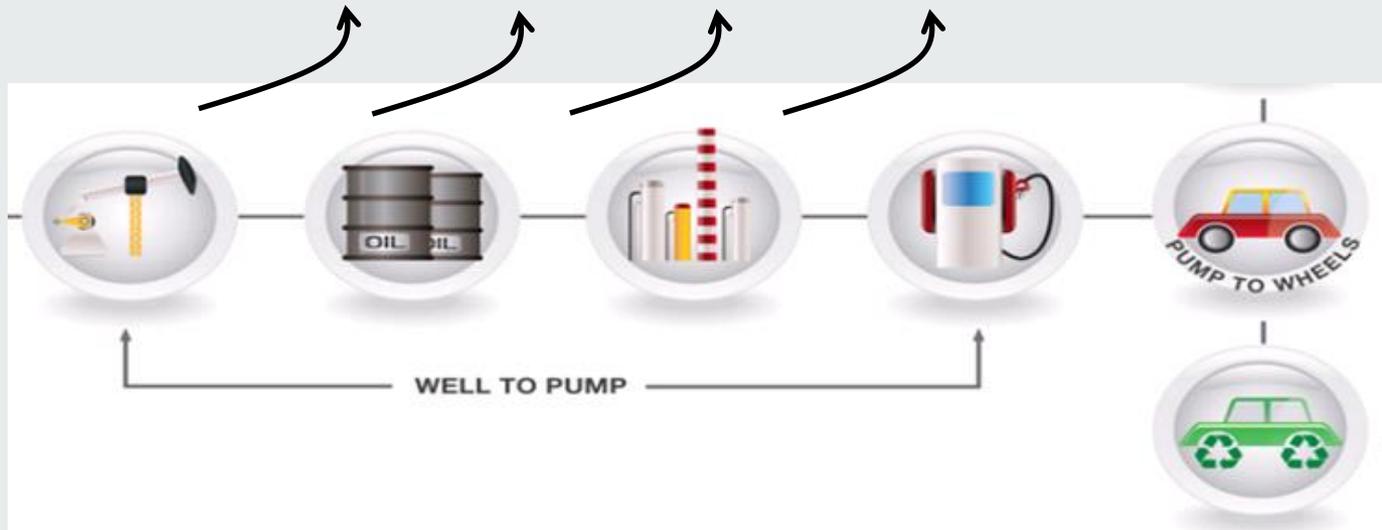


2. Well-to-Tank (WTT) - fuel production stage.

The total energy of the WTT pathways (MJ_{ex}) is the **WTT expended energy** so it does not include the energy content of the produced fuel.

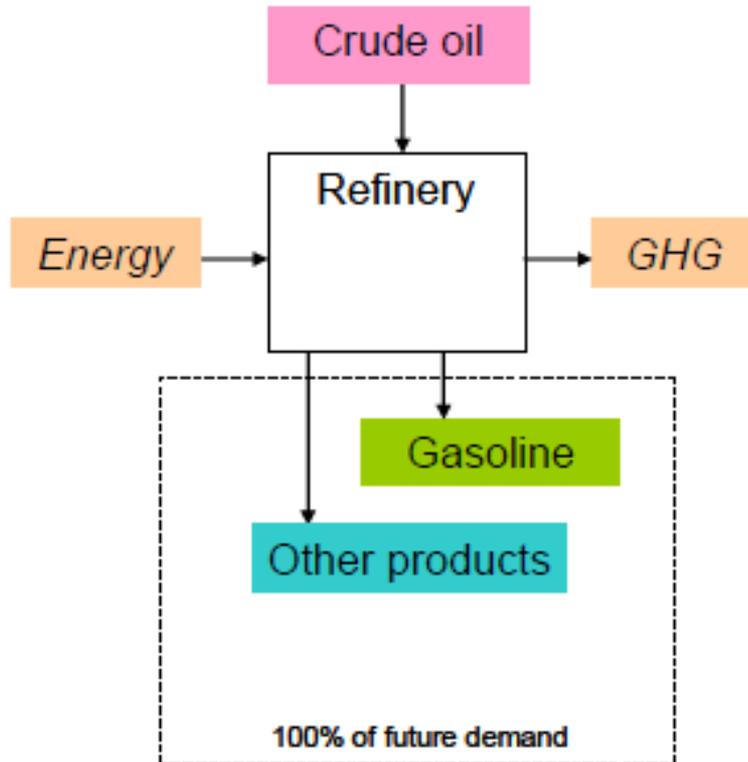
Losses in the WTT stage:

- MJ expended
- grams of CO_2 emitted



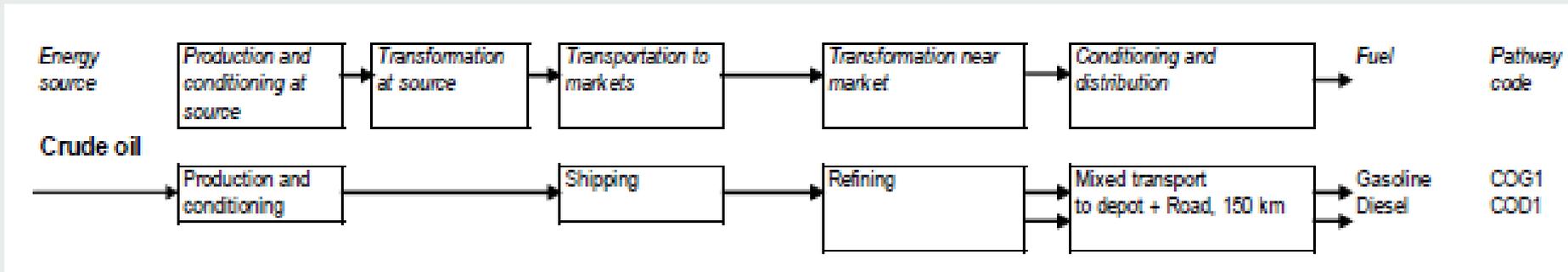
WTW factor = 1 unit of energy (MJ) + expended energy (MJ)

2. Well-to-Tank (WTT) – conventional fuels



Para cada etapa do processo, inclusão de todos os inputs (materiais, energéticos, etc.) e de todos os outputs (materiais, emissões, etc) em cada um dos processos

2. Well-to-Tank (WTT) – conventional fuels



- Contabilização de todas as etapas desde a extracção, produção e disponibilização da fonte energética

2. Well-to-Tank (WTT) – conventional fuels

WTT Gasoline		Energy expended MJ/MJ _{gasoline}	GHG emissions g CO _{2eq} /MJ _{gasoline}			
			Total	as CO ₂	as CH ₄	as N ₂ O
<i>Standard steps</i>	<i>Actual steps</i>					
Production & conditioning at source	Crude oil production	0.07	4.6	3.94	0.66	0.00
Transformation at source	NA					
Transportation to market	Crude oil transport	0.01	1.0	0.95	0.00	0.00
Transformation near market	Crude refining, marginal gasoline	0.08	7.0	7.01	0.00	0.00
Conditioning & distribution	Distribution	0.01	0.6	0.61	0.01	0.01
	Dispensing at retail site	0.01	0.6	0.53	0.03	0.00
Total WTT		0.18	13.8			

WTT Diesel		Energy expended MJ/MJ _{diesel}	GHG emissions g CO _{2eq} /MJ _{diesel}			
			Total	as CO ₂	as CH ₄	as N ₂ O
<i>Standard steps</i>	<i>Actual steps</i>					
Production & conditioning at source	Crude oil production	0.07	4.7	4.00	0.67	0.00
Transformation at source	NA					
Transportation to market	Crude oil transport	0.01	1.0	0.97	0.00	0.00
Transformation near market	Crude refining, marginal diesel	0.10	8.6	8.60	0.00	0.00
Conditioning & distribution	Distribution	0.01	0.6	0.58	0.02	0.01
	Dispensing at retail site	0.01	0.5	0.48	0.03	0.00
Total WTT		0.20	15.4			

2. Well-to-Tank (WTT) – conventional fuels

Conversion yields?

WTT gasoline = $1/1.18 = 85\%$

WTT diesel = $1/1.20 = 83\%$

WTT Gasoline		Energy expended MJ/MJ _{gasoline}	GHG emissions g CO _{2eq} /MJ _{gasoline}			
			Total	as CO ₂	as CH ₄	as N ₂ O
<i>Standard steps</i>	<i>Actual steps</i>					
Production & conditioning at source	Crude oil production	0.07	4.6	3.94	0.66	0.00
Transformation at source	NA					
Transportation to market	Crude oil transport	0.01	1.0	0.95	0.00	0.00
Transformation near market	Crude refining, marginal gasoline	0.08	7.0	7.01	0.00	0.00
Conditioning & distribution	Distribution	0.01	0.6	0.61	0.01	0.01
	Dispensing at retail site	0.01	0.6	0.53	0.03	0.00
Total WTT		0.18	13.8			

To obtain 1 MJ of gasoline (final energy),
 1.18 MJ of primary energy are required:

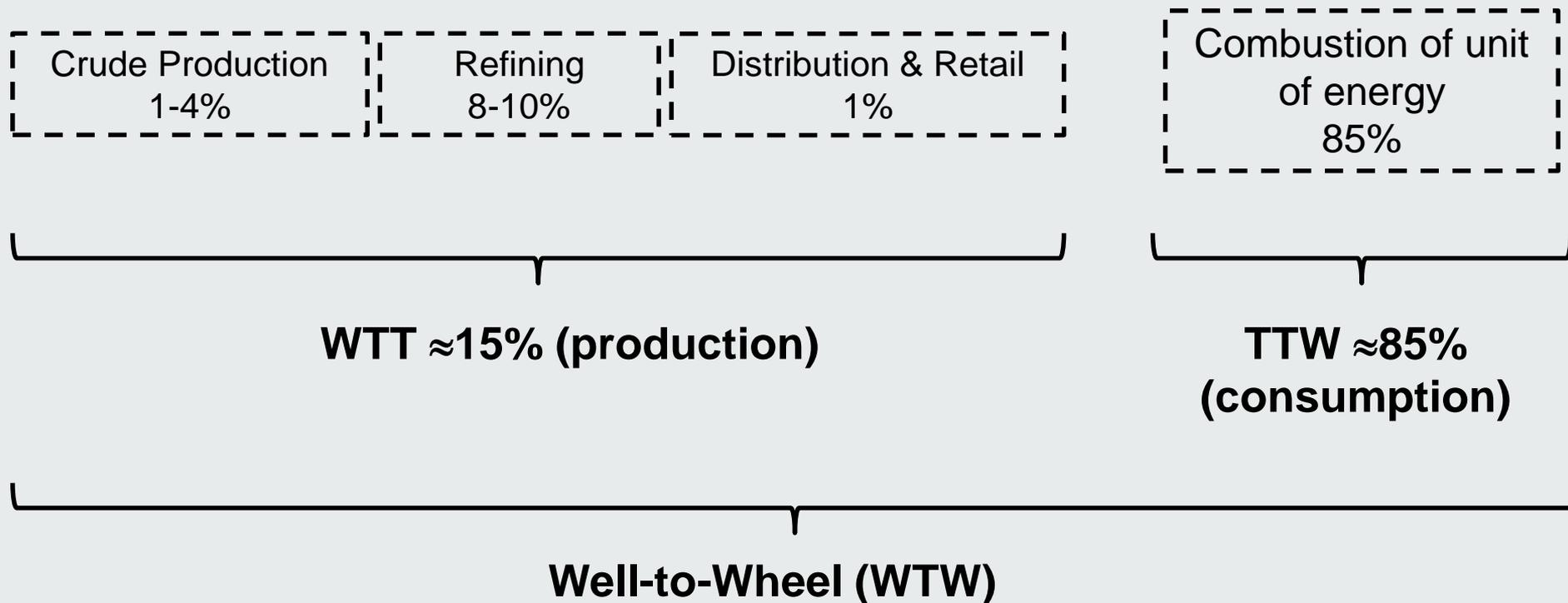
- WTT expended energy – the losses are of **0.18 MJ**.

- WTT emission factor – 14 g per MJ of **gasoline**.

		Energy expended MJ/MJ _{diesel}	GHG emissions g CO _{2eq} /MJ _{diesel}			
			Total	as CO ₂	as CH ₄	as N ₂ O
<i>Standard</i>	<i>Actual</i>					
Production & conditioning at source	Crude oil production	0.07	4.7	4.00	0.67	0.00
Transformation at source	NA					
Transportation to market	Crude oil transport	0.01	1.0	0.97	0.00	0.00
Transformation near market	Crude refining, marginal diesel	0.10	8.6	8.60	0.00	0.00
Conditioning & distribution	Distribution	0.01	0.6	0.58	0.02	0.01
	Dispensing at retail site	0.01	0.5	0.48	0.03	0.00
Total WTT		0.20	15.4			

2. Well-to-Tank (WTT) – conventional fuels

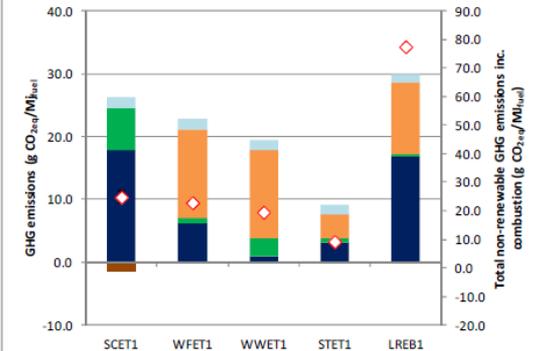
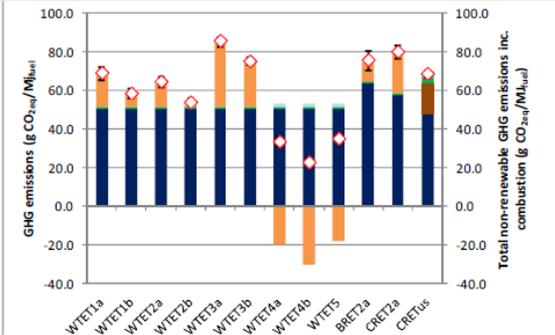
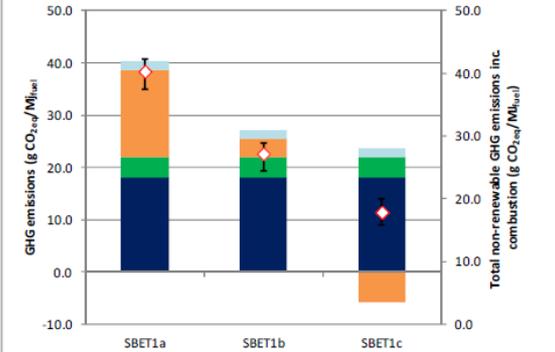
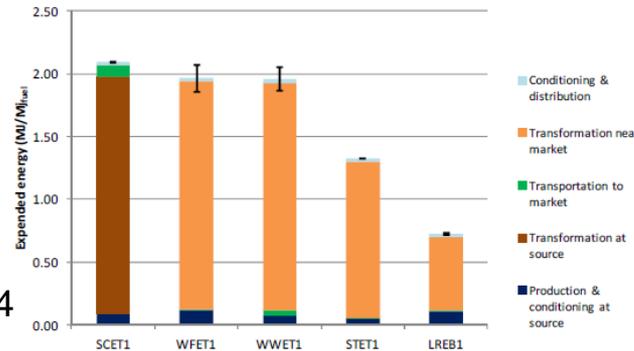
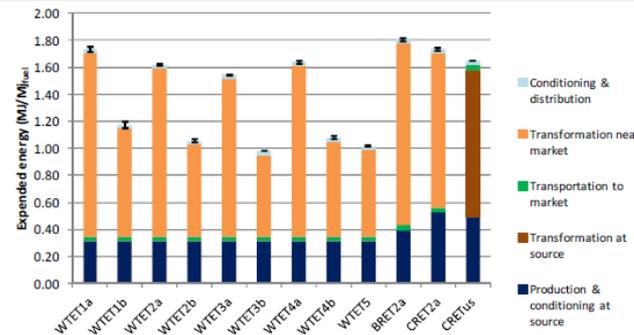
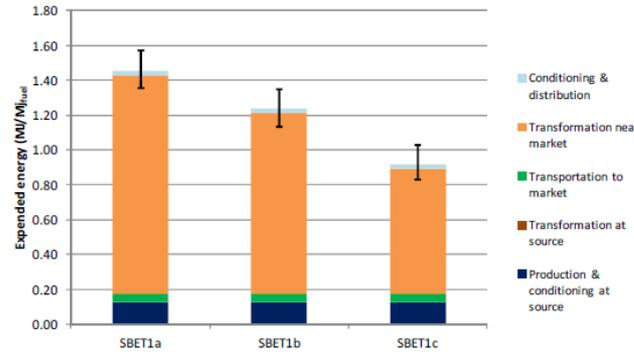
Diesel and Gasoline GHG life-cycle emissions per unit of energy



2. Well-to-Tank (WTT) – alternative energy sources

Ethanol

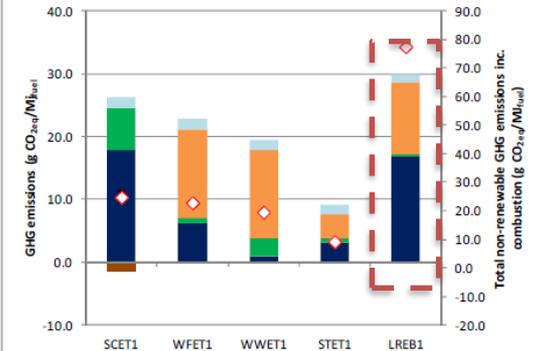
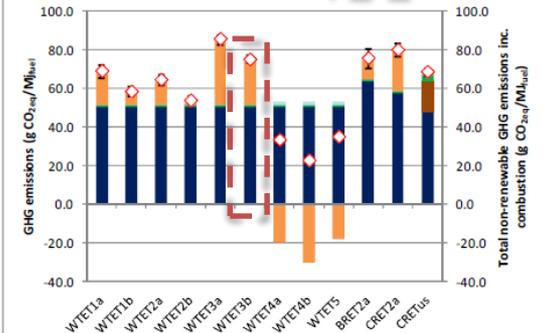
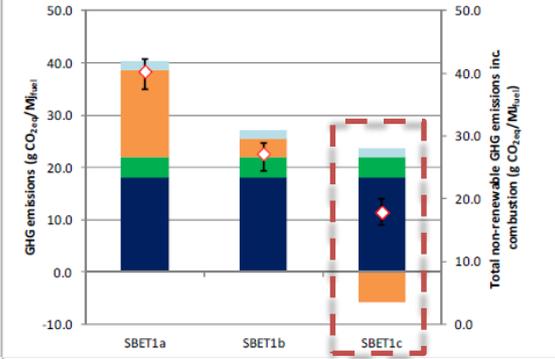
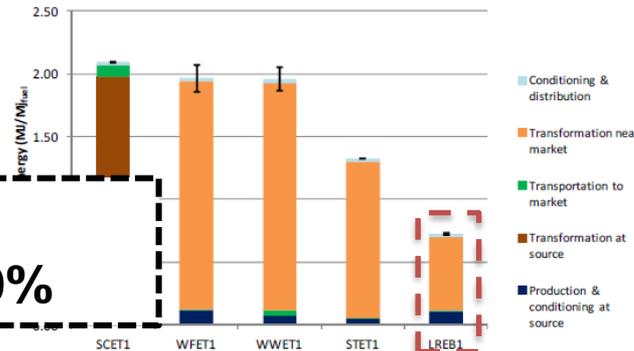
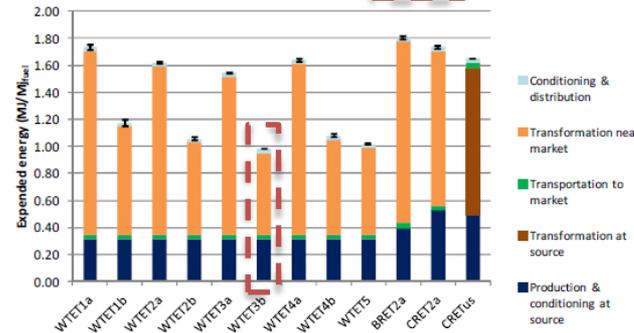
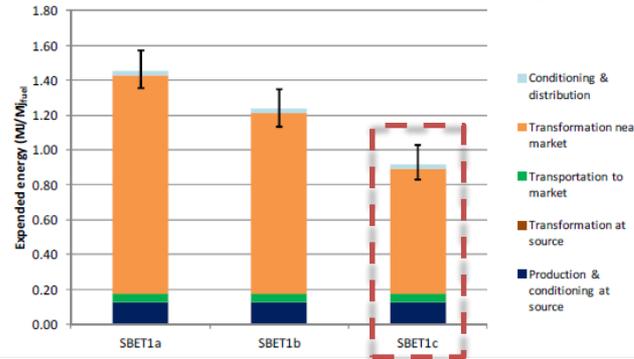
Ethanol	
SBET1a	Sugar beet, pulp to AF, slops not used
SBET1b	Sugar beet, pulp to AF, slops to biogas
SBET1c	Sugar beet, pulp to fuel, slops to biogas
WTET1a	Wheat, conv NG boiler, DDGS as AF
WTET1b	Wheat, conv NG boiler, DDGS as fuel
WTET2a	Wheat, NG GT+CHP, DDGS as AF
WTET2b	Wheat, NG GT+CHP, DDGS as fuel
WTET3a	Wheat, Lignite CHP, DDGS as AF
WTET3b	Wheat, Lignite CHP, DDGS as fuel
WTET4a	Wheat, Straw CHP, DDGS as AF
WTET4b	Wheat, Straw CHP, DDGS as fuel
WTET5	Wheat, DDGS to biogas
BRET2a	Barley/Rye, NG GT+CHP, DDGS as AF
CRET2a	Maize, NG GT+CHP, DDGS as AF
CRETus	Corn US, DDGS as AF
SCET1	Sugar cane (Brazil)
WFET1	F wood
WWET1	W wood
STET1	Wheat straw
ETBE	
LREB1	ETBE: imported C4 and wheat ethanol



2. Well-to-Tank (WTT) – alternative energy sources

Ethanol

Ethanol	
SBET1a	Sugar beet, pulp to AF, slops not used
SBET1b	Sugar beet, pulp to AF, slops to biogas
SBET1c	Sugar beet, pulp to fuel, slops to biogas
WTET1a	Wheat, conv NG boiler, DDGS as AF
WTET1b	Wheat, conv NG boiler, DDGS as fuel
WTET2a	Wheat, NG GT+CHP, DDGS as AF
WTET2b	Wheat, NG GT+CHP, DDGS as fuel
WTET3a	Wheat, Lignite CHP, DDGS as AF
WTET3b	Wheat, Lignite CHP, DDGS as fuel
WTET4a	Wheat, Straw CHP, DDGS as AF
WTET4b	Wheat, Straw CHP, DDGS as fuel
WTET5	Wheat, DDGS to biogas
BRET2a	Barley/Rye, NG GT+CHP, DDGS as AF
CRET2a	Maize, NG GT+CHP, DDGS as AF
CRETus	Corn US, DDGS as AF
SCET1	Sugar cane (Brazil)
WFET1	F wood
WWET1	W wood
STET1	Wheat straw
ETBE	
LREB1	ETBE: imported C4 and wheat ethanol

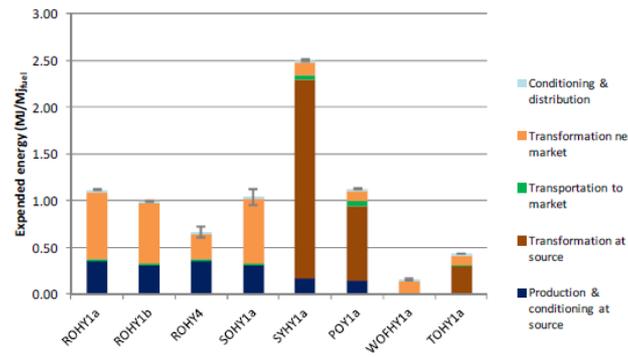
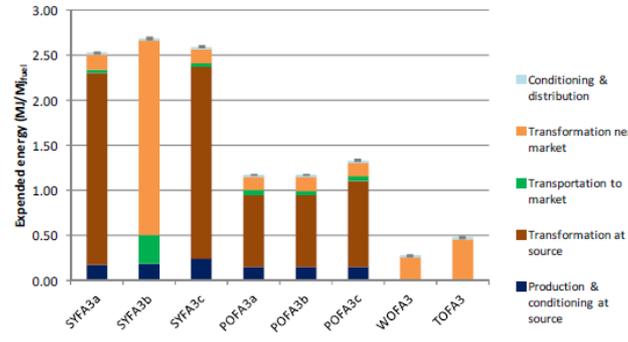
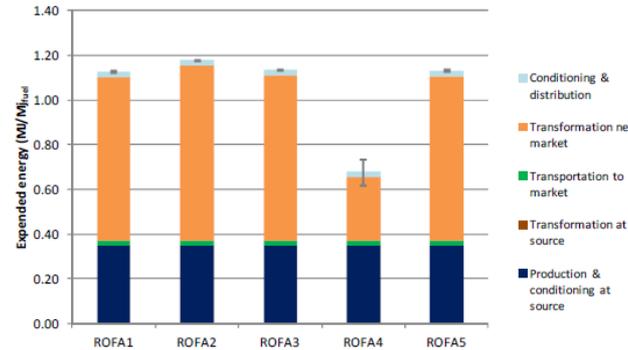


Conversion yields?

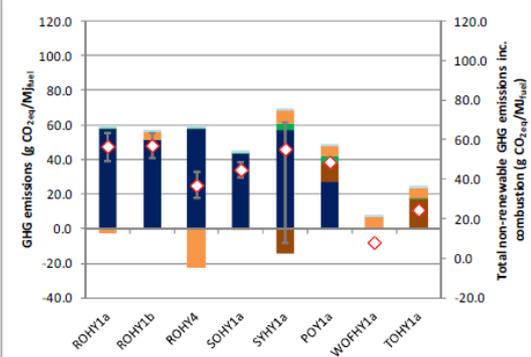
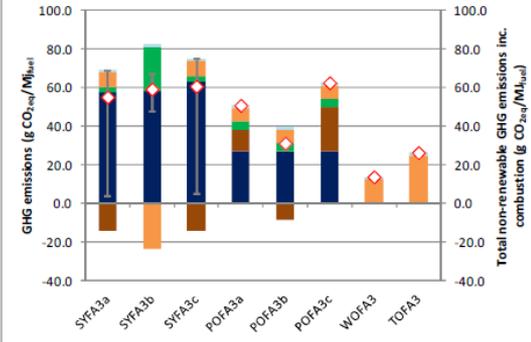
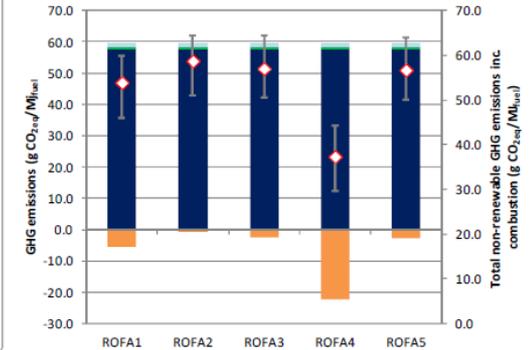
WTT ethanol = $1/1.70 = 59\%$

2. Well-to-Tank (WTT) – alternative energy sources

Conventional fossil fuels	
COD1	Diesel
Biodiesel	
ROFA1	RME: Meal as AF, glycerine as chem.
ROFA2	RME: Meal and glycerine as AF
ROFA3	RME: Meal as AF, glycerine to biogas
ROFA4	RME: Meal and glycerine to biogas
ROFA5	RME: Meal as AF, Glycerine to hydrogen
ROFE3	REE: Meal as AF, glycerine to biogas
SOFA3	RME: Meal as AF, glycerine to biogas
SYFA3a	SYME: No till, oil import, meal as AF, glycerine to biogas
SYFA3b	SYME: No till, beans import, meal as AF, glycerine to biogas
SYFA3c	SYME: Conv. culture, oil import, meal as AF, glycerine to biogas
POFA3a	POME: Meal as AF, no CH4 rec., heat credit, glycerine to biogas
POFA3b	POME: Meal as AF, CH4 rec., heat credit, glycerine to biogas
POFA3c	POME: Meal as AF, no CH4 rec., no heat credit, glycerine to biogas
WOFA3a	FAME: waste cooking oil
TOFA3a	FAME: tallow oil
HVO	
ROHY1a	HRO (NExBTL), meal as AF
ROHY1b	HRO (UOP), meal as AF
ROHY4	HRO (NExBTL), meal to biogas
SOHY1a	HSO (NExBTL), meal as AF
SYHY1a	HSO (NExBTL), oil imported
POY1a	HPO (NExBTL), no CH4 rec.
WOHY1a	HWO (NExBTL), waste cooking oil
TOHY1a	HTO (NExBTL), tallow oil



Biodiesel



Ciclo de vida Conversion yields?

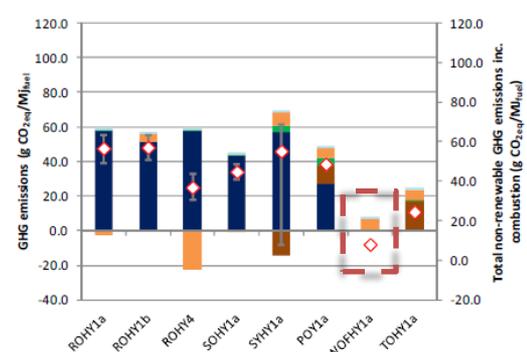
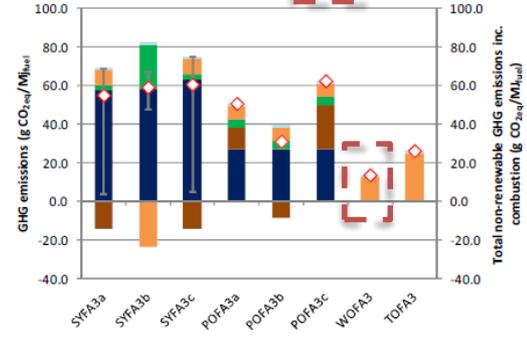
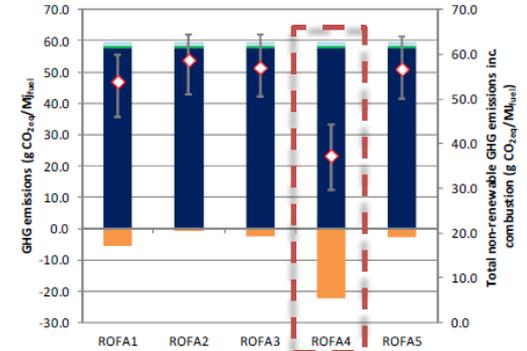
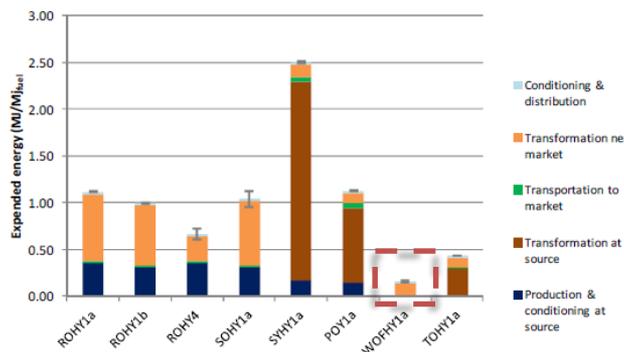
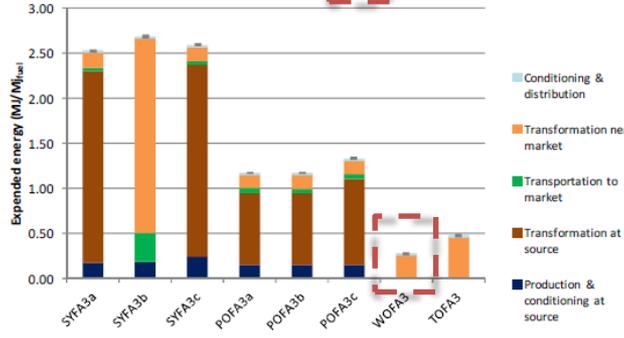
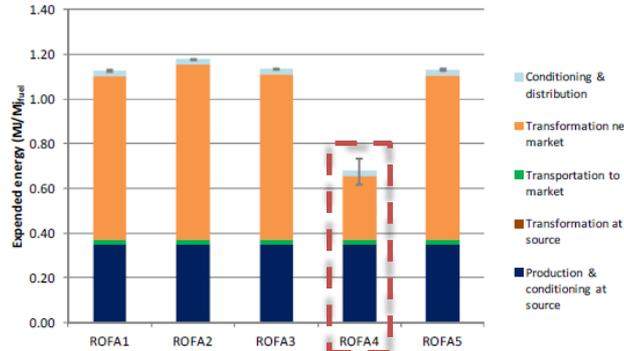
WTT biodiesel FAME = $1/1.68 = 35\%$

WTT biodiesel OAU = $1/1.28 = 78\%$

WTT biodiesel HVO = $1/1.16 = 86\%$

2. Well-to-Tank (WTT) – alternative energy sources

Conventional fossil fuels	
COD1	Diesel
Biodiesel	
ROFA1	RME: Meal as AF, glycerine as chem.
ROFA2	RME: Meal and glycerine as AF
ROFA3	RME: Meal as AF, glycerine to biogas
ROFA4	RME: Meal and glycerine to biogas
ROFA5	RME: Meal as AF, Glycerine to hydrogen
ROFE3	REE: Meal as AF, glycerine to biogas
SOFA3	RME: Meal as AF, glycerine to biogas
SYFA3a	SYME: No till, oil import, meal as AF, glycerine to biogas
SYFA3b	SYME: No till, beans import, meal as AF, glycerine to biogas
SYFA3c	SYME: Conv. culture, oil import, meal as AF, glycerine to biogas
POFA3a	POME: Meal as AF, no CH4 rec., heat credit, glycerine to biogas
POFA3b	POME: Meal as AF, CH4 rec., heat credit, glycerine to biogas
POFA3c	POME: Meal as AF, no CH4 rec., no heat credit, glycerine to biogas
WOFA3a	FAME: waste cooking oil
TOFA3a	FAME: tallow oil
HVO	
ROHY1a	HRO (NExBTL), meal as AF
ROHY1b	HRO (UOP), meal as AF
ROHY4	HRO (NExBTL), meal to biogas
SOHY1a	HSO (NExBTL), meal as AF
SYHY1a	HSO (NExBTL), oil imported
POY1a	HPO (NExBTL), no CH4 rec.
WOHY1a	HWO (NExBTL), waste cooking oil
TORY1a	HTO (NExBTL), tallow oil

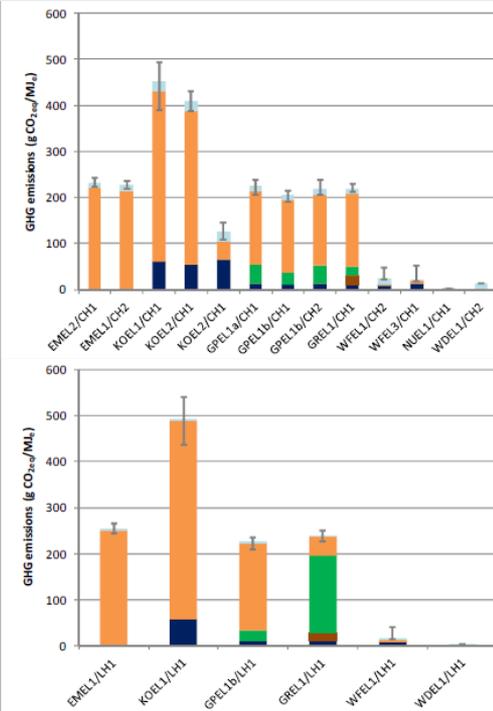
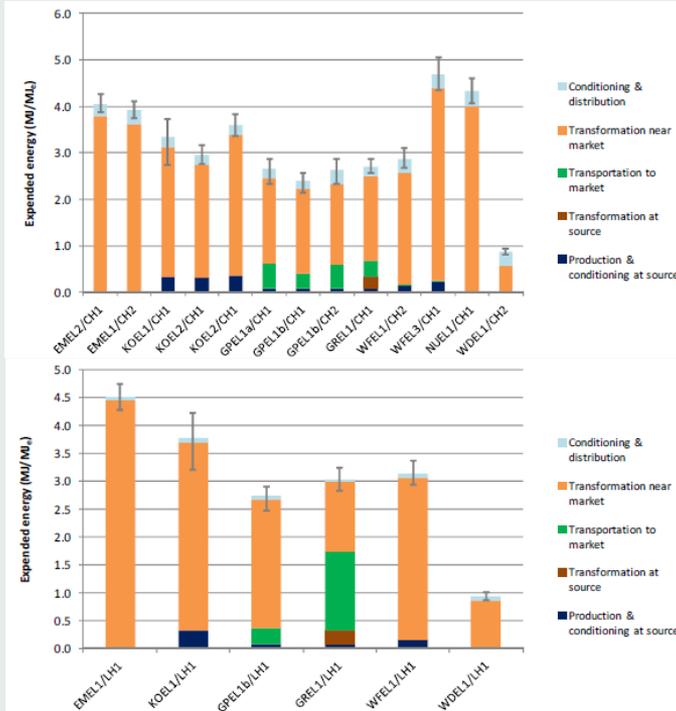


2. Well-to-Tank (WTT) – alternative energy sources

Bio-H₂

Hydrogen (electrolysis)

GP1a/CH1	C-H2: NG 7000 km, CCGT, O/S Ely
GP1b/CH1	C-H2: NG 4000 km, CCGT, O/S Ely
GP1b/CH2	C-H2: NG 4000 km, CCGT, Cen Ely, Pipe
GR1/CH1	C-H2: LNG, O/S Ely
WF1/CH2	C-H2: F Wood, 200 MW gasif, CCGT, Cen eLy, Pipe
WF3/CH1	C-H2: F Wood, Conv power, O/S Ely
EM2/CH1	C-H2: Elec EU-mix, O/S Ely
EM1/CH2	C-H2: Elec EU-mix, Cen eLy, Pipe
EM1/LH1	Co-H2: Elec EU-mix, Cen eLy, Liq, Road
KO1/CH1	C-H2: Elec coal EU-mix conv., O/S Ely
KO2/CH1	C-H2: Elec coal EU-mix IGCC, O/S Ely
KO2C/CH1	C-H2: Elec coal EU-mix IGCC + CCS, O/S Ely
NU1/CH1	C-H2: Elec nuclear, O/S Ely
WD1/CH2	C-H2: Wind, Cen Ely, Pipe
GP1b/LH1	Co-H2: NG 4000 km, CCGT, Cen Ely, Liq, Road
GR1/LH1	Co-H2: LNG, Ely
WF1/LH1	Co-H2: F Wood, 200 MW gasif, CCGT, Cen Ely, Liq, Road
EM1/LH1	Co-H2: Elec EU-mix, Cen Ely, Liq, Road
KO1/LH1	Co-H2: Elec coal EU-mix, Cen Ely, Liq, Road
WD1/LH1	Co-H2: Wind, Cen Ely, Liq, Road

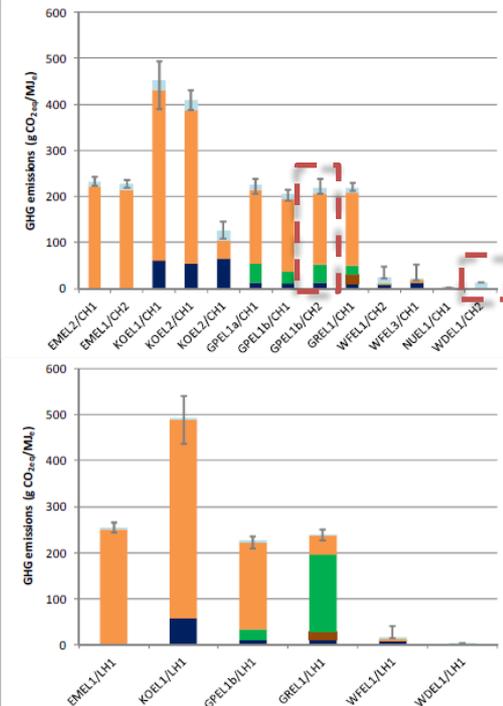
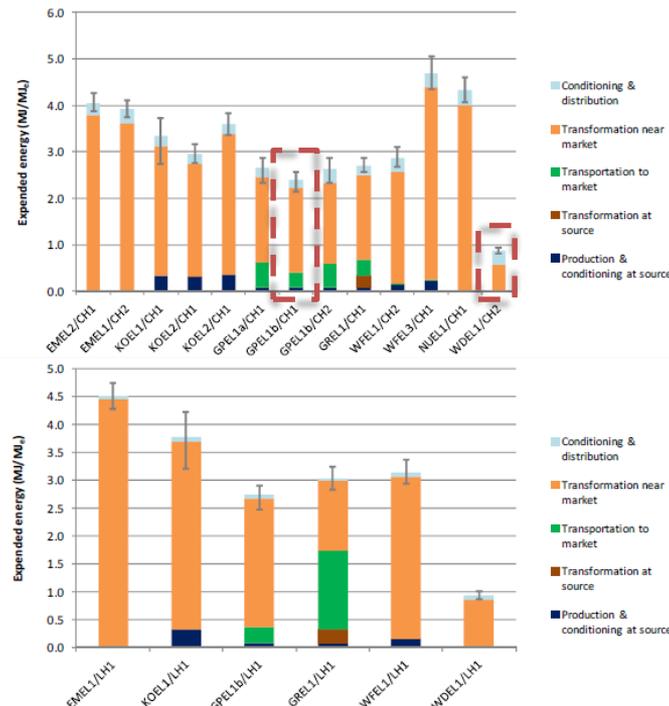


Concawe, 2014

2. Well-to-Tank (WTT) – alternative energy sources

Bio-H₂

Hydrogen (electrolysis)	
GPFL1a/CH1	C-H2: NG 7000 km, CCGT, O/S Ely
GPFL1b/CH1	C-H2: NG 4000 km, CCGT, O/S Ely
GPFL1b/CH2	C-H2: NG 4000 km, CCGT, Cen Ely, Pipe
GREL1/CH1	C-H2: LNG, O/S Ely
WFEL1/CH2	C-H2: F Wood, 200 MW gasif, CCGT, Cen eLy, Pipe
WFEL3/CH1	C-H2: F Wood, Conv power, O/S Ely
EMEL2/CH1	C-H2: Elec EU-mix, O/S Ely
EMEL1/CH2	C-H2: Elec EU-mix, Cen eLy, Pipe
EMEL1/LH1	Co-H2: Elec EU-mix, Cen eLy, Liq, Road
KOEL1/CH1	C-H2: Elec coal EU-mix conv., O/S Ely
KOEL2/CH1	C-H2: Elec coal EU-mix IGCC, O/S Ely
KOEL2C/CH1	C-H2: Elec coal EU-mix IGCC + CCS, O/S Ely
NUEL1/CH1	C-H2: Elec nuclear, O/S Ely
WDEL1/CH2	C-H2: Wind, Cen Ely, Pipe
GPFL1b/LH1	Co-H2: NG 4000 km, CCGT, Cen Ely, Liq, Road
GREL1/LH1	Co-H2: LNG, Ely
WFEL1/LH1	Co-H2: F Wood, 200 MW gasif, CCGT, Cen Ely, Liq, Road
EMEL1/LH1	Co-H2: Elec EU-mix, Cen Ely, Liq, Road
KOEL1/LH1	Co-H2: Elec coal EU-mix, Cen Ely, Liq, Road
WDEL1/LH1	Co-H2: Wind, Cen Ely, Liq, Road



Conversion yields?

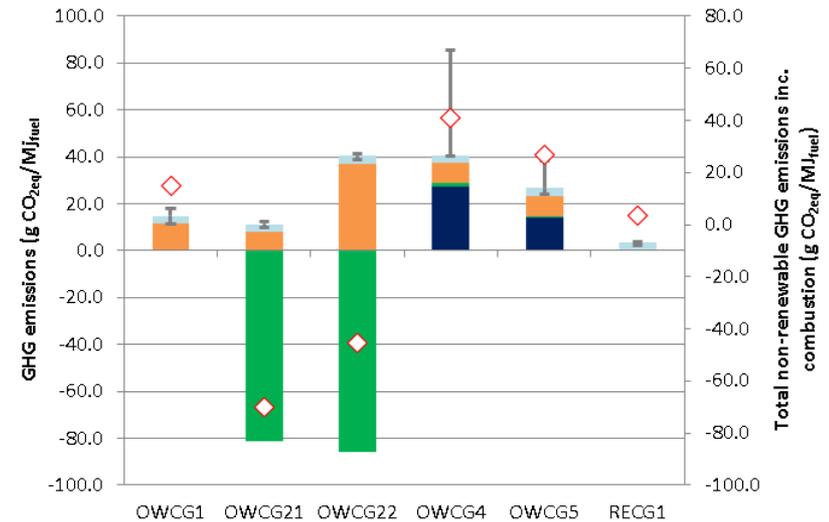
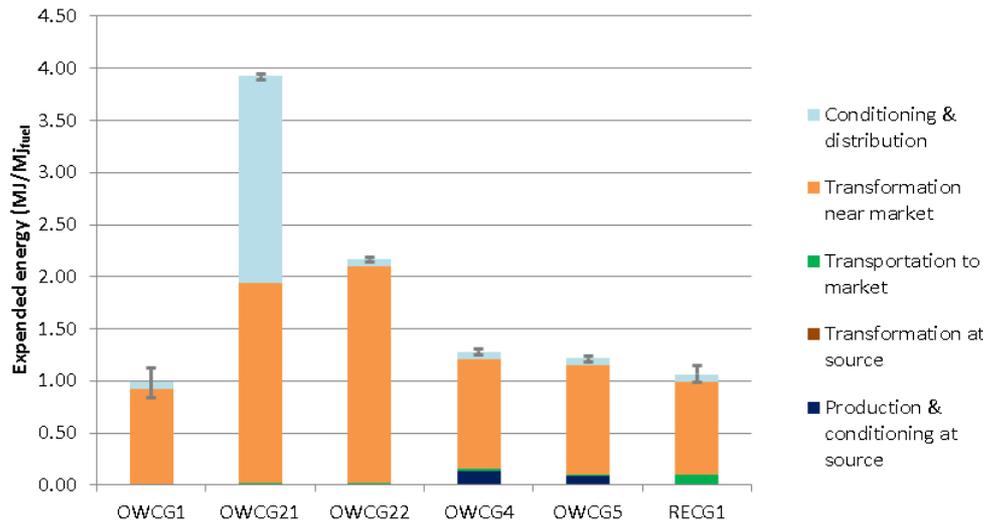
$$\text{WTT H}_2 = 1/3.40 = \mathbf{29\%}$$

$$\text{WTT H}_2 = 1/1.94 = \mathbf{52\%}$$

Concawe, 2014

2. Well-to-Tank (WTT) – alternative energy sources

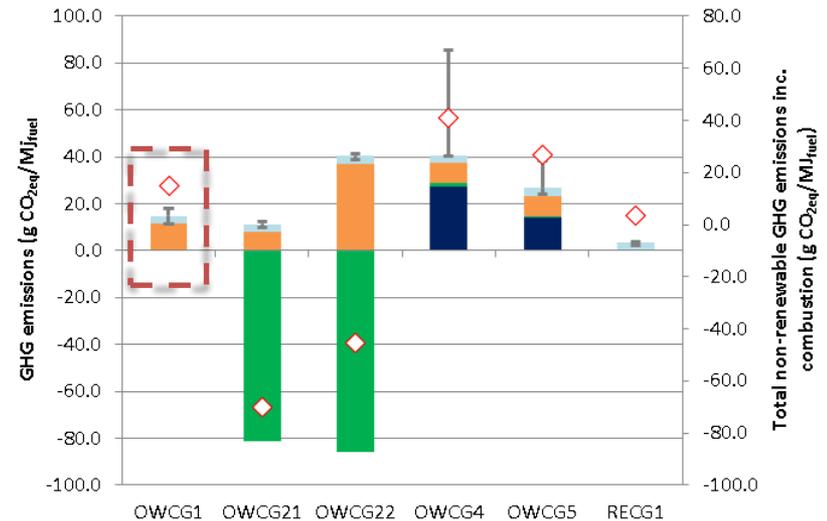
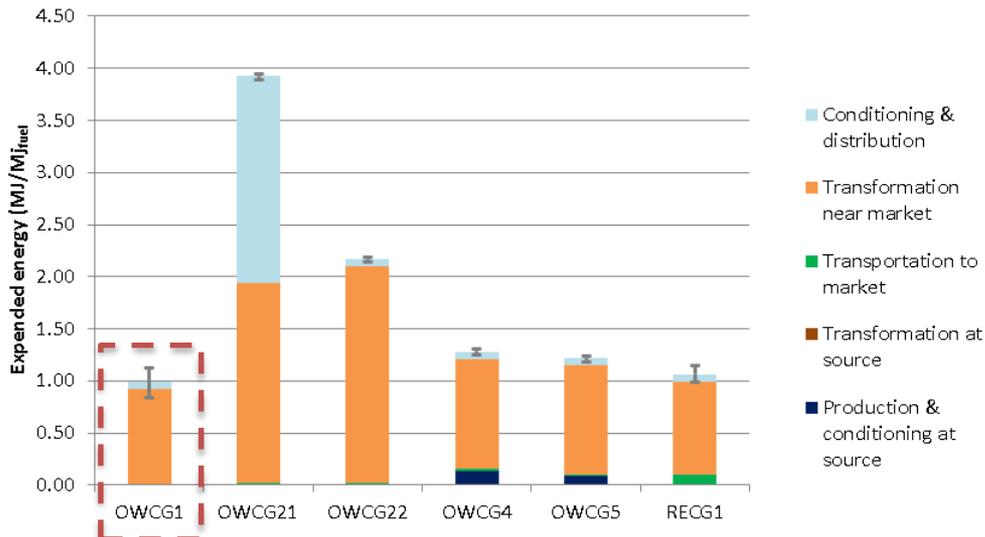
Biogas



OWCG1	CBG	Upgraded biogas from municipal organic waste as CBG. Closed digestate storage.
OWCG21/2		Upgraded biogas from wet manure as CBG. Digestate storage closed (21) or open (22)
OWCG4		Upgraded biogas from maize (wole plant) as CBG. Closed digestate storage.
OWCG5		Upgraded biogas from double cropping (barley/maize) as CBG. Closed digestate storage.
RECG1		SNG

2. Well-to-Tank (WTT) – alternative energy sources

Biogas



OWCG1	CBG	Upgraded biogas from municipal organic waste as CBG. Closed digestate storage.
OWCG21/2		Upgraded biogas from wet manure as CBG. Digestate storage closed (21) or open (22)
OWCG4	CBG	Upgraded biogas from maize (wole plant) as CBG. Closed digestate storage.
OWCG5		Upgraded biogas from double cropping (barley/maize) as CBG. Closed digestate storage.
RECG1	SNG	Synthetic methane (as CNG) from renewable electricity and CO ₂ from flue gases

Conversion yields?

$$\text{WTT biogas} = 1/1.99 = 50\%$$

Concawe, 2014

2. Well-to-Tank (WTT) – alternative energy sources

Table 37 – WTT Energy consumption and emission factors for the different energy pathways considered.

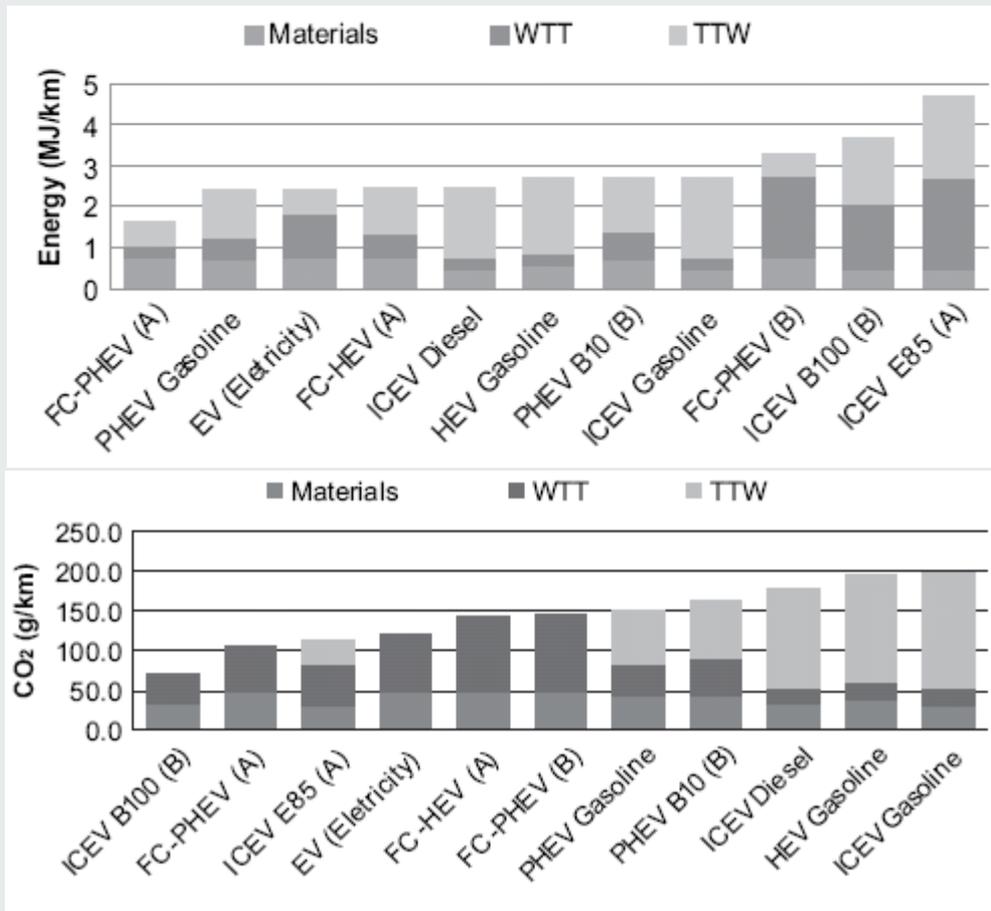
Energy source	Pathway	WTT					
		Energy MJ _{exp} /MJ	CO ₂ g/MJ ⁸	HC g/GJ	CO g/GJ	PM g/GJ	NO _x g/GJ
Gasoline	EU mix [96]	0.14	13				
Diesel	EU mix [96]	0.16	14				
Ethanol	Sugar cane ethanol [26, 97]	0.95	24				
Ethanol	Farmed wood ethanol [26, 97]	0.79	20				
Biodiesel	Portuguese mix ⁹ [94]	0.79	55				
Biodiesel	Hydrotreated vegetable oil from palm oil (process with methane capture at oil mill) [26]	0.33	29				
Biodiesel	Waste wood Fischer-Tropsch diesel [26]	0.12	4				
Electricity	2010 mix	1.05	100				
Hydrogen	From central natural gas reforming plants with steam co-generation [81, 96]	0.57	88				
	Produced in refueling stations via onsite electrolysis generation [81, 96]	3.60	207				
Natural gas	EU mix [96]	0.12	6	251	1	1	11

Biofuels – variable profile
(large uncertainty on feedstock and processes)

Hydrogen – large variability;
 possibility of energy intensive processes

Gasoline, diesel, NG –
 optimized processes

Full life cycle for alternative energy sources



Vehicle perspective

Source: Baptista, P., Tom s, M., and Silva, C., *Plug-in hybrid fuel cell vehicles market penetration scenarios*, International Journal of Hydrogen Energy, 2010, 35 (18), p. 10024-10030.

Life cycle inventory versus Life cycle assessment

Life Cycle Inventory (LCI) analysis involves creating an inventory of flows from and to nature for a product system. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water.

LC impact assessment - Inventory analysis is followed by impact assessment. This phase of LCA is aimed at evaluating the significance of potential environmental impacts based on the LCI flow results:

- **Selection of impact categories**, category indicators, and characterization models;
- **Classification stage**, where the inventory parameters are sorted and assigned to specific impact categories; and
- **Impact measurement**, where the categorized LCI flows are characterized, using one of many possible LCIA methodologies, into common equivalence units that are then summed to provide an overall impact category total.

What is the life cycle impacts of mobility products in Europe?

- The **basket-of-products** for mobility considers 2 product groups:
 1. Private road transport - transportation service not available to the general public, which is divided in:
 - Passenger cars; and
 - Two wheelers (2W, including mopeds and motorcycles).
 2. Mass transit - shared passenger transport service available to the general public, which is divided in the following categories:
 - Buses (including Urban buses, mainly used for urban transport, and coaches for long distance transport);
 - Rail; and
 - Air.
- **76 products were considered**

Analysis per country

Fleet composition

Road transport

Light duty vehicles

Gasoline <1.4l

Conventional, Euros 1, 2, 3, 4 and 5

Gasoline 1.4l - 2l

Conventional, Euros 1, 2, 3, 4 and 5

Gasoline >2l

Conventional, Euros 1, 2, 3, 4 and 5

Diesel <2l

Conventional, Euros 1, 2, 3, 4 and 5

Diesel >2l

Conventional, Euros 1, 2, 3, 4 and 5

LPG

Conventional, Euros 1, 2, 3, 4 and 5

Mopeds 2-stroke

Conventional, Euros 1, 2 and 3

Motorcycles <250cm³

Conventional, Euros 1, 2, and 3

Motorcycles >250cm³

Conventional, Euros 1, 2, and 3

Diesel Urban buses

Conventional, Euros 1, 2, 3, 4 and 5

Diesel Coaches

Conventional, Euros 1, 2, 3, 4 and 5

CNG Urban buses

Conventional, Euros 1, 2, 3, 4 and 5

Electric

Diesel

Electric

Electric

Diesel

Other

Steam

Rail transport

Railcars

Locomotives

Air transport

68 Types of aircrafts

Aircraft type 1

...

Aircraft type 68

National flights

Intra-EU flights

Extra-EU flights

Private transport

Mass transit

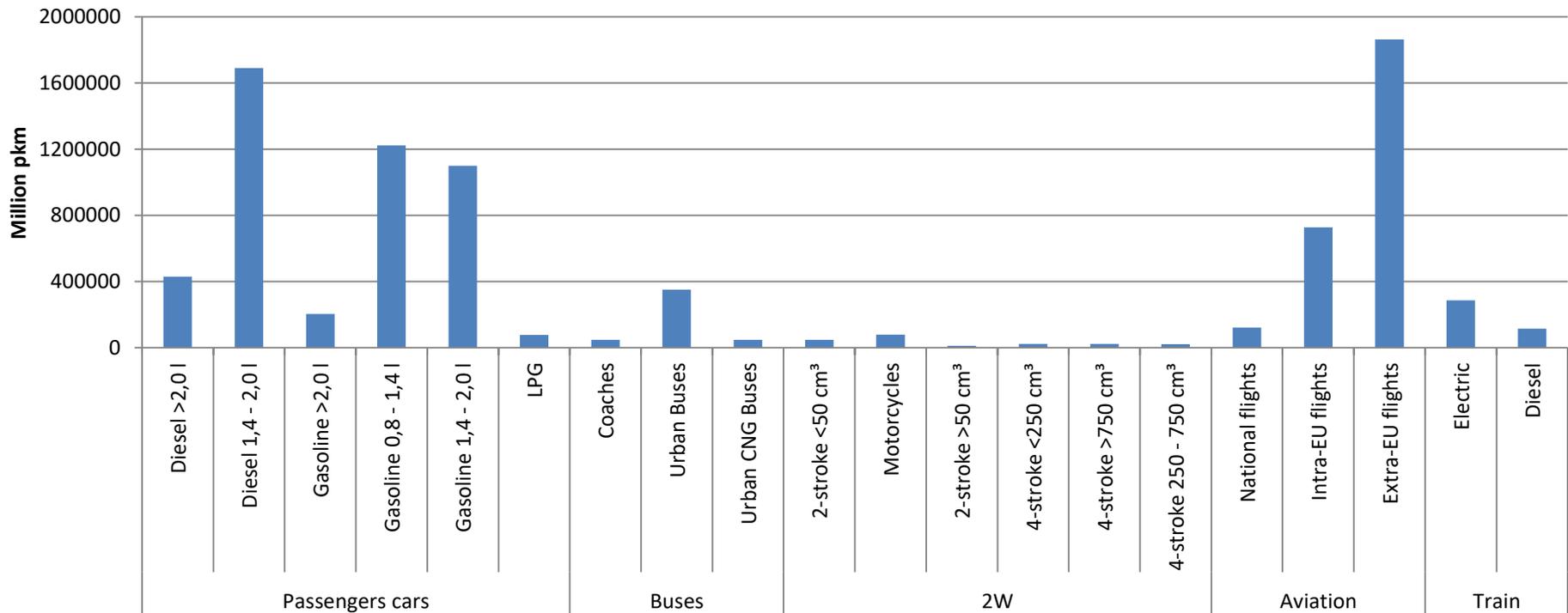
What is the life cycle impacts of mobility products in Europe?

Road transport basket-of-products in EU27, in 2010 (Eurostat, 2014)

Country	Number of passenger cars (million)	Number of 2W (million)		Number of Buses (thousands)	
		Mopeds	Motorcycles	Urban Bus	Coach
Austria	4.44	0.30	0.39	8.84	0.81
Belgium	5.28	0.12	0.42	14.79	1.44
Bulgaria	2.60	0.06	0.07	22.26	2.20
Cyprus	0.46	0.02	0.02	2.23	1.17
Czech Republic	4.50	0.48	0.92	17.45	2.20
Denmark	2.58	0.06	0.14	13.32	1.13
Estonia	0.55	0.01	0.02	3.92	0.36
Finland	2.88	0.26	0.23	12.44	1.21
France	30.70	1.26	1.25	82.59	7.86
Germany	42.30	1.74	3.83	69.76	6.70
Greece	3.84	1.62	0.97	25.09	2.41
Hungary	3.01	0.00	0.20	16.17	1.55
Ireland	1.88	0.04	0.04	9.24	0.87
Italy	36.75	2.55	6.31	91.38	8.52
Latvia	0.64	0.02	0.02	5.20	0.47
Lithuania	1.69	0.02	0.04	12.58	1.15
Luxembourg	0.33	0.03	0.02	1.48	0.14
Malta	0.23	0.01	0.01	0.11	0.01
Netherlands	7.74	0.53	0.64	10.33	0.95
Poland	17.24	0.92	1.01	95.79	1.58
Portugal	4.69	0.29	0.21	14.07	1.35
Romania	4.32	0.01	0.08	38.04	2.60
Slovakia	1.67	0.03	0.06	8.86	0.76
Slovenia	1.06	0.04	0.05	2.25	0.15
Spain	22.15	2.29	2.71	56.97	5.48
Sweden	4.34	0.09	0.28	12.35	1.05
United Kingdom	28.42	0.08	1.15	157.02	14.18
Total	236.30	12.87	21.08	804.53	68.32

What is the life cycle impacts of mobility products in Europe?

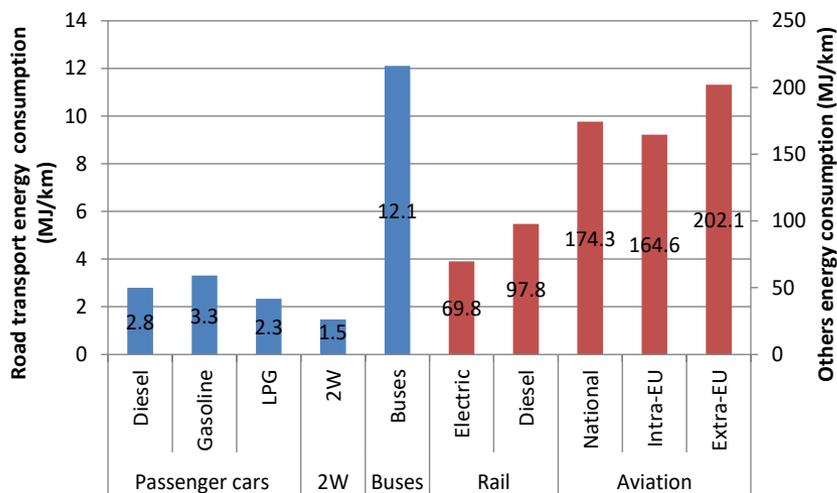
- The total EU mobility service provided by the Basket-of-products is quantified in **passenger.kilometers (pkm) per sub-product**:
 - 56% passenger cars
 - 32% aviation
 - 5% buses
 - 5% rail
 - 2% two-wheelers



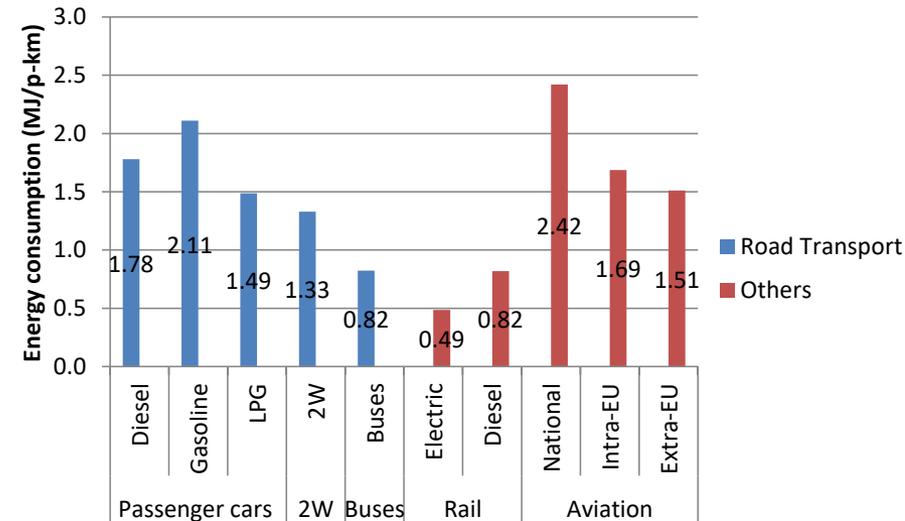
What is the life cycle impacts of mobility products in Europe?

- The **energy consumption** (MJ/km or MJ/pkm) of each sub-product of the Basket-of-products is estimated from the level of service and international reference sources.
- The MJ/pkm analysis shows closer values between the road transport and other types of transport, due to the higher occupancy factors of rail and air transport.

MJ/km



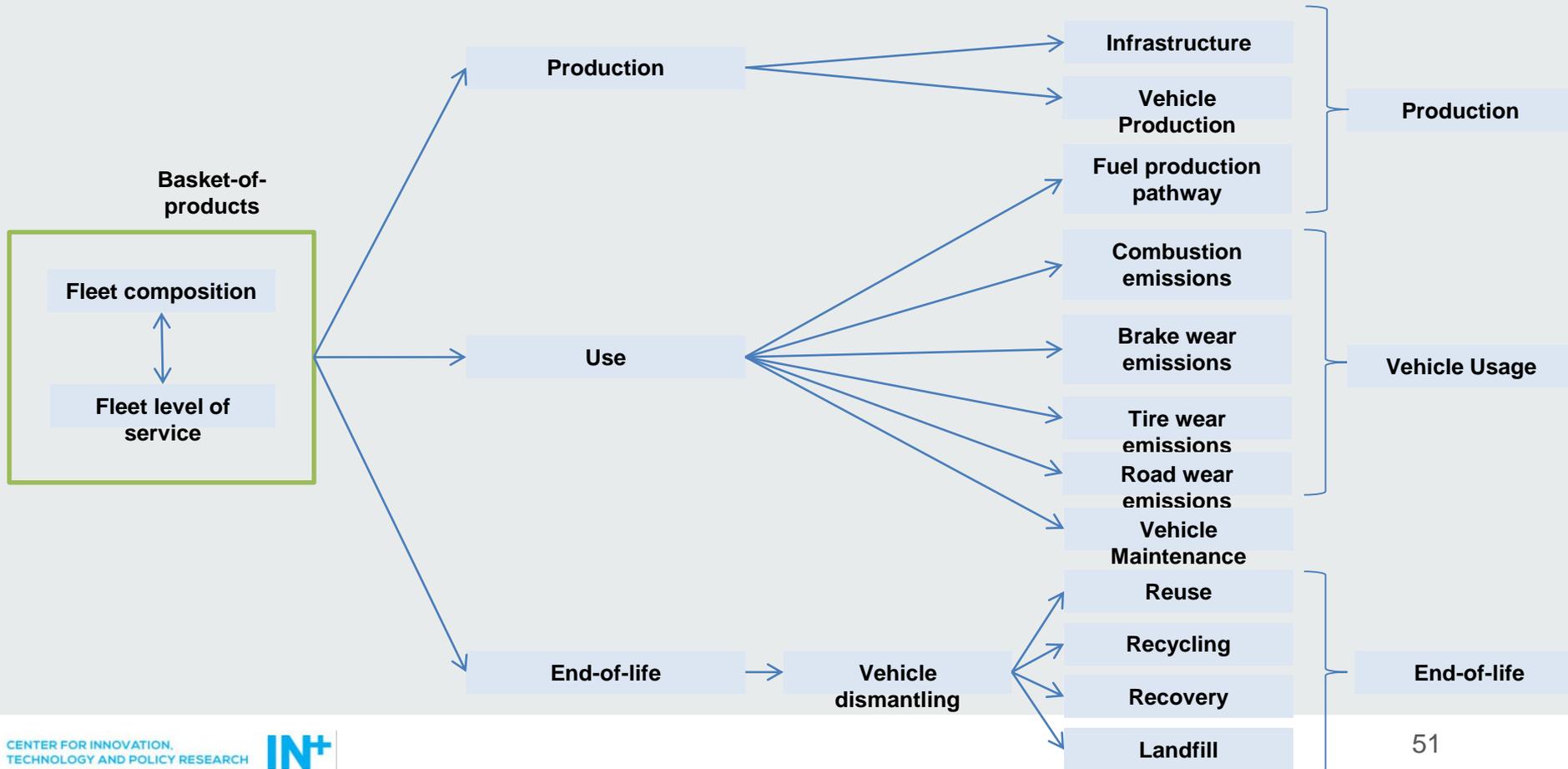
MJ/pkm



Mobility Life Cycle Impacts

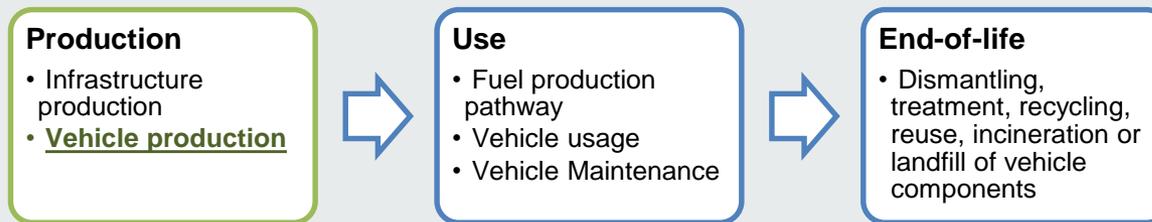
What is the life cycle impacts of mobility products in Europe?

The life cycle inventories were quantified for each product and considering three life stages: Production, Use and End-of-Life.



What is the life cycle impacts of mobility products in Europe?

Summarized assumptions – **Production**:



Vehicle production:

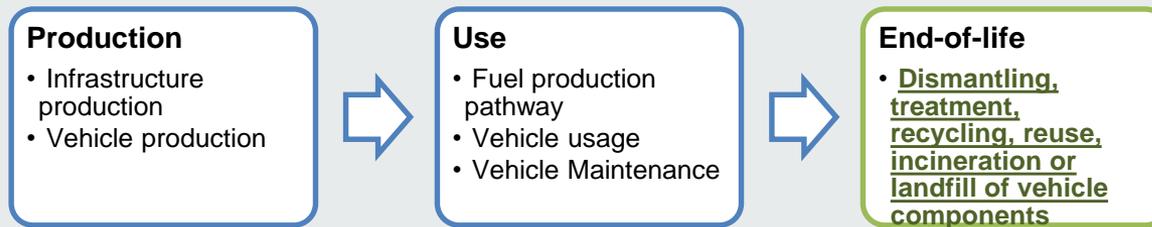
Material composition of each vehicle type modelled in Simapro (percentage)

Material type	Passenger cars	2W	Bus	Train	Aircraft
Aluminium	12	15	16	50	90
Coppers	1	1	1	3	0
Ferro metals	0	0	14	0	0
Glass	2	0	5	3	0
LO	1	0	1	0	0
Non-ferro	1	1	1	0	0
Others	2	1	5	0	0
Paint	0	0	0	2	0
PE	2	16	5	24	10
PET	0	0	0	0	0
Plastics	2	0	0	0	0
PP	4	7	0	0	0
PUR	2	0	0	0	0
PVC	1	2	0	0	0
Rubber	4	3	4	0	0
Steel	66	52	49	17	0
Textile	1	0	0	0	0
Zincs	0	0	0	0	0

Based on ecoinvent, 2014

What is the life cycle impacts of mobility products in Europe?

Summarized assumptions – **End-of-life**:



End-of-life:

- For each material, the shares of materials that go through waste processes are:

Material type	Reuse	Recycling	Recovery	Landfill
Aluminium	10.0	87.8	0.0	2.2
Coppers	10.0	87.8	0.0	2.2
Ferro metals	4.8	94.0	0.0	1.2
Glass	3.3	46.7	0.0	50.0
Lubricating oils	0.0	0.0	100.0	0.0
Non-ferro	10.0	87.8	0.0	2.2
Others	0.0	0.0	0.0	100.0
Paint	0.0	0.0	0.0	100.0
PE	1.7	18.3	10.0	70.0
PET	1.7	18.3	10.0	70.0
Plastics	1.7	18.3	10.0	70.0
PP	1.7	18.3	10.0	70.0
PUR	1.7	18.3	10.0	70.0
PVC	1.7	18.3	10.0	70.0
Rubber	20.0	30.0	50.0	0.0
Steel	4.8	94.0	0.0	1.2
Textile	0.0	10.0	0.0	90.0
Zincs	10.0	87.8	0.0	2.2

Waste scenario modelled in Simapro (percentage)

Total reuse, recycling, recovery and landfill rates per vehicle type (percentage)

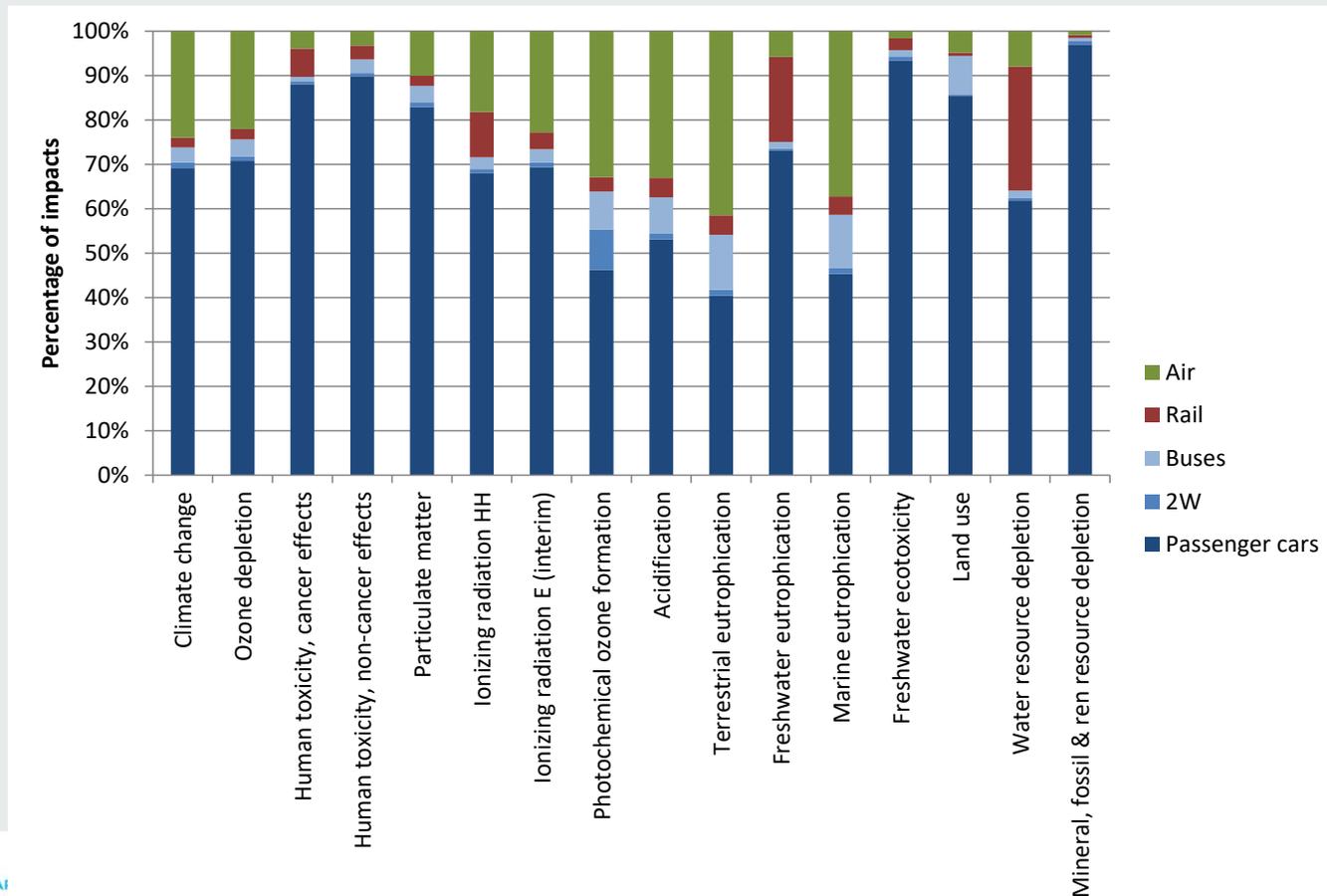


Vehicle type	Reuse	Recycling	Recovery	Landfill
Passenger car	5.5	77.9	3.5	13.1
2W	5.3	70.0	4.1	20.6
Bus	5.7	79.0	3.1	12.1
Train	6.7	69.0	2.4	21.9
Aircraft	9.2	80.8	1.0	9.0

Based on GHK, BIS, 2006

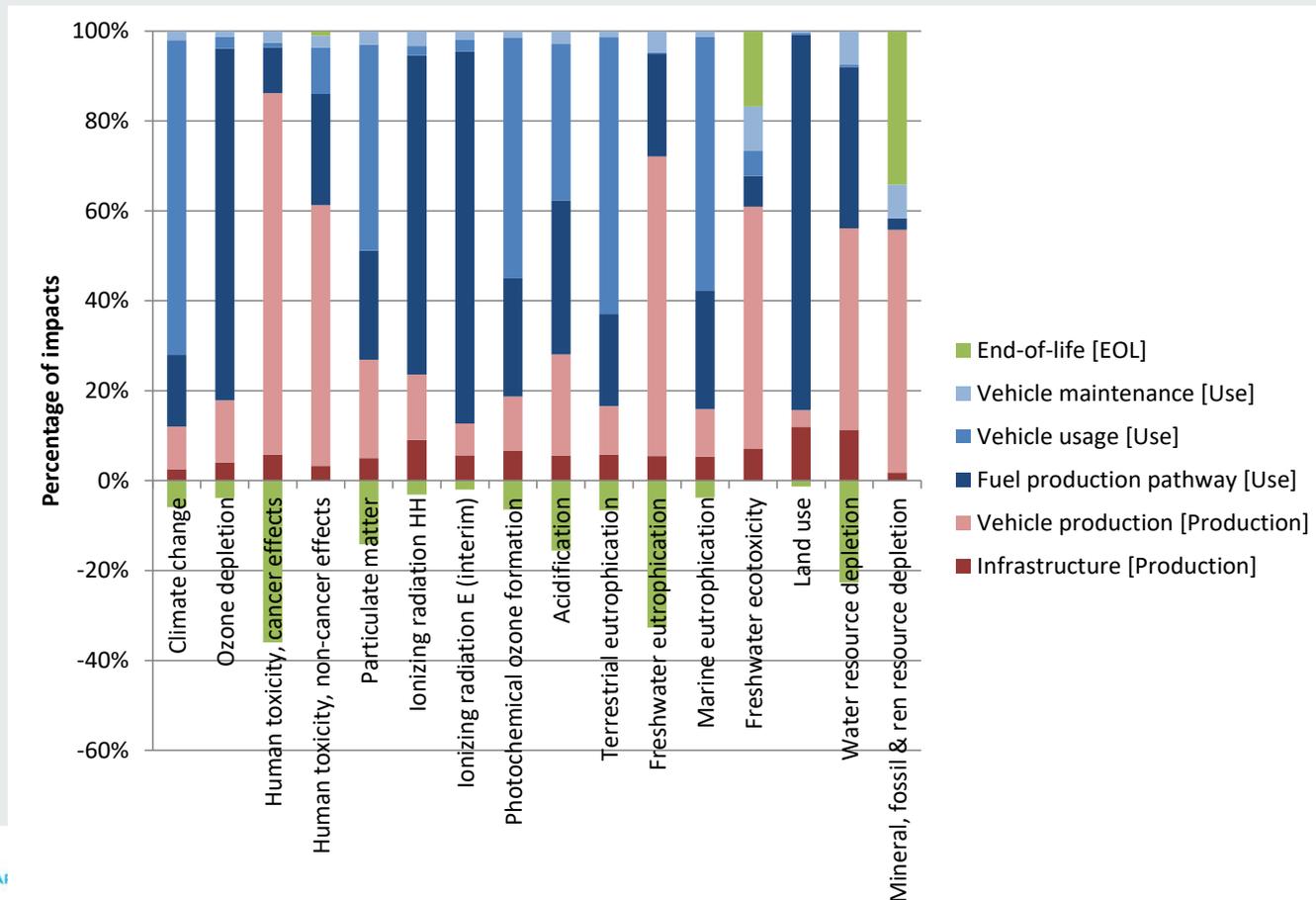
What is the life cycle impacts of mobility products in Europe?

- The passenger cars transport is the main responsible in most environmental categories, followed by air transport



What is the life cycle impacts of mobility products in Europe?

- The Use stage dominates in most impact categories, with the Production stage being still very relevant in several impact categories



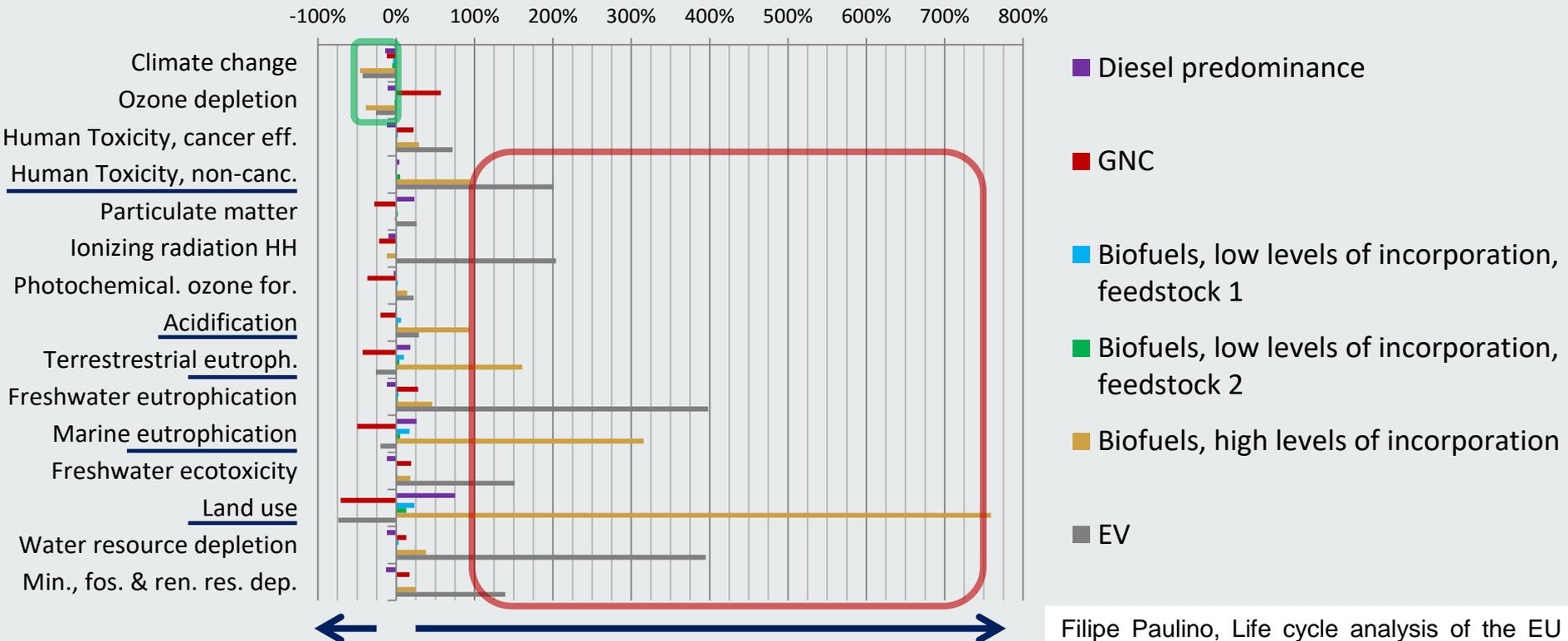
What is the life cycle impacts of mobility products in Europe?

Policy options for improving the sustainability of the mobility basket-of-products

- **Production stage:**
 - Light-weighting and more sustainable materials, to reduce the impact of vehicle manufacturing
 - More efficient vehicle production facilities
- **Use stage:**
 - Improve fuel efficiency, in line with the current CO₂ reduction targets, coupled with the *promotion of alternative energy sources*
 - Reduce vkm either through promoting the increase of vehicle occupancy or the use of alternative transportation modes (rail, biking and walking)
- **End-of-life stage:**
 - Stricter end-of-life waste treatment guidelines, which points to a 95% reduction and reuse target for 2015

What is the life cycle impacts of mobility products in Europe?

Policy options for improving the sustainability of the mobility basket-of-products

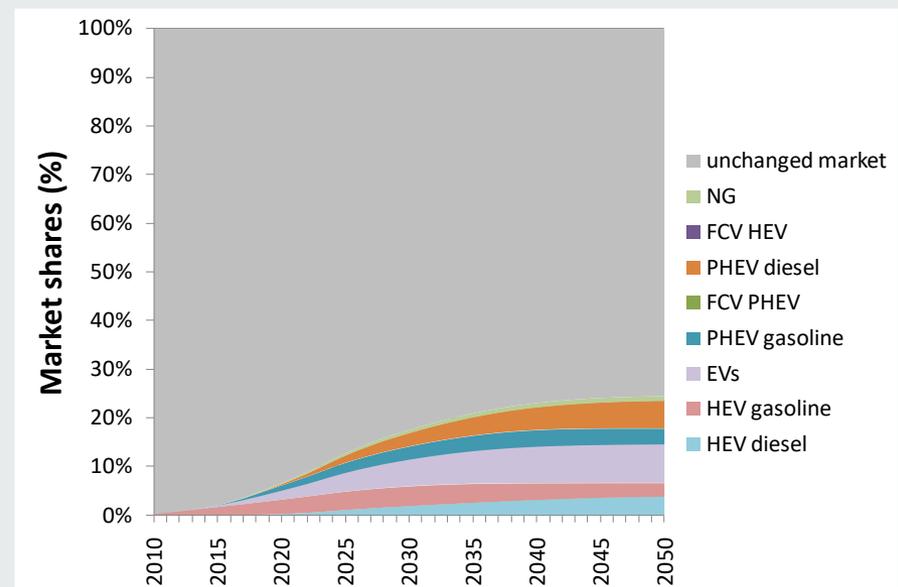
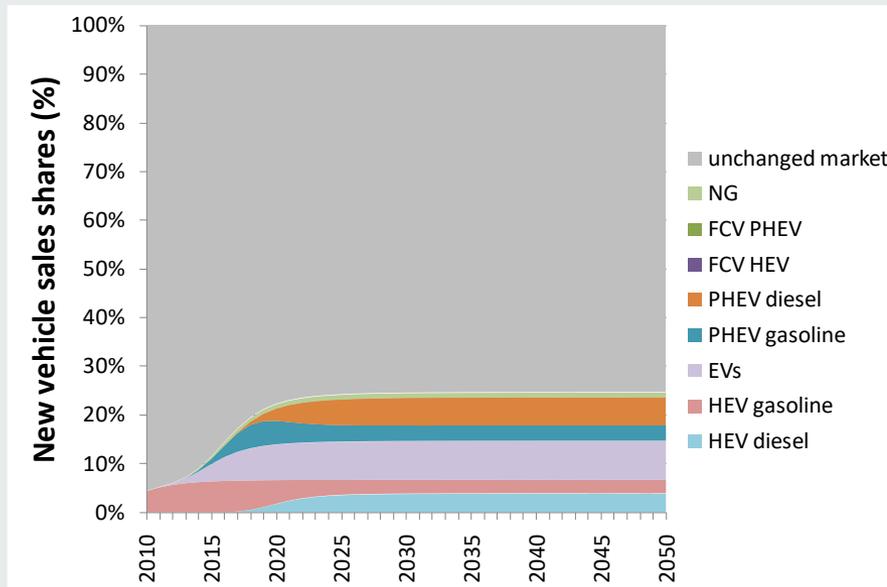


Filipe Paulino, Life cycle analysis of the EU transportation sector, MSc thesis in Mechanical Engineering, IST, 2016.

What is the life cycle impacts of mobility products in Europe?

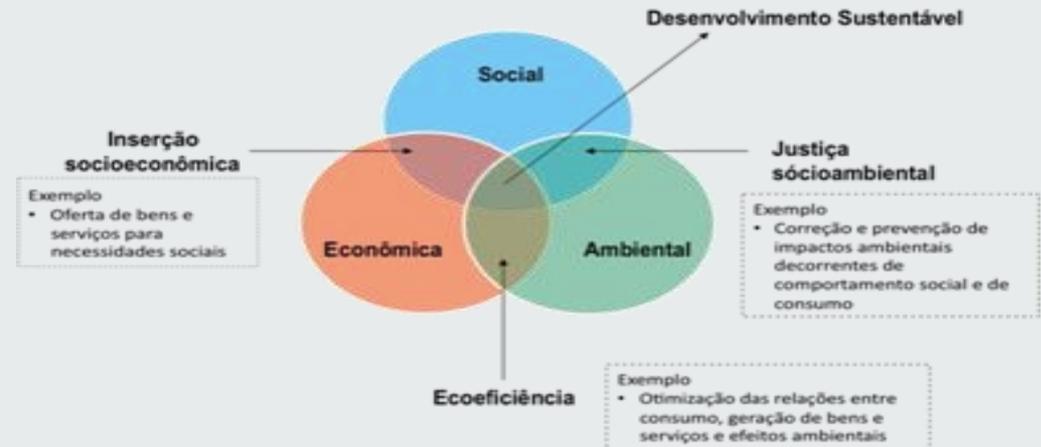
However, some policy options might have a slow effect due to fleet turnovers lasting for several decades.

- Slow fleet turnover



- The real effects of an alternative technology entering the car stock are delayed for **more than a decade** -> Higher for bus and freight fleets

Nem só energia, CO₂ e outros impactos ambientais são contabilizados no contexto da sustentabilidade...



1. Análise técnico/económica de fontes energéticas
2. Como é que a regulamentação pode ser utilizada na promoção de fontes energéticas alternativas?

Como é que a regulamentação pode ser utilizada na promoção de fontes energéticas alternativas?

Exemplos de regulamentação da EU:

Energy Source / Energy “Chain”

- **Renewable Energy Directive - RED:** 2020 target of 10% of renewable energy in the transportation sector
- **Fuel Quality Directive – FQD:** 10% reduction of GHG life-cycle emissions of fossil fuels (6% through the introduction of biofuels)
- **Infrastructure changes - COM/2013/018 final**

4. Each Member State shall ensure that the share of energy from renewable sources in all forms of transport in 2020 is at least 10 % of the final consumption of energy in transport in that Member State.

For the purposes of this paragraph, the following provisions shall apply:

- (a) for the calculation of the denominator, that is the total amount of energy consumed in transport for the purposes of the first subparagraph, only petrol, diesel, biofuels consumed in road and rail transport, and electricity shall be taken into account;
- (b) for the calculation of the numerator, that is the amount of energy from renewable sources consumed in transport for the purposes of the first subparagraph, all types of energy from renewable sources consumed in all forms of transport shall be taken into account;
- (c) for the calculation of the contribution from electricity produced from renewable sources and consumed in all types of electric vehicles for the purpose of points (a) and (b), Member States may choose to use either the average share of electricity from renewable energy sources in the Community or the share of electricity from renewable energy sources in their own country as measured two years before the year in question. Furthermore, for the calculation of the electricity from renewable energy sources consumed by electric road vehicles, that consumption shall be considered to be 2,5 times the energy content of the input of electricity from renewable energy sources.

Como é que a regulamentação pode ser utilizada na promoção de fontes energéticas alternativas?

Exemplos de regulamentação da EU:

Energy Source / Energy “Chain”

- **Renewable Energy Directive - RED:** 2020 target of 10% of renewable energy in the transportation sector
- **Fuel Quality Directive – FQD:** 10% reduction of GHG life-cycle emissions of fossil fuels (6% through the introduction of biofuels)
- **Infrastructure changes - COM/2013/018 final**

Targets for 2030 - Diretiva (UE) 2018/2001 (REDII)

- Sectorial transport target of renewables of **14%** by 2030
- Sub-target for advanced biofuels of 3.5% by 2030
- Multipliers of 1.2 for shipping and aviation, 4 for EV, 1.5 for electricity in trains
- 1st generation biofuels are capped at 7%

Biofuel production pathway	Typical greenhouse gas emission saving	Default greenhouse gas emission saving
Sugar beet ethanol	61 %	52 %
Wheat ethanol (process fuel not specified)	32 %	16 %
Wheat ethanol (lignite as process fuel in CHP plant)	32 %	16 %
Wheat ethanol (natural gas as process fuel in conventional boiler)	45 %	34 %
Wheat ethanol (natural gas as process fuel in CHP plant)	53 %	47 %
Wheat ethanol (straw as process fuel in CHP plant)	69 %	69 %
Corn (maize) ethanol, Community produced (natural gas as process fuel in CHP plant)	56 %	49 %
Sugar cane ethanol	71 %	71 %
The part from renewable sources of ethyl-Tertio-butyl-ether (ETBE)	Equal to that of the ethanol production Pathway used	
The part from renewable sources of tertiary-amyl-ethyl-ether (TAEE)	Equal to that of the ethanol production pathway used	
Rape seed biodiesel	45 %	38 %
Sunflower biodiesel	58 %	51 %
Soybean biodiesel	40 %	31 %
Palm oil biodiesel (process not specified)	36 %	19 %
Palm oil biodiesel (process with methane capture at oil mill)	62 %	56 %
Waste vegetable or animal (*) oil biodiesel	88 %	83 %
Hydrotreated vegetable oil from rape seed	51 %	47 %
Hydrotreated vegetable oil from sunflower	65 %	62 %
Hydrotreated vegetable oil from palm oil (process not specified)	40 %	26 %
Hydrotreated vegetable oil from palm oil (process with methane capture at oil mill)	68 %	65 %
Pure vegetable oil from rape seed	58 %	57 %
Biogas from municipal organic waste as compressed natural gas	80 %	73 %
Biogas from wet manure as compressed natural gas	84 %	81 %
Biogas from dry manure as compressed natural gas	86 %	82 %

Exemplos de regulamentação da EU:

Energy Source / Energy “Chain”

- **Renewable Energy Directive - RED: 2020** target of 10% of renewable energy in the transportation sector
- **Fuel Quality Directive – FQD:** 10% reduction of GHG life-cycle emissions of fossil fuels (6% through the introduction of biofuels)
- **Infrastructure changes - COM/2013/018 final**

Como é que a regulamentação pode ser utilizada na promoção de fontes energéticas alternativas?

Exemplos de regulamentação da EU:

Energy Source / Energy “Chain”

- **Renewable Energy Directive - RED: 2020** target of 10% of renewable energy in the transportation sector
- **Fuel Quality Directive – FQD: 10%** reduction of GHG life-cycle emissions of fossil fuels (6% through the introduction of biofuels)
- **Infrastructure changes - COM/2013/018 final**

Member States on the territory of which exist already at the day of the entry into force of this Directive hydrogen refuelling points shall ensure that a sufficient number of publicly accessible refuelling points are available, with distances not exceeding 300 km, to allow the circulation of hydrogen vehicles within the entire national territory by 31 December 2020 at the latest.

Member States shall cooperate to ensure that heavy duty motor vehicles running on LNG can travel all along the roads on the TEN-T Core Network. For this purposes, publicly accessible refuelling points for LNG shall be established within distances not exceeding 400 km by 31 December 2020 at the latest.

Member States shall ensure that a sufficient number of publicly accessible refuelling points are available, with maximum distances of 150 km, to allow the circulation of CNG vehicles Union-wide by 31 December 2020 at the latest.

Exemplos de regulamentação da UE

Energy Source / Energy “Chain”

- **Renewable Energy Directive - RED:** 2020 target of 10% of renewable energy in the transportation sector
- **Fuel Quality Directive – FQD:** 10% reduction of GHG life-cycle emissions of fossil fuels (6% through the introduction of biofuels)
- **Infrastructure changes - COM/2013/018 final**

Member State	Number of recharging points (in thousands)	Number of publicly accessible recharging points (in thousands)
BE	207	21
BG	69	7
CZ	129	13
DK	54	5
DE	1503	150
EE	12	1
IE	22	2
EL	128	13
ES	824	82
FR	969	97
IT	1255	125
CY	20	2
LV	17	2
LT	41	4
LU	14	1
HU	68	7
MT	10	1
NL	321	32
AT	116	12
PL	460	46
PT	123	12
RO	101	10
SI	26	3
SK	36	4
FI	71	7
SE	145	14
UK	1221	122
HR	38	4

Conclusões

Viabilidade de fonte energética alternativa dependente de:

- **Factores operacionais**
- **Factores económicos**
- **Regulamentação**
- ...

Análise de Sustentabilidade Ambiental (ASA) incluindo perspectiva de ciclo de vida de diferentes fontes energéticas



Patrícia Baptista

IN+ Center for Innovation, Technology and Policy Research of
Instituto Superior Técnico

patricia.baptista@tecnico.ulisboa.pt