14th Concawe Symposium –
SESSION 4 “ALTERNATIVE FUELS TOWARDS 2050

LCA ANALYSIS – ROLE OF FUELS AND POWERTRAINS

SEPTEMBER 28, 2021 – ANNE BOUTER, CYPRIEN TERNEL (IFP ÉNERGIES NOUVELLES)

IFP Energies nouvelles

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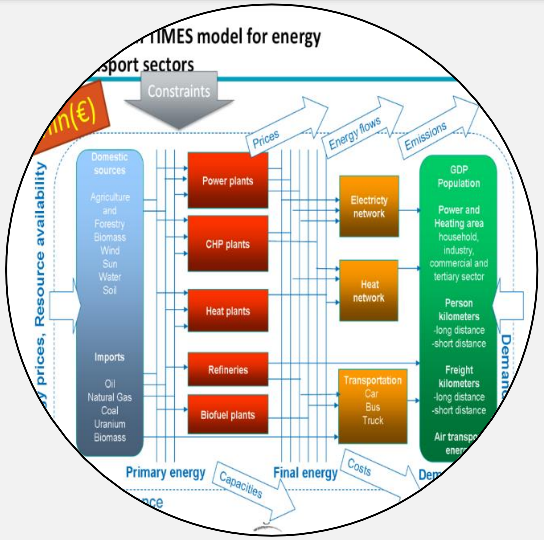
IFPEN ECONOMICS AND ENVIRONMENTAL ASSESSMENT DEPARTMENT

Exploring technological pathways: Scenario building, Prospective and LCA Analysis

Demand Analysis

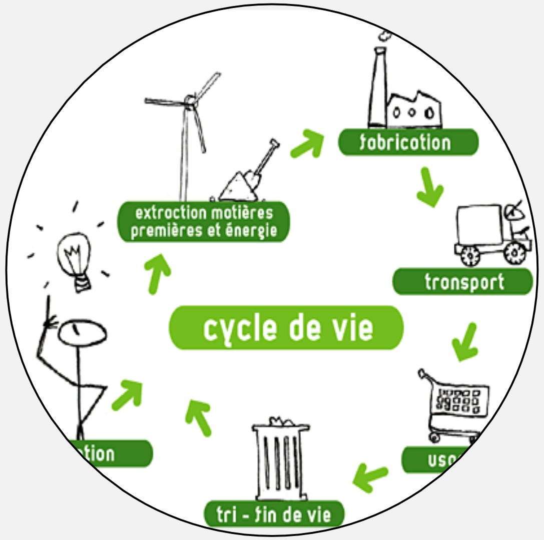
- Prospective modeling of mobility
- Analysis of the determinants of mobility
- Vehicle fleet models
- Techno-economic analysis (TCO)
- Analysis of the impacts of public policies

Energy Modelling



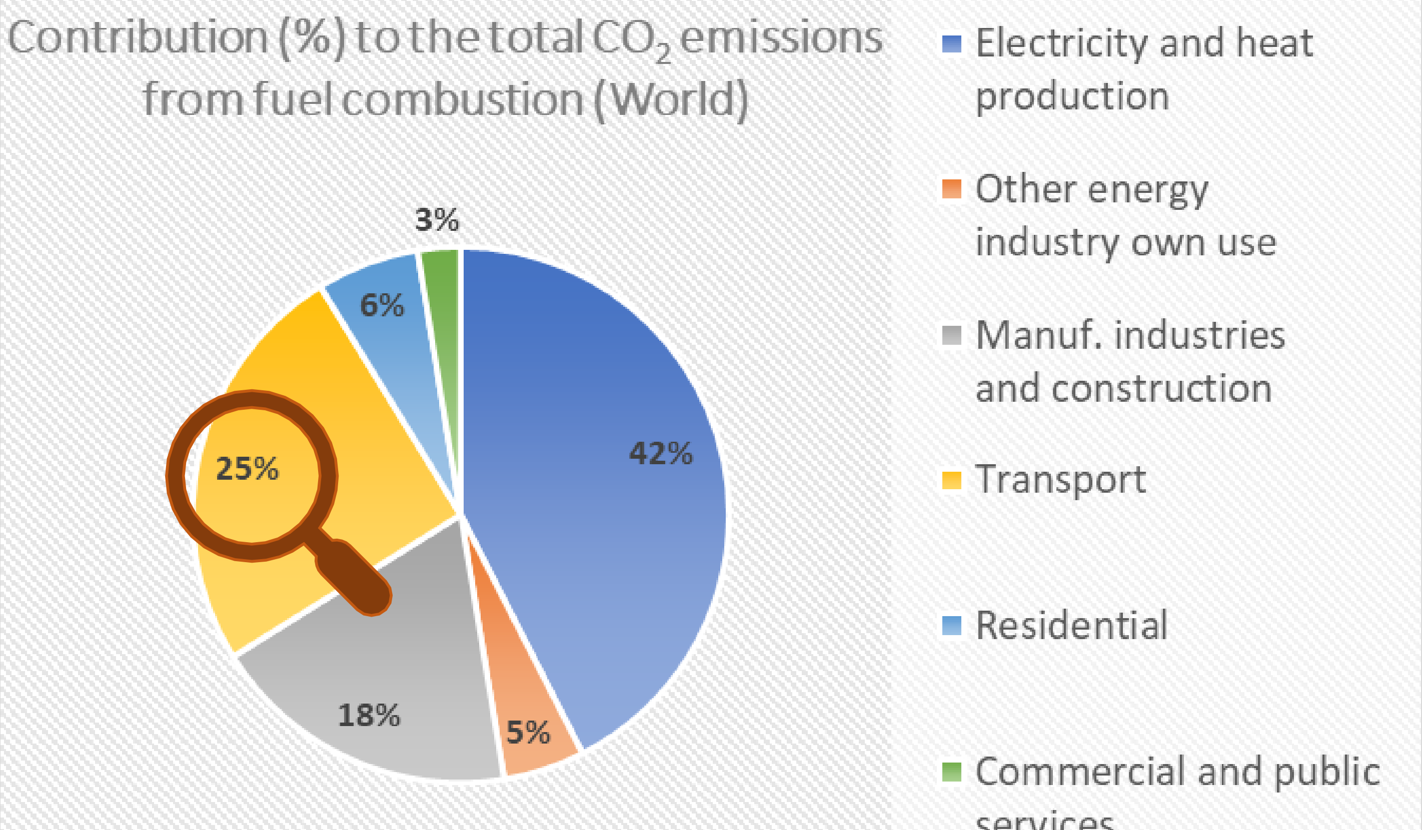
- TIMES/Markal optimization technology models - RAFGEN
- Techno-economic analysis of energy systems: fossil fuels, renewable energies, energy storage
- Analysis of the impacts of public policies
- Analysis of long-term climate scenarios

Life Cycle Analysis



- Attributional LCA: Analysis of ceteris paribus impacts
- Consequential LCA: analysis of the environmental impacts induced by decision-making
- Spatialization / Regionalization

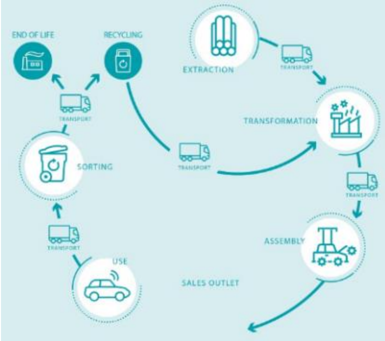
- The Paris Agreement sets out objectives to limit greenhouse gas (GHG) emissions in all sectors by fostering low carbon technologies.



Source: IEA (2020), *CO_2 Emissions from Fuel Combustion*

- The EU has set ambitious targets for reducing net emissions by at least 55% by 2030 compared to 1990.
- Transportation sector is brought to center stage as it accounts for almost a **quarter** of global CO_2 emissions.
- Deployment of low-carbon vehicles' technologies is exploding, as well as alternative fuels.
- Directives ruling for both fuels and powertrains must be considered.
- Life cycle assessment (LCA) methodology is a **powerful tool to assess several options to decrease environmental impacts of transportation sector.**

LIFE CYCLE ASSESSMENT
A POWERFUL TOOL

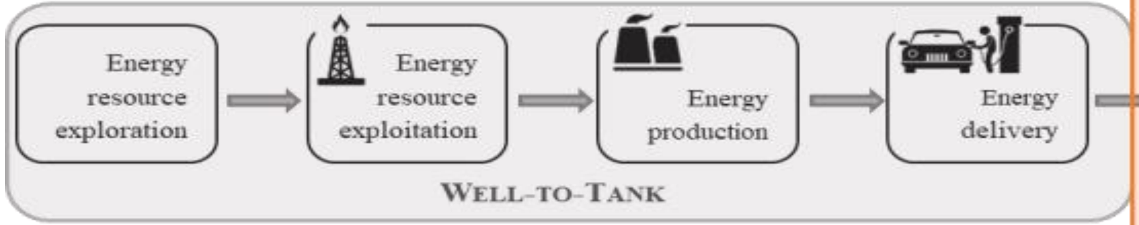


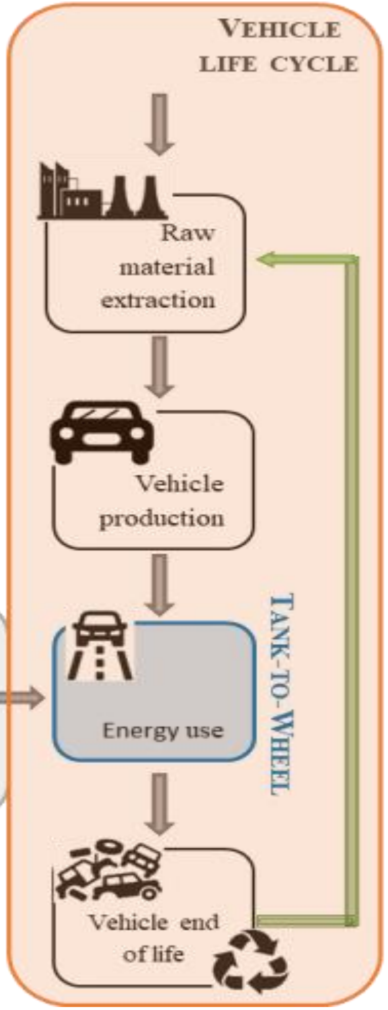
SUSTAINABLE MOBILITY

- Life Cycle Assessment (LCA) methodology is ruled by ISO norms 14040-44 and is defined by its multiple stages approach: from cradle to grave, combined to an environmental multicriteria impact assessment method.

- With the development of the electrification in transport, all the vehicles' life cycle must be considered, combined to the well-to-wheel assessment.

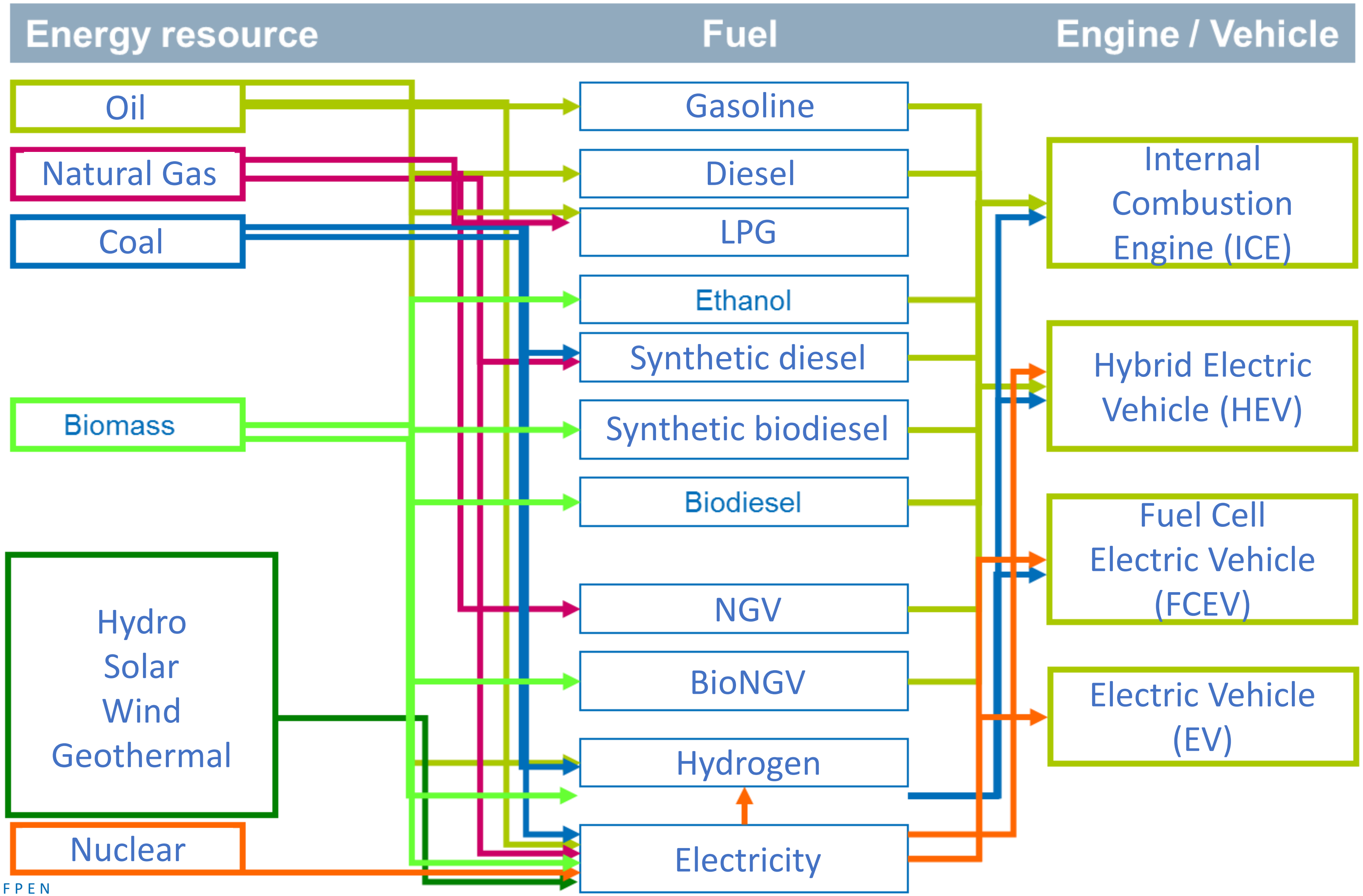
- It is also crucial to assess other environmental impacts than the sole climate change impact trying to avoid environmental impacts' transfers.



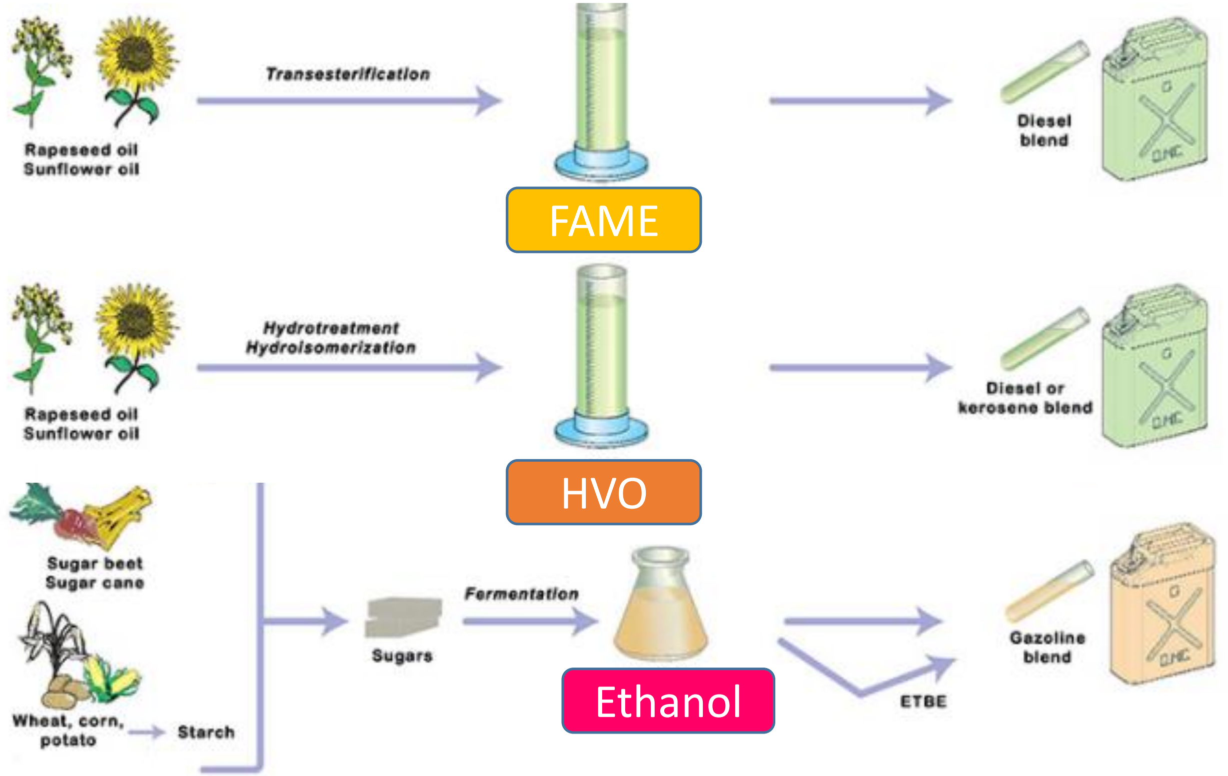


Source: inspired from Bouter et al., 2020

WHY BIOMASS IN TRANSPORTATION SECTOR?
VARIABILITY AND COMPETITIVENESS OF TECHNOLOGY



DIFFERENT CLASSIFICATION OF BIOFUELS (1/2)



Conventional biofuels

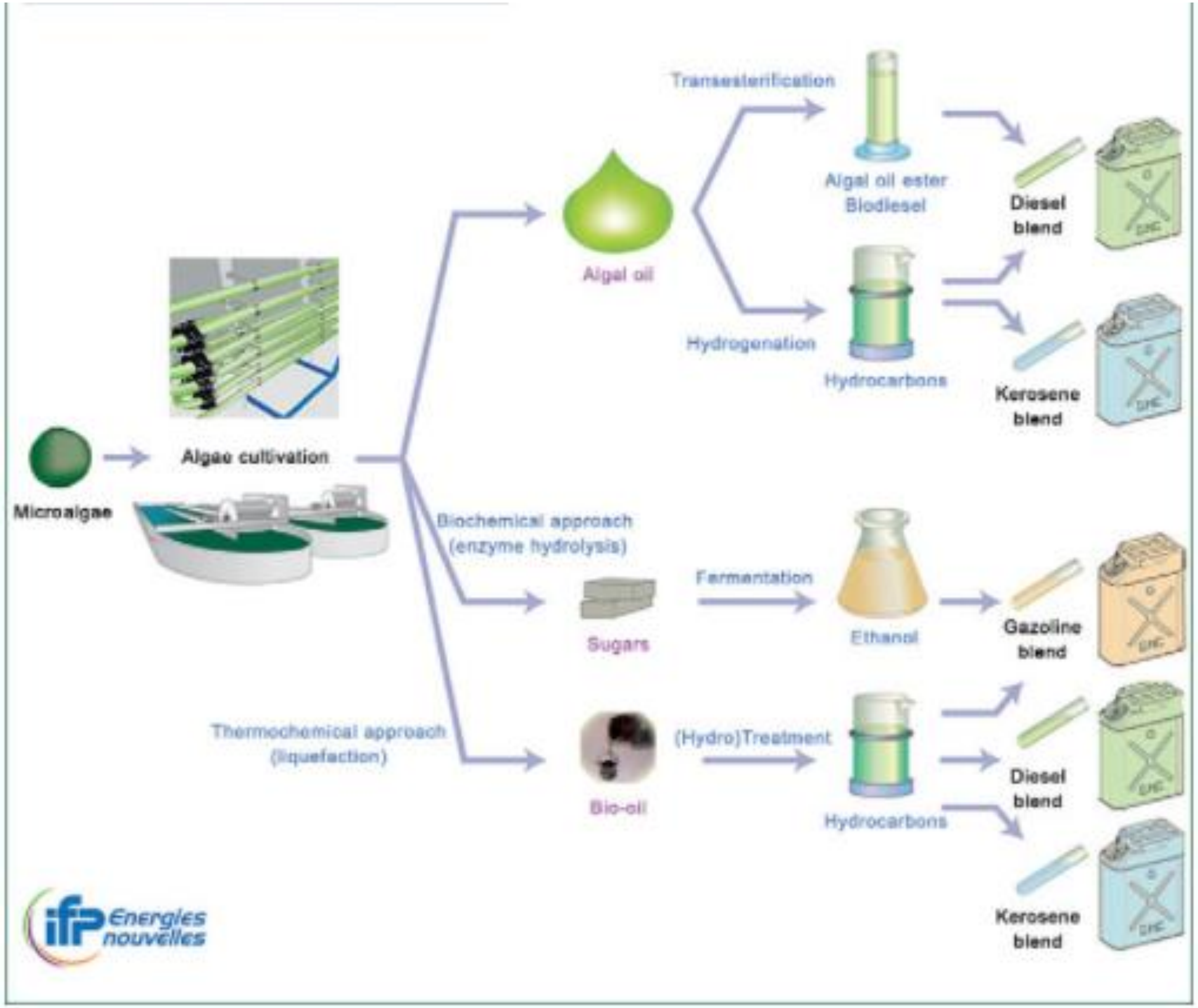
- Mature technologies
- 79.6 Mtoe in 2017, i.e. nearly 4% of the energy consumption of road transport worldwide
- Main production areas: USA, Brazil, EU28, China

Lignocellulosic biofuels

- New technologies for a different type of resource
- Technological maturity expected by 2020
- Industrial maturity expected by 2025

DIFFERENT CLASSIFICATION OF BIOFUELS (2/2)

- **Other biofuels**
  - The same conversion processes as for conventional biofuels (mature technologies), but from new resources
    - Industrial oily lipid by-products
    - Co-products of the sugar and starch industries
  - Microbial biofuels via microorganisms producing sugars or lipids
  - Lipidic algae



LCA OF BIOFUELS
SCOPE DEFINITION

The main steps defining the boundaries of the LCA of a biofuel chain

Cultivation & harvesting of biomass

→

Conversion 1

→

Conversion 2

→

Distribution

→

Biofuel use

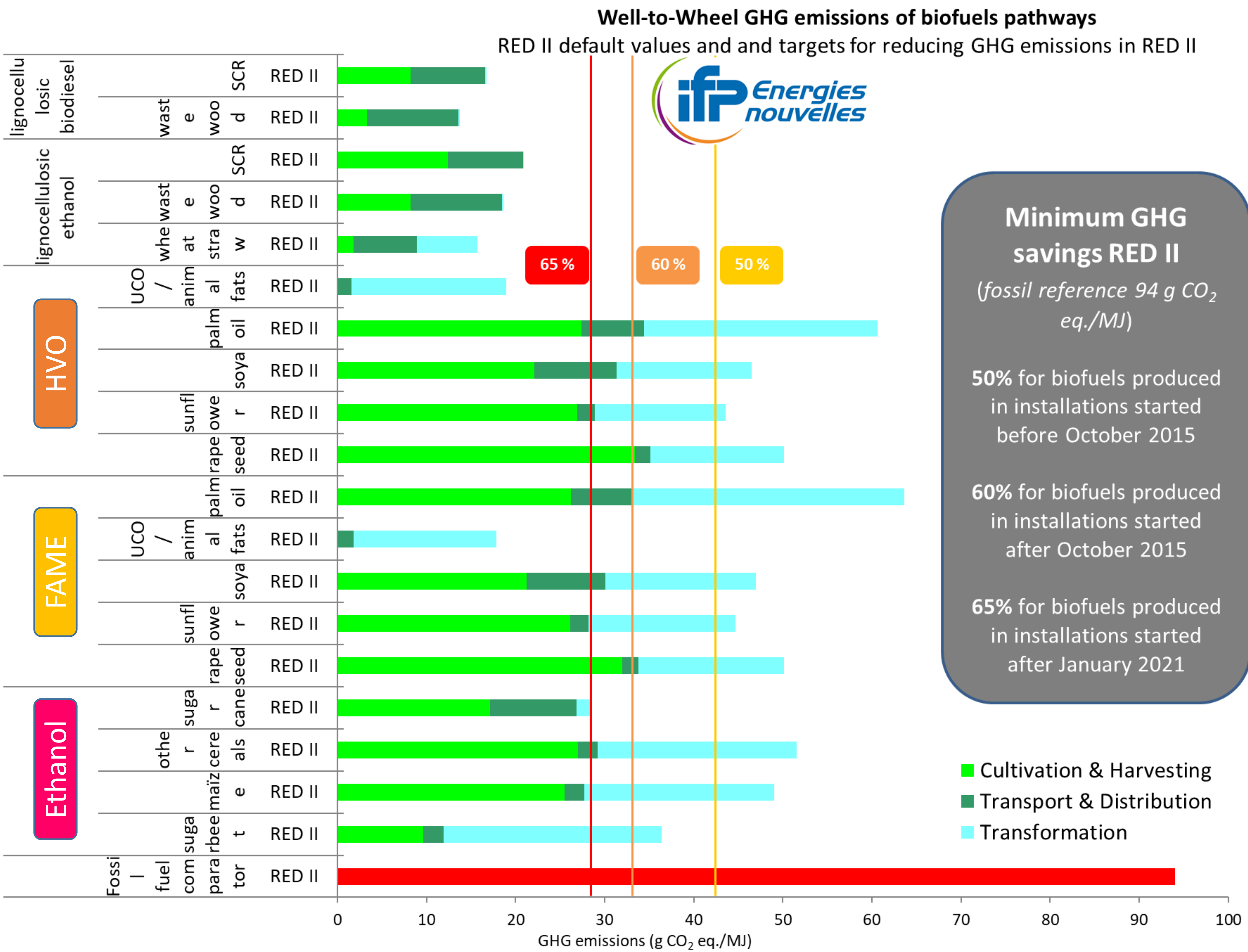
1 km

Intermediate transport stages of biomass, intermediate products and final fuel
(road and/or rail and/or river or even sea for biomass imports)

and/or

and/or

and/or



Minimum GHG savings RED II

(fossil reference 94 g CO_2 eq./MJ)

50% for biofuels produced in installations started before October 2015

60% for biofuels produced in installations started after October 2015

65% for biofuels produced in installations started after January 2021

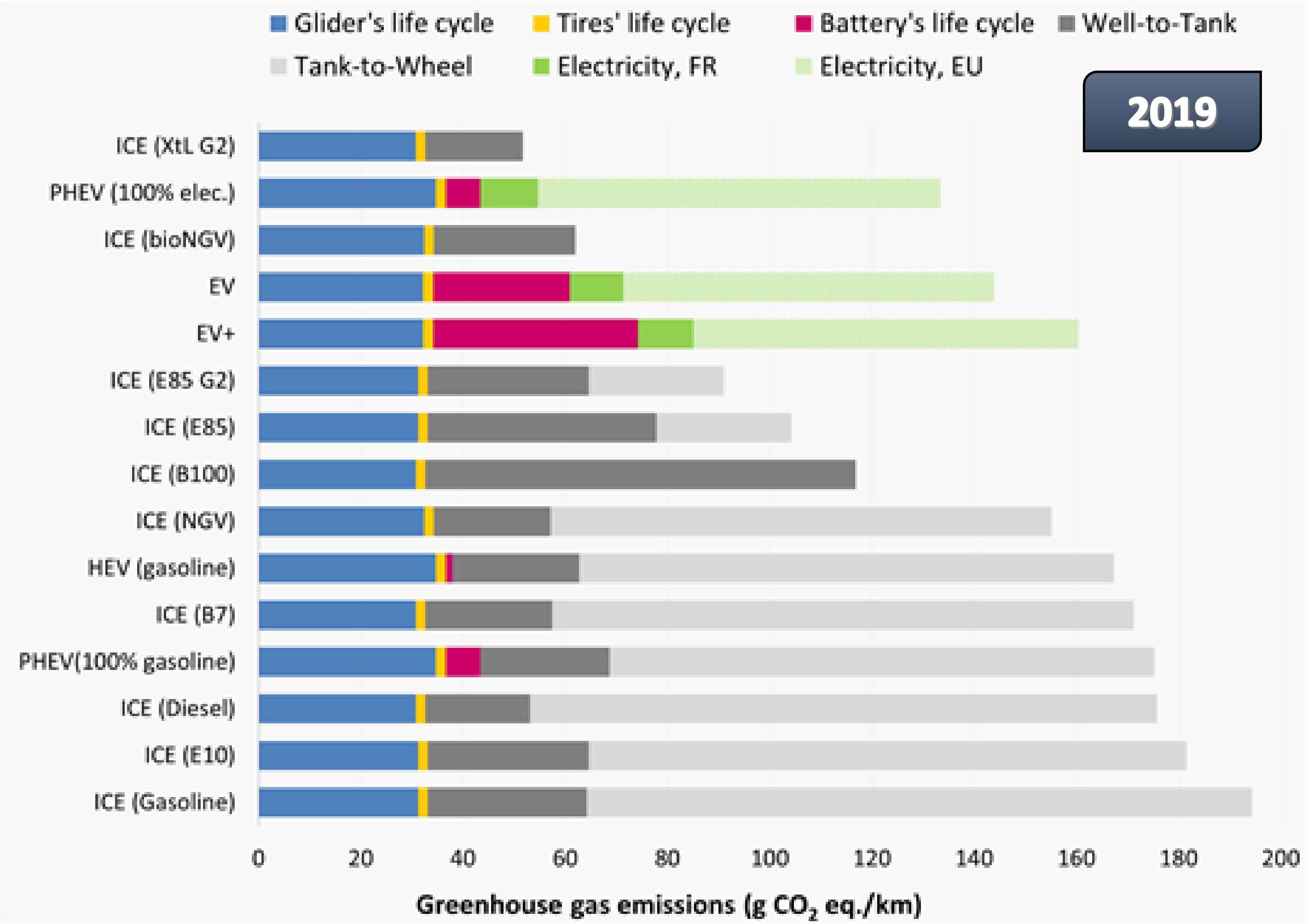
ENVIRONMENTAL IMPACT ASSESSMENT OF SEVERAL POWERTRAINS PROPELLED WITH SEVERAL ENERGY PATHWAYS

CLIMATE CHANGE IMPACT INDICATOR

SUSTAINABLE MOBILITY

Potential global warming impacts for a C-segment passenger vehicle in 2019, WLTC cycle

- Significant contribution of **battery life cycle** to total vehicle life cycle GHG impacts
  - 4% for an HEV
  - 16% for a PHEV
  - From 45% to 55% for an EV
- High sensitivity to the **charging electricity mix** for electrified vehicle
- Resource mix used by the average biofuel mix pumped in France in 2017 (DGEC)
- Default REDII average values for biofuels: GHG emissions and LHV
- **Glider's life cycle** roughly equivalent among powertrains
- ICE: high impact of WTW stage, especially TTW for fossil fuel ≠ from biofuels where WTT has greater impacts



Sources: Bouter, A., Hache, E., Ternel, C., Beauchet, S., ***2020***, *Comparative environmental life cycle assessment of several powertrain types for cars and buses in France for two driving cycles: "worldwide harmonized light vehicle test procedure" cycle and urban cycle.* Int J Life Cycle Assess.
Ternel, C.; Bouter, A.; Melgar, J., **2021,** *Life cycle assessment of mid-range passenger cars powered by liquid and gaseous biofuels – Focus on GHG emissions, comparison with electric vehicles and forecast to 2030.* Tr Research Part D.

THE GROWING MARKET OF ELECTRIFIED VEHICLES

- Context
  - Growing electrification of the vehicle fleet supported by the countries
  - A 14-fold growth forecast by 2030 (according to the EC)
- Market response
  - Diversified offer of battery technologies: Li-ion, NiMH, all-solid, etc.
  - Increased performance of existing technologies
  - Increase in the number of batteries in circulation
- **Question: if electric vehicles do not emit exhaust emissions, what about the environmental impact of battery production?**
- Answer: not so simple...
  - Many studies exist BUT the range of values is very disparate
  - Often little transparency on the assumptions and data available
  - Few studies on the end of life of batteries
  - Regulatory obligation on the end of life of batteries in quantity but not in quality
  - Which environmental impact indicator(s)?

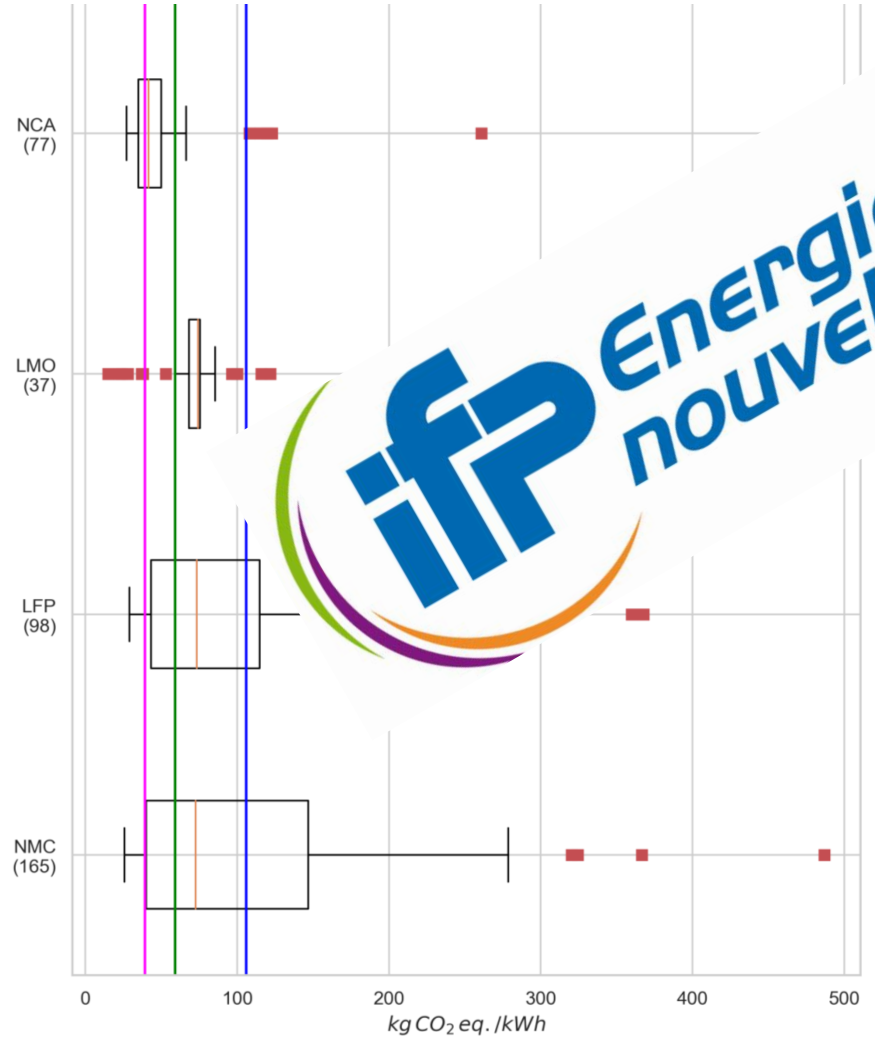
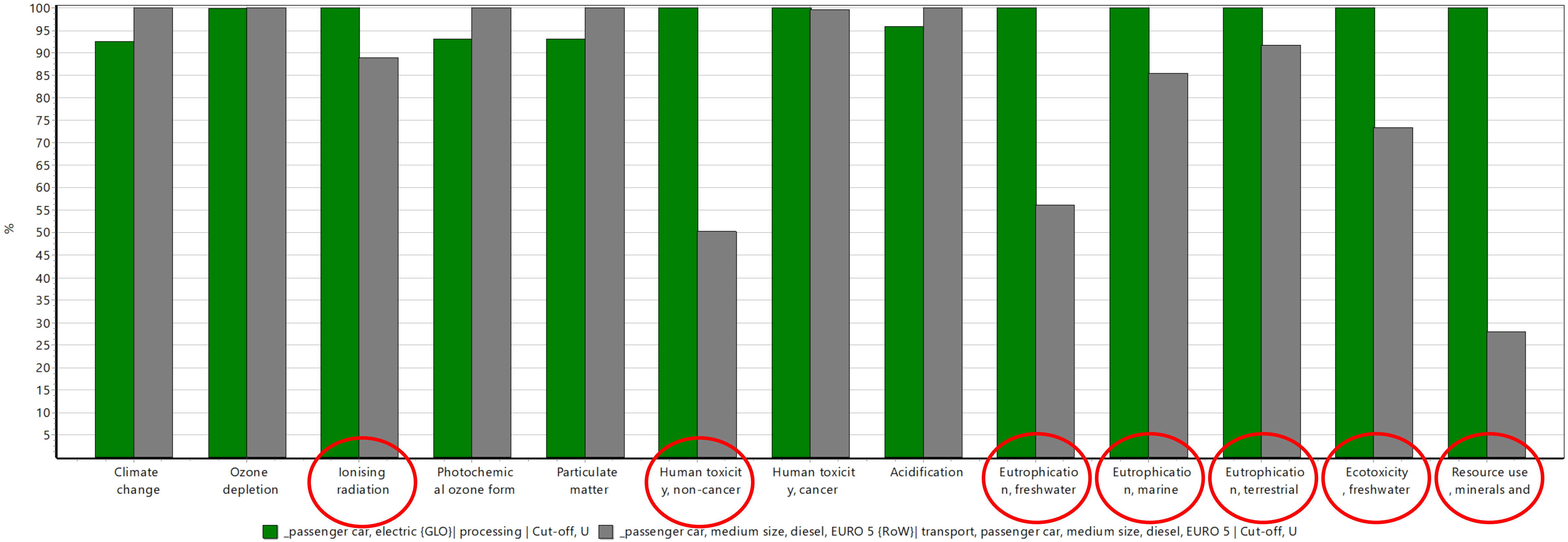


Figure 1: Dispersion of LCA GHG emission results for the different types of LIB cathodes (32 studies, 377 observations)

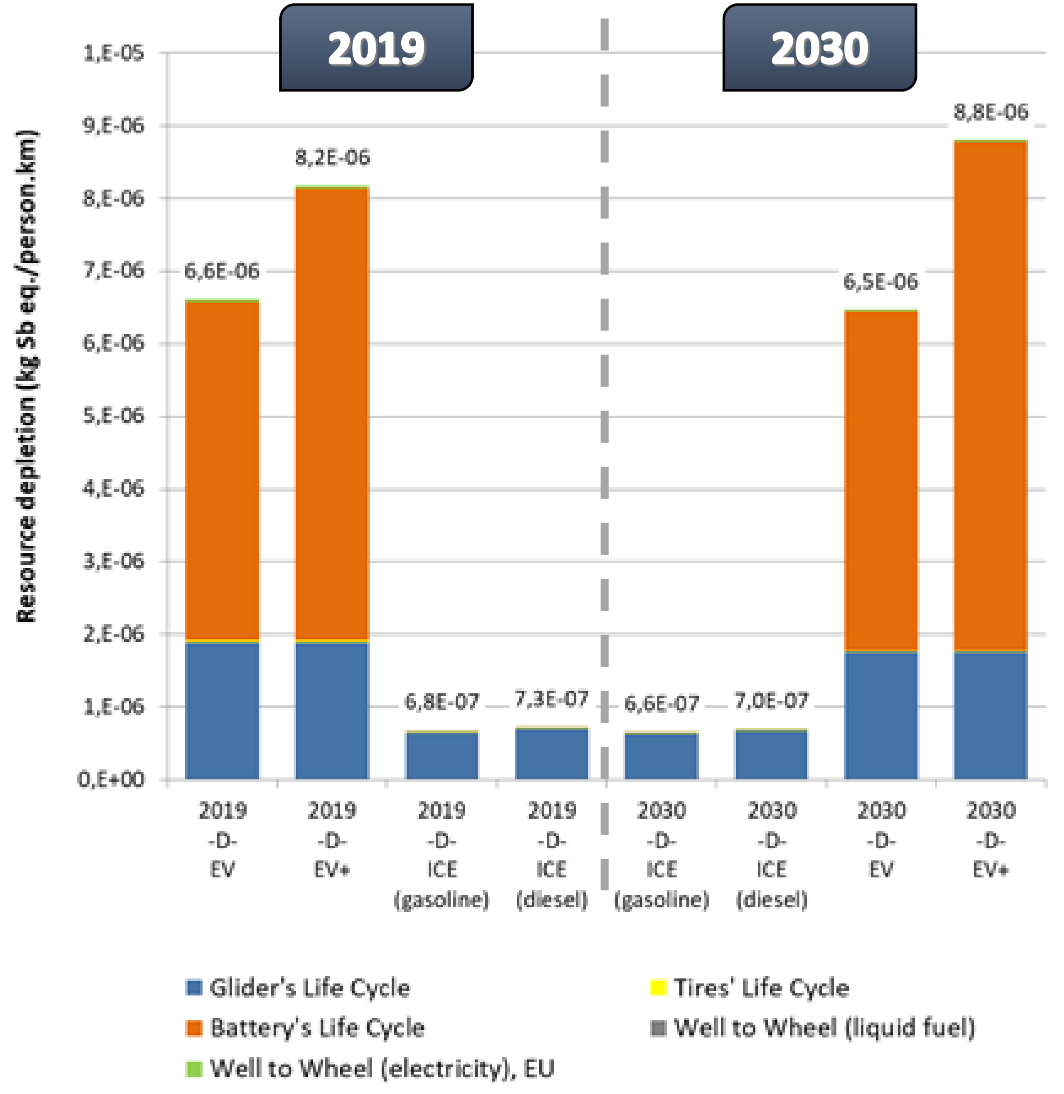
BATTERIES' ENVIRONMENTAL IMPACTS
OTHER THAN CLIMATE CHANGE INDICATOR

- Comparison between **ICE diesel vehicle** versus **Electric Vehicle**



Method: EF 3.0 Method (adapted) V1.01 / EF 3.0 normalization and weighting set / Characterization
Comparing 1 km '_passenger car, electric {GLO}| processing | Cut-off, U' with 1 km '_passenger car, medium size, diesel, EURO 5 {RoW}| transport, passenger car, medium size, diesel, EURO 5 | Cut-off, U';

BATTERIES ENVIRONMENTAL IMPACTS
RESOURCE DEPLETION INDICATOR



- Based on UNEP-SETAC recommendations, resource depletion environmental indicator recommended for electric mobility is the Abiotic Depletion Potential (ADP) method, based on a depletion concept.
- The results express the accessibility of resources with the ratio of the current extraction rate to the size of the natural stock.

- **Battery's life cycle** contributes to more than 70% to the ADP indicator.
- More than 70% of the battery's impact is related to the gold, from printed wiring board: ➔ low abundance in the earth's crust
  - Copper contributes at 11%
  - Silver (4,1%),
  - Nickel (1,7%)
  - Zinc (1,4%)
  - Tin (0,8%)
  - Lithium <0,003%
  - Cobalt has almost no contribution to this indicator

➔ What if the resource depletion indicator is assessed with a supply risk indicator?

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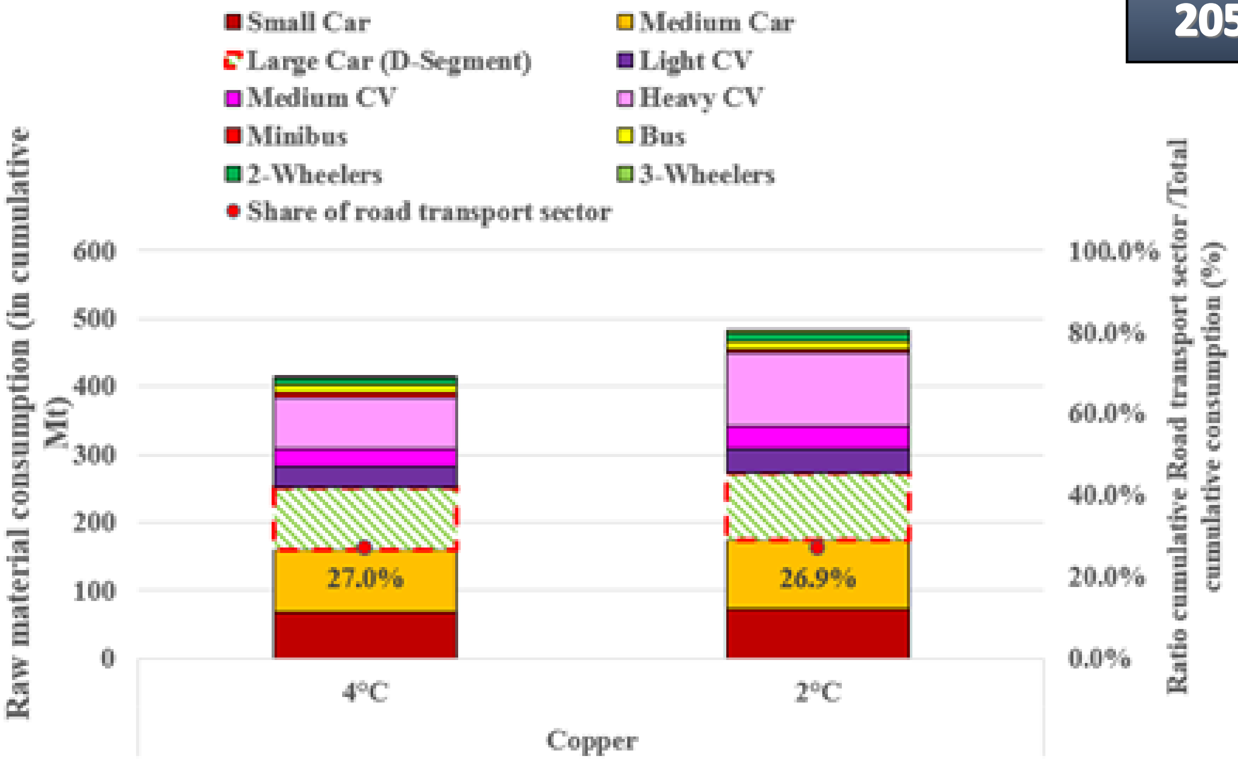
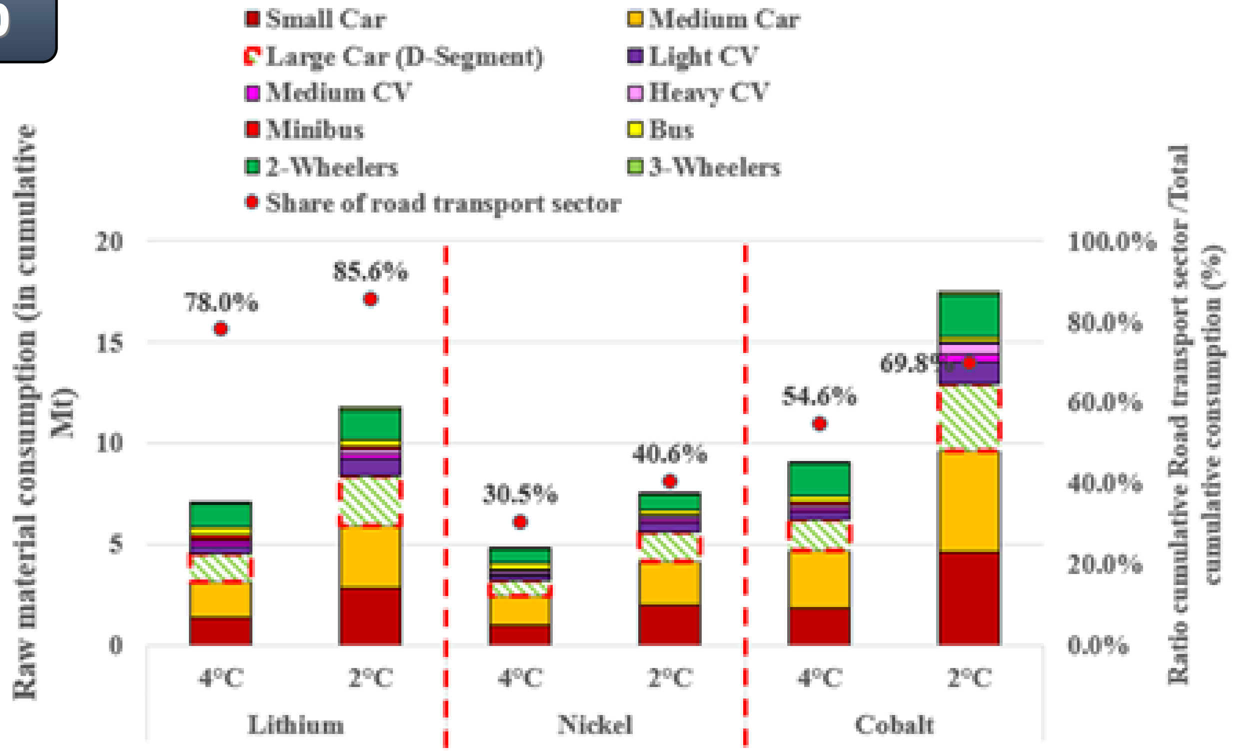
BATTERIES ENVIRONMENTAL IMPACTS
SUPPLY RISK PERSPECTIVE

2050





- Evolution of the raw material consumption disaggregated by road transport segments by 2050 based on their known resources in 2010
- 2 climate constraints scenario: +4°C and +2°C
- Copper, lithium, nickel and cobalt
- Pressure on copper and cobalt in a global constraint (+2°C) scenario: respectively 96,1% and 93,6% of these resources would be consumed by 2050.
- Transportation sector accounts for 85,6% of lithium consumption, also pinpointing a potential sectorial issue.

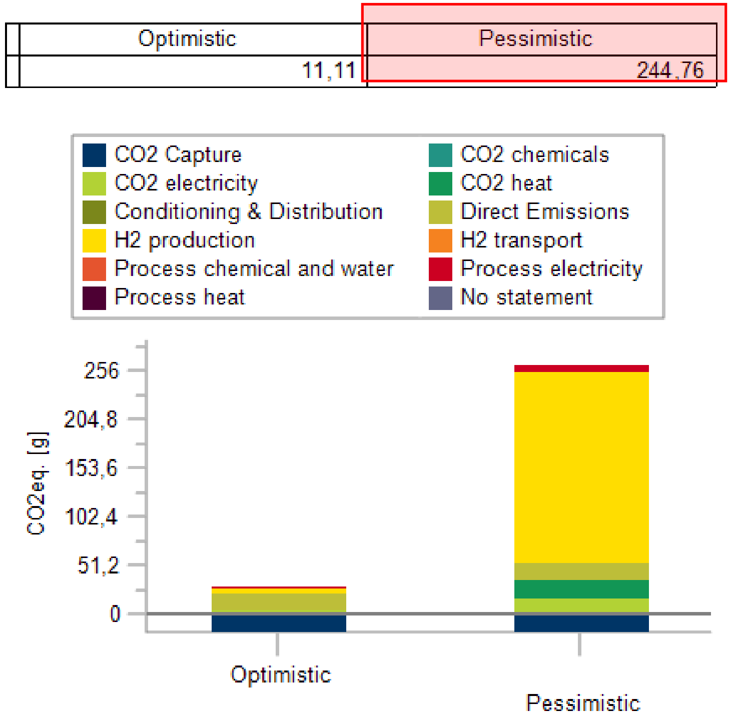
Source: Bouter, A., Hache, E., Seck, G., **2021**, *Transport electrification at all environmental costs.* icRS conference

WHAT ABOUT E-FUELS?

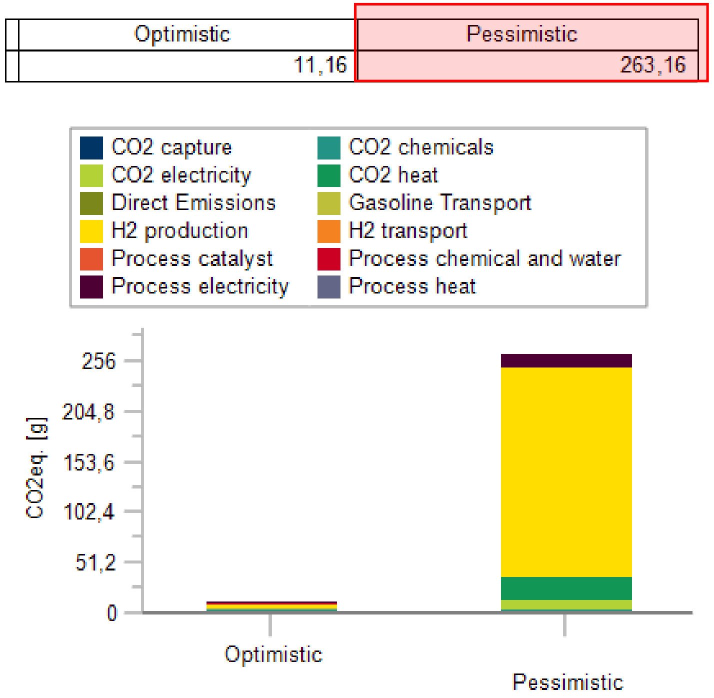
Results in $gCO_2eq./MJ$

(based on JEC v5 data, with Ecoinvent data, energetic allocation rather than substitution)

E-diesel



E-gasoline



Optimistic scenario

- Wind electricity

Pessimistic scenario

- European electricity

Fossil fuel ref. (RED II)
94 g CO_2 eq. / MJ

- E-fuels are very promising from a climate change perspective according to the energy used for their production.
- From a cumulative energy demand perspective, e-fuels are 2 to 3 times more energy consuming than other alternative pathways.

➔ The origin of the energy used to produce e-fuels is crucial for their impacts on climate change indicator

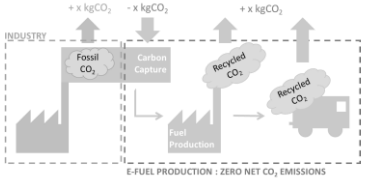
- The production of H_2 stage has a significant role to play about the deployment of e-fuels, especially the origin of the electricity for H_2 production.

 |

TAKE-HOME MESSAGES

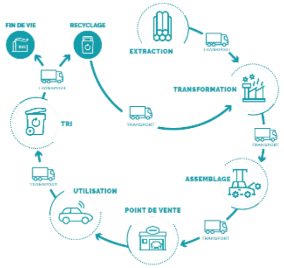
PROS

- Biomass
  - Important lever for reducing pollutants in the transportation sector
  - Potentially abundant source of renewable energy
  - Biofuels are easily substitutable for conventional fuels
- Electrified vehicles
  - Zero tailpipe emissions
  - Could be a game changer for GHG reduction according to batteries' weight and energetic sizing
- E-fuels
  - Drop-in
  - Promising solution in terms of GHG reduction



CONS

- Biomass
  - Possible competition of food versus fuel
  - Potential rebounds effects on LUC (direct and indirect)
  - Tailpipe pollutants emissions (other than CO_2)
- Electrified vehicles
  - Consumption of critical raw materials to produce battery
  - Battery's management end of life of batteries could be a game changer between pros and cons
- E-fuels
  - Production: energy consuming
  - Balance depending on the energy source



- LCA is
  - A very powerful multi-criteria environmental decision support tool to guide future policies
  - Which is sensitive to hypothesis and requires sensitivity analysis
  - It seems also urgent to considered other environmental indicators than the only climate change impact indicator to have a broader view of the impacts
  - Large-scale scenario should also be assessed
  - It is the diversity of low-carbon solutions which seems to be the smarter way

REFERENCES

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THE RESOURCE DEPLETION ENVIRONMENTAL IMPACT INDICATOR

- Several LCIA methodologies exist to quantify resource depletion environmental impacts:
  - Depletion methods: reduction of a resource stock (proxy for accessibility of resources).
  - Future efforts methods: assess the consequences of current resource use on future efforts such as resource quality, surplus energy, or surplus cost.
  - Thermodynamic accounting methods: quantify the cumulative energy or exergy use in a product system.
  - Supply risk methods: “criticality” of raw materials (outside LCA community).
- Gold dominates the results for ADP_{UR} → low abundance in the earth’s crust.
- Tantalum dominates for ADP_{ER} → high pressure due to current extraction rates.
- Copper causes a relevant contribution in all the inside-out related methods but in none of the outside-in focused methods.
- Nickel: large contributor to the result for the future efforts methods.
- Cobalt and tantalum cause a relevant contribution in outside-in methods
- Differences: perspective on global production (ESSENZ) or European imports (GeoPolRisk).

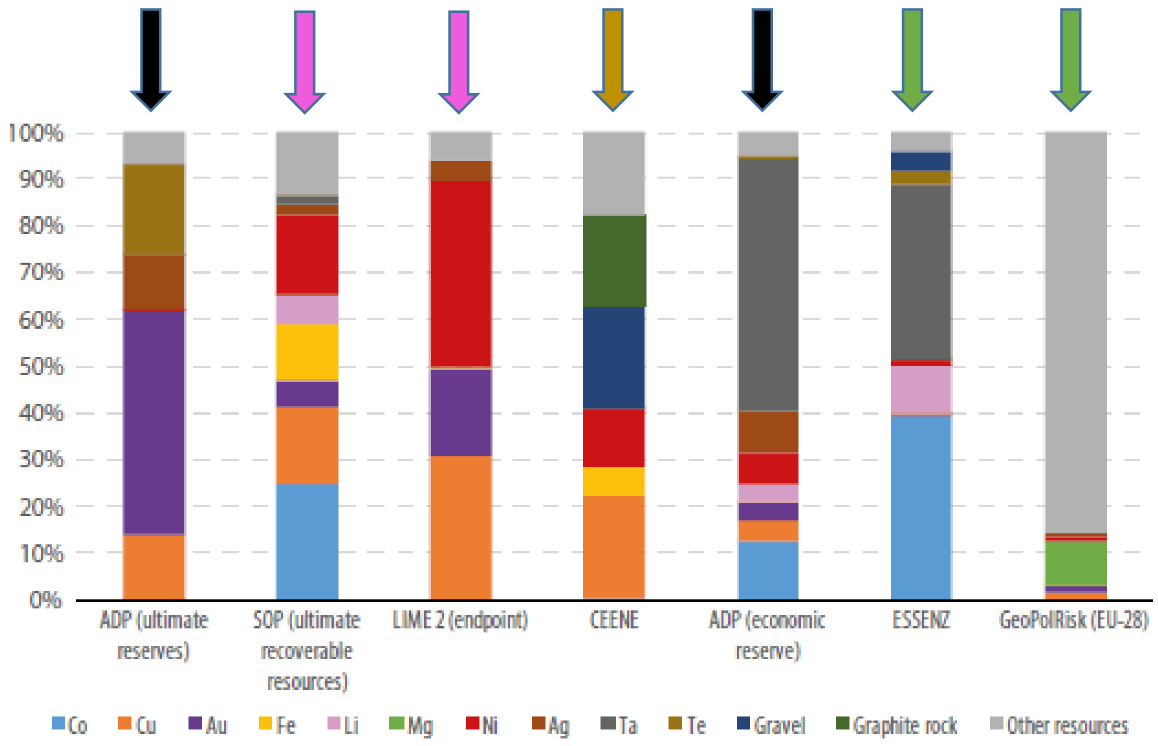
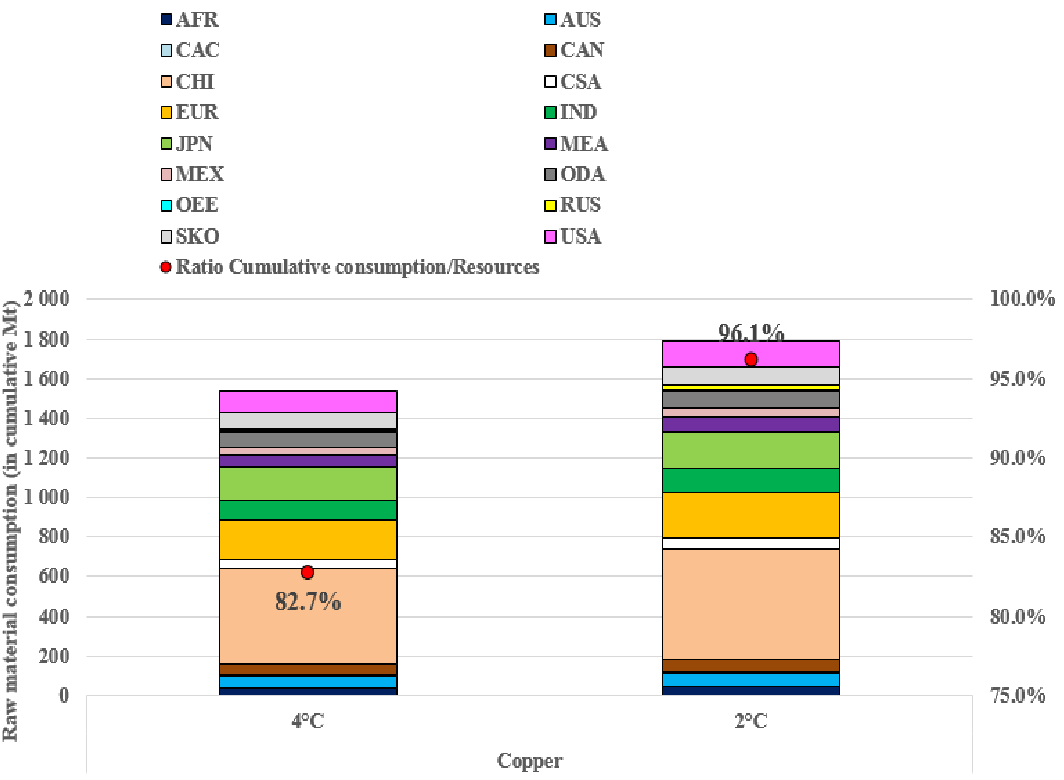
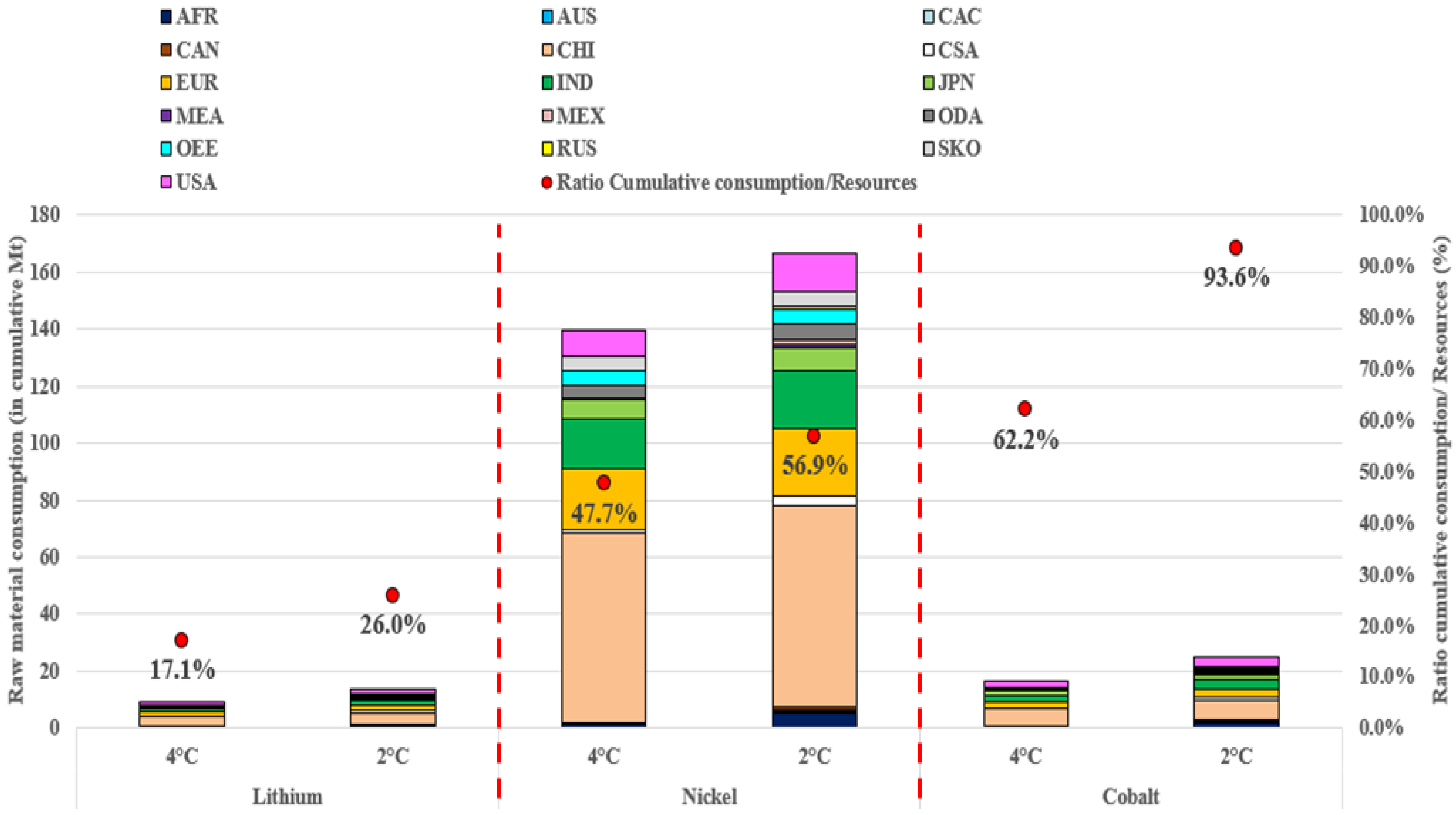


Figure 5.3. Case study impact assessment results for the selected methods (driving 1 km with an electric car)

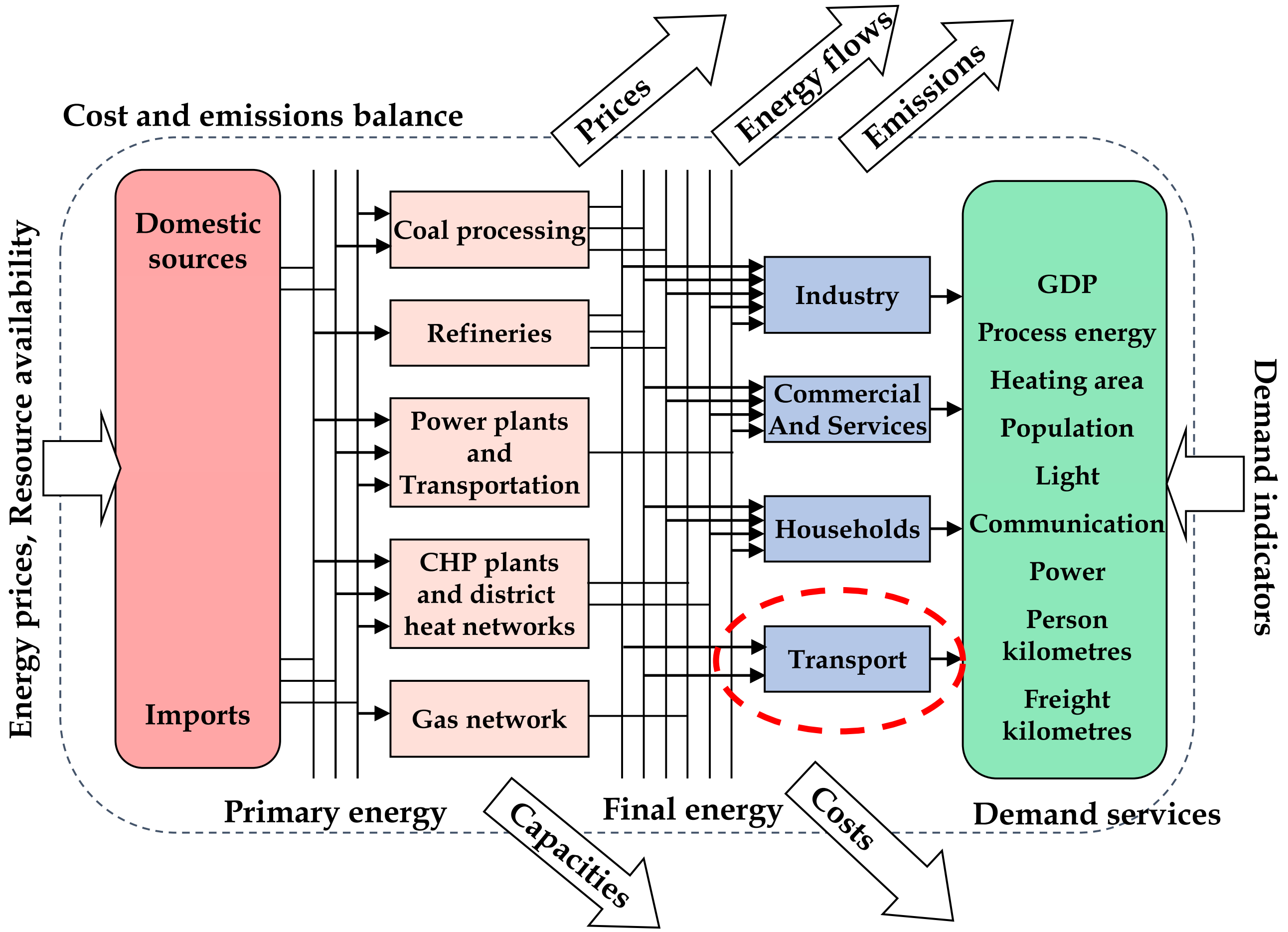
Source : UNEP/SETAC 2019

COMPARISON OF CUMULATIVE CONSUMPTION OF RAW MATERIALS BY REGIONS BY 2050 AND THEIR KNOWN RESOURCES IN 2010.





MATERIALS AND METHODS
INTEGRATED ASSESSMENT MODEL (TIAM-IFPEN)



- **Criticality** is often described as all the risks related to the production, use or end-of-life management of a raw material, including geopolitical risks, economic risks, production risks and environmental or social risks.
- **TIAM-IFPEN** is a linear programming World energy model
- Disaggregated into 16 regions
- Each region has its own energy system with their main demand sectors, and can trade fossil resources, biomass, materials or emission permits with other regions or in a centralized market.

➔ The model fully describes within each region all existing and future technologies from supply (primary resources) through the different conversion steps to end-use demands.

- Allows examining two climate scenario: +2°C and +4°C.
- Estimate the consequences of the fast roll-out of low-carbon technologies in the transport sector and how it is likely to significantly increase metals demand by 2050.
- Focus on European Union is made.

ALTERNATIVE FUELS IN THE ROAD TRANSPORT SECTOR

- In 2018, global energy consumption in the road transport sector amounted to just over 2.1 Gtoe

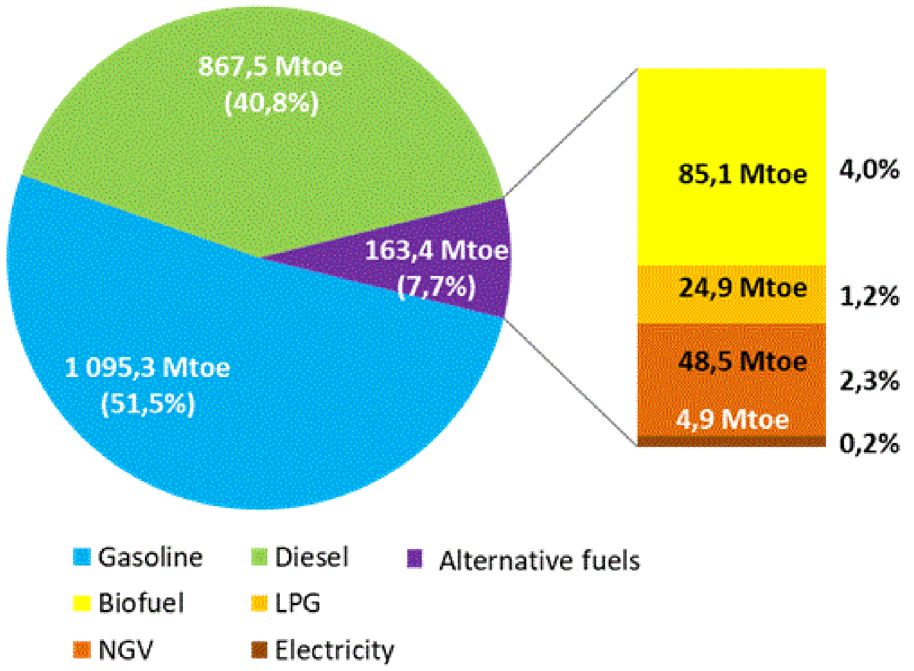
➔ About 25% of global GHG emissions

- The share of alternative fuels to oil-based gasoline and diesel stagnated at 7.7% of total consumed fuels
- Among alternative fuels, biofuels represented 52% of the alternative fuel market share.
- Throughout the World, the volume of biofuels consumed in the transport sector has been increasing constantly since 2011.
- Today, the road transport sector accounts for 29% of GHG emissions in Europe and this share has increased in recent years.

➔ Goal of a 90% reduction in GHG emissions from transportation by 2050.

- The EC has adopted a series of proposals to adapt the EU's climate, energy, transport and taxation policies to reduce GHG emissions by at least 55% by 2030 compared to 1990 levels.

Global energy consumption in the road transport sector in 2018



Source : IFPEN, from Enerdata and FO Licht's

RENEWABLE ENERGY DIRECTIVE II (REDII)

NEW ENERGIES

- Conventional biofuels: produced from food and feed crops (formerly G1)
- Advanced biofuels: biofuels produced from feedstocks listed in Annex IX, Part A
- Other biofuels
  - Annex IX Part B: from animal fats and used cooking oils
  - Other

Part A (advanced biofuels)
(a) Algae if cultivated on land in ponds or photobioreactors.
(b) Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC.
(c) Bio-waste as defined in Article 3(4) of Directive 2008/98/EC from private households subject to separate collection as defined in Article 3(11) of that Directive.
(d) Biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro-food and fish and aquaculture industry, and excluding feedstocks listed in part B of this Annex.
(e) Straw.
(f) Animal manure and sewage sludge.
(g) Palm oil mill effluent and empty palm fruit bunches.
(h) Tall oil pitch.
(i) Crude glycerine.
(j) Bagasse.
(k) Grape marcs and wine lees.
(l) Nut shells.
(m) Husks.
(n) Cobs cleaned of kernels of corn.
(o) Biomass fraction of wastes and residues from forestry and forest-based industries, i.e. bark, branches, pre-commercial thinnings, leaves, needles, tree tops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil.
(p) Other non-food cellulosic material as defined in point (q) of the second paragraph of Article 2.
(q) Other ligno-cellulosic material as defined in point (p) of the second paragraph of Article 2 except saw logs and veneer logs.
Part B
(a) Used cooking oil.
(b) Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009 of the European Parliament and of the Council

LA RÈGLEMENTATION EUROPÉENNE

Avec les amendements 2021

NEW ENERGIES

- **Les états-membres imposent un objectif aux fournisseurs de carburants pour augmenter l'utilisation d'énergies renouvelables.**

- **Cible pour 2030 :**

13 %
De réduction de GES dans le transport

- **Pour être éligibles, les biocarburants doivent répondre à des critères de durabilité**
  → mécanisme de certification
  → conditionne l'éligibilité à un soutien financier

≤ 7% *

Biocarburants plafonnés *(en compétition avec l'alimentaire et à fort risque ILUC)*

Plafond défini au niveau national : contribution ne devant pas dépasser 1% de plus que le niveau de consommation atteint en 2020 (2017 en France), avec un maximum de 7%

*** « High ILUC risk + significant expansion of production on high carbon stock lands »** (vise en particulier l'huile de palme) : diminution progressive à partir de 2024 pour atteindre 0% en 2030.

≥ 2,2%
0,2% 2022
0,5% 2025

Biocarburants avancés *(à faible risque ILUC)*

Eligibilité basée sur la ressources et/ou la technologie listés en Annexe IX Partie A

≤ 1,7%

Biocarburants issus de ressources listées à l'annexe IX part B

Graisses animales et huiles de cuisson usagées

≥ 2,6%

Carburants renouvelables liquides ou gazeux d'origine non biologique (e-fuels, H2)

Autres

- Electricité ENR

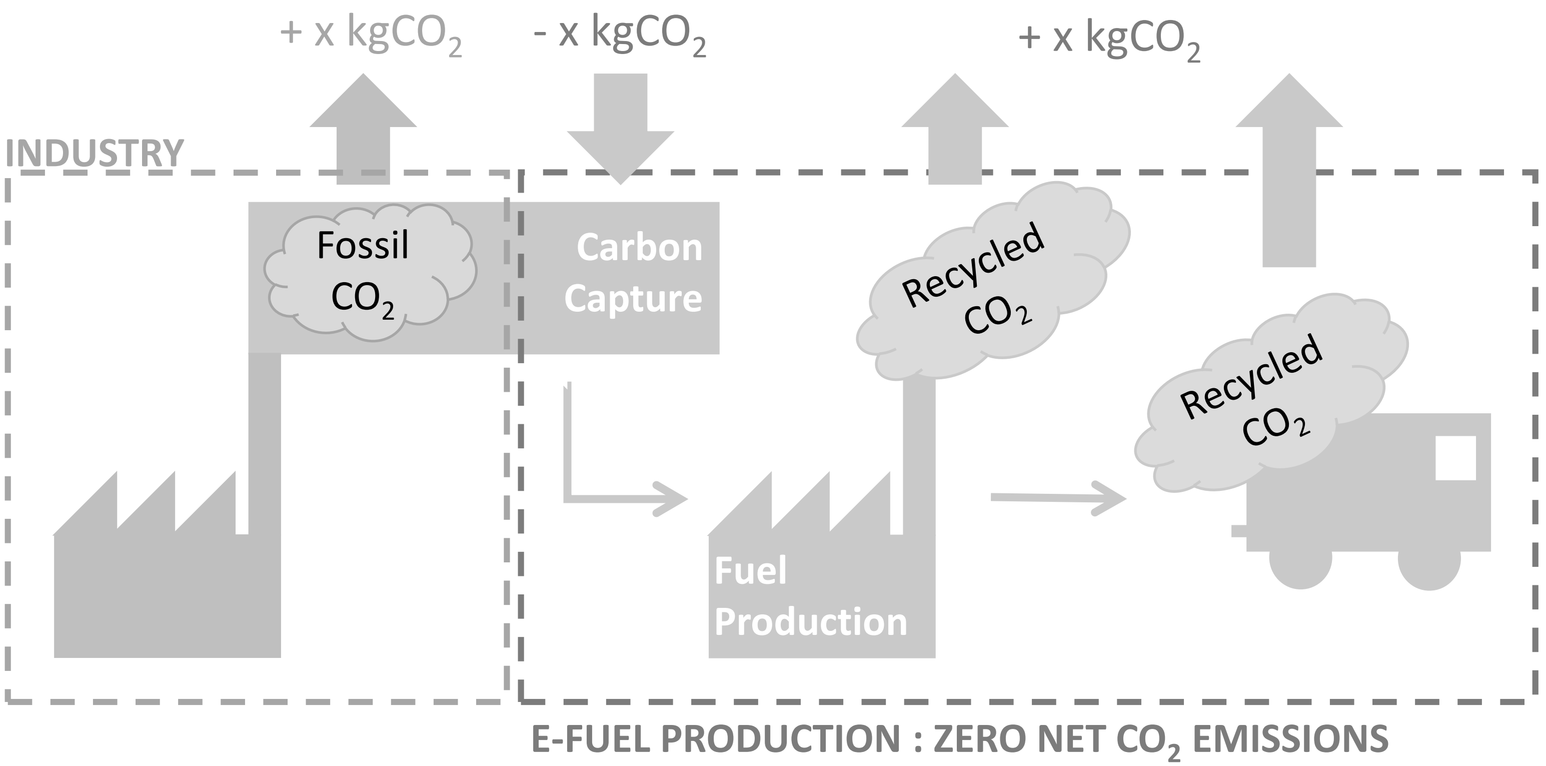
- Carburants issus de carbone recyclé

Mesures complémentaires

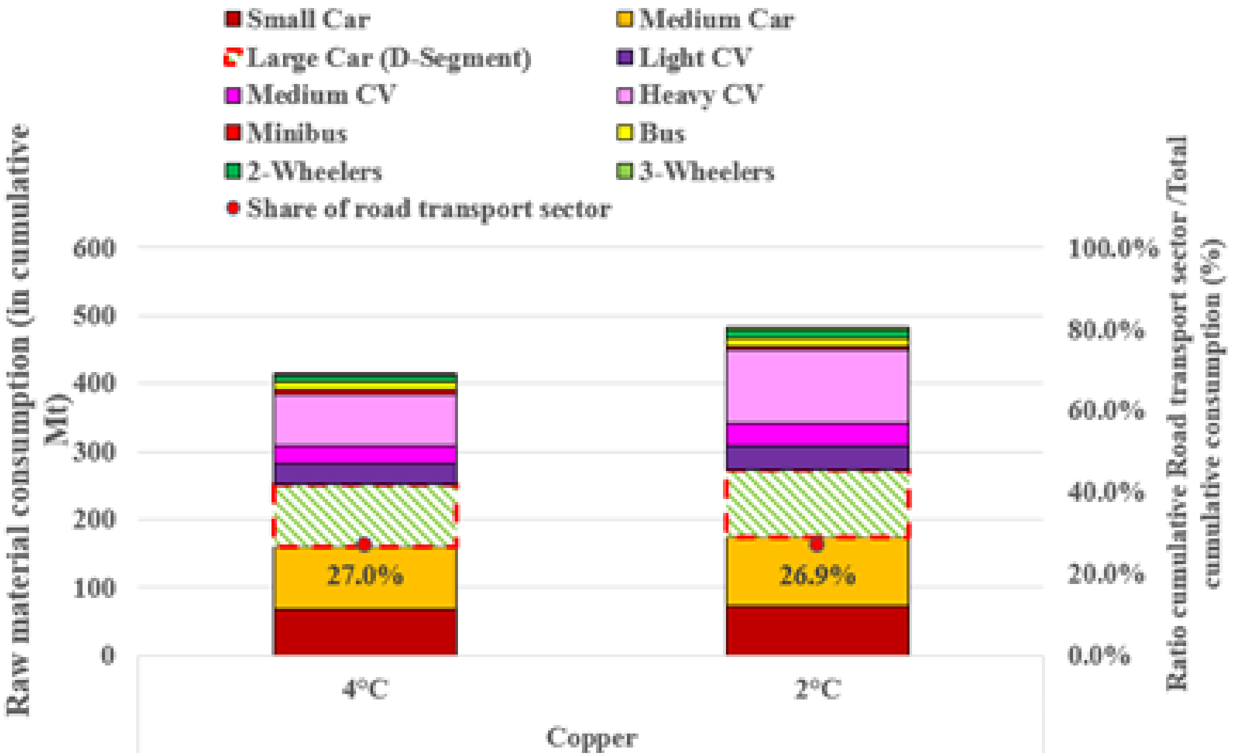
Plus de coefficients multiplicateurs, sauf pour l'aérien et le maritime (x1,2)

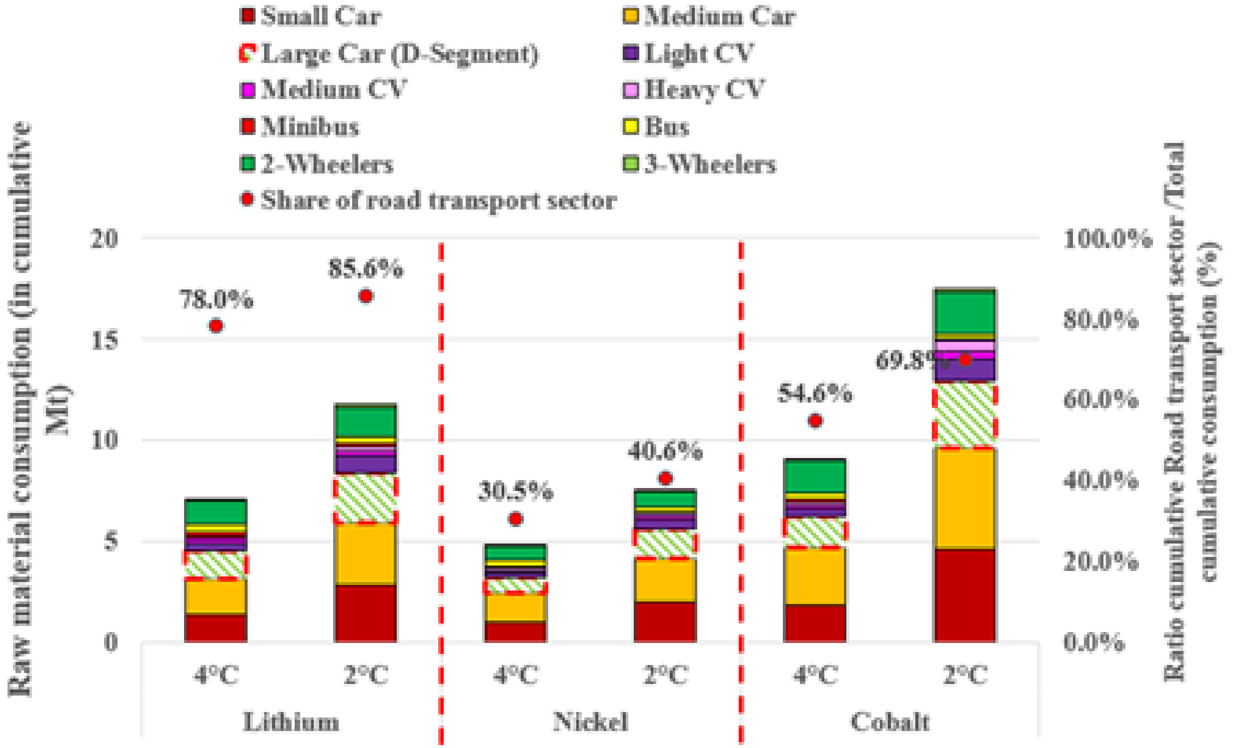
Modifications des modalités de calculs des objectifs: sur base de consommation d'énergie touts modes de transport confondus.

CARBON ACCOUNTING FOR CAPTURE FROM FLUE GAS



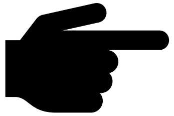
RESULTS – RESOURCE DEPLETION INDICATOR (2/2)
SUPPLY RISK PERSPECTIVE





- Evolution of the total cumulative demand of copper, lithium, nickel and cobalt with climate constraints.
- Focus on transportation sector
- Due to the fast roll-out of electric vehicles, the D-segment represents around 20% of the transport cumulative consumption of any raw material considered while it is less than 15% of the global fleet worldwide.
- Europe represents around 8% of the D-segment worldwide.
- European import dependency on raw materials for batteries is on stake.
- The European willingness to create a battery consortium in order to limit this future risk should be considered as the development of battery recycling sector.

INTRODUCTION (3/3)



Objectives

- Find out how much increasing BEV’s operating range affects climate change and resource depletion indicators.
- Identify the trade-off for BEVs’ development between battery’s weight and autonomy from a GHG perspective for large passenger duty-vehicle (D-segment) in Europe.
- Consider the criticality issues of raw materials in a more global context as a complementary analysis to LCA resource depletion indicator, as recommended by UNEP-SETAC guidelines (supply-risk method).

How?

- Based on LCA methodology (ISO 14040, 14044)
- Based on an integrated assessment model (IAM): TIAM-IFPEN
- Comparison of BEVs to their internal combustion engine (ICE) equivalents, and their future technological improvements by 2030.
- Putting the LCA resource depletion indicator in perspective with the supply-risk resource indicator.

CONCLUSION AND PERSPECTIVES

SUSTAINABLE MOBILITY

- LCA analysis focused on the climate change impact and resource depletion potential of large (D-segment) BEVs and ICEs for two time horizons (2019 & 2030) in Europe simulated over the WLTC cycle.

- Demand and import dependency on materials through to 2050 were assessed thanks to our linear programming world energy-transport model, TIAM-IFPEN.

- BEVs could be a game changer for GHG reduction according to batteries' weight and energetic sizing.

- Nevertheless, batteries' production consume critical materials and the two resources indicators pinpoint the fact that these two methodologies should be performed in parallel in order to have a broad view of the environmental impacts of the future development of transport sector.
  - Resource depletion indicator assessed throughout LCIA methodology shows that raw materials such as gold or copper contribute more to the ADP indicator, whereas others such as cobalt, nickel or lithium have very limited contribution to the impact.
  - Criticality assessment of these materials give a more complete view by considering a tri-dimensional approach based on geological, economical and geopolitical factors, highlighting the pressure on copper and cobalt in a global constraint (+2°C) scenario: respectively 96,1% and 93,6% of these resources would be consumed by 2050.
  - Transportation sector accounts for 85,6% of lithium consumption, also pinpointing a potential sectorial issue.

- It seems urgent to take into account in resource depletion methodologies the recycled or soon-to-be recycled materials.
- A large-scale deployment of an electric fleet should also be assessed.