

# LCA of lignin-based products

## The case of Biobased Asphalt

Main Findings and Conclusions from the CHAPLIN XL & TKI Projects

Prof. Dr. Martin Junginger, Utrecht University

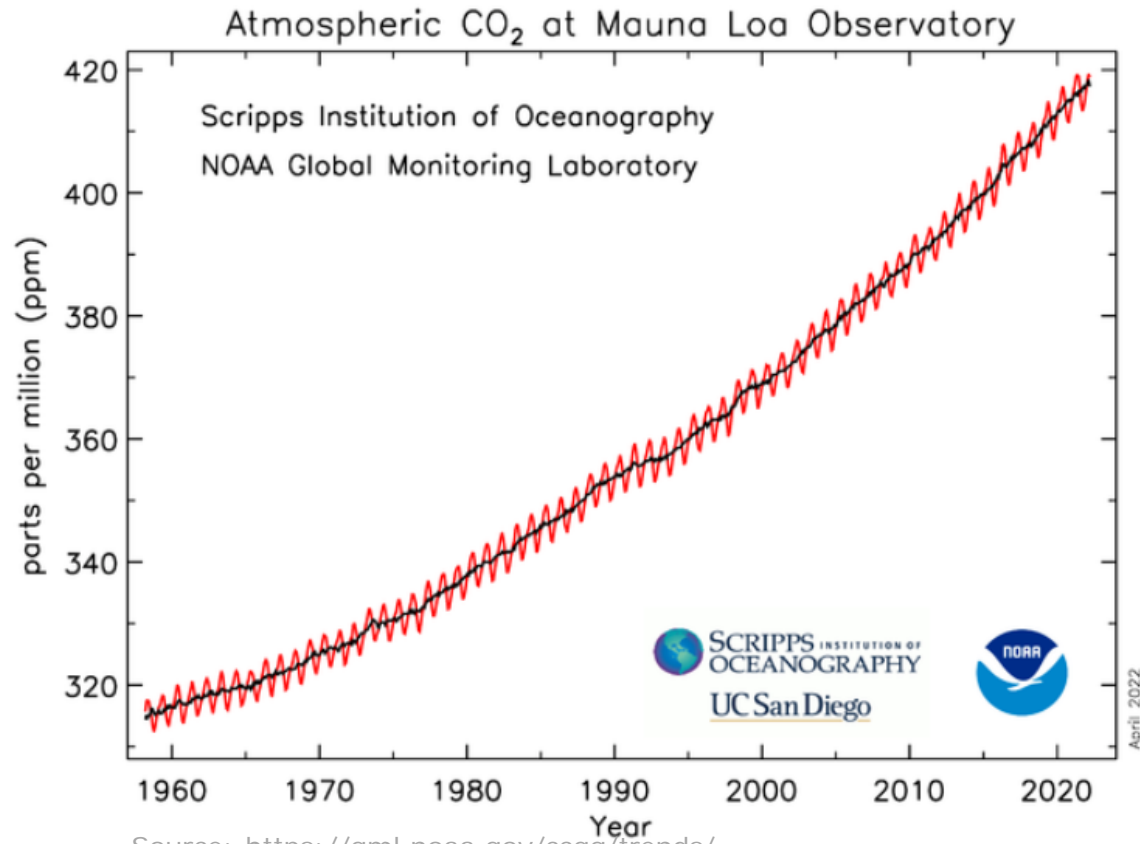


Co-authors: Richard Gosselink, Blanca Corona, Ric Hoefnagels, Marco van Veen, Christian Moretti, Iris Vural-Gürsel, Ted Slaghek, Paul Landa, Hendrik Post, Annelie Jongerius, Ed de Jong, Joop Groen, Albertus Steenbergen, Martijn Verschuren, Dave van Vliet



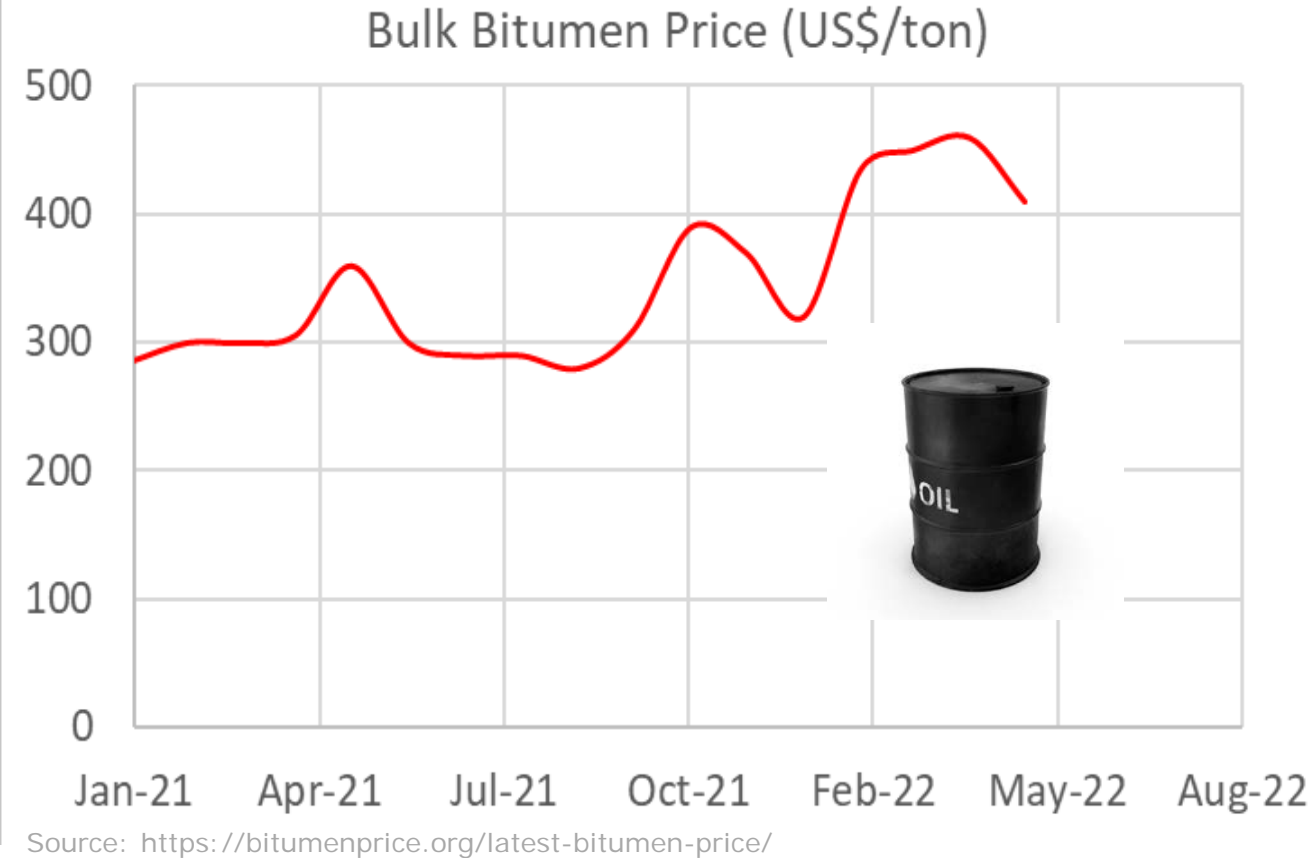


# The problems



Building operations and construction account for nearly **40%** of global energy-related CO<sub>2</sub> emissions

Source: Global Alliance for Building and Construction



**Quality, quantity and price** of bitumen as binder for road becoming increasingly problematic for road construction.



# A solution: Biobased asphalt



- Replacing fossil bitumen with up to 50% lignin
- Lignin 2<sup>nd</sup> most abundant biopolymer in the world
- Sourcing both from existing pulp mills and future biorefineries
- Current low value, non-circular application for process heat
- Long-term biogenic carbon storage in asphalt as a strategy for negative emissions



# CHAPLIN XL project partners

(Collaboration in aspHalt APplications with LIgniN)



This project was carried out with subsidy of the Dutch Ministry of Economic Affairs & Climate, Nationale regelingen EZ-subsidies, Topsector Energie, executed by Rijksdienst voor Ondernemend Nederland.







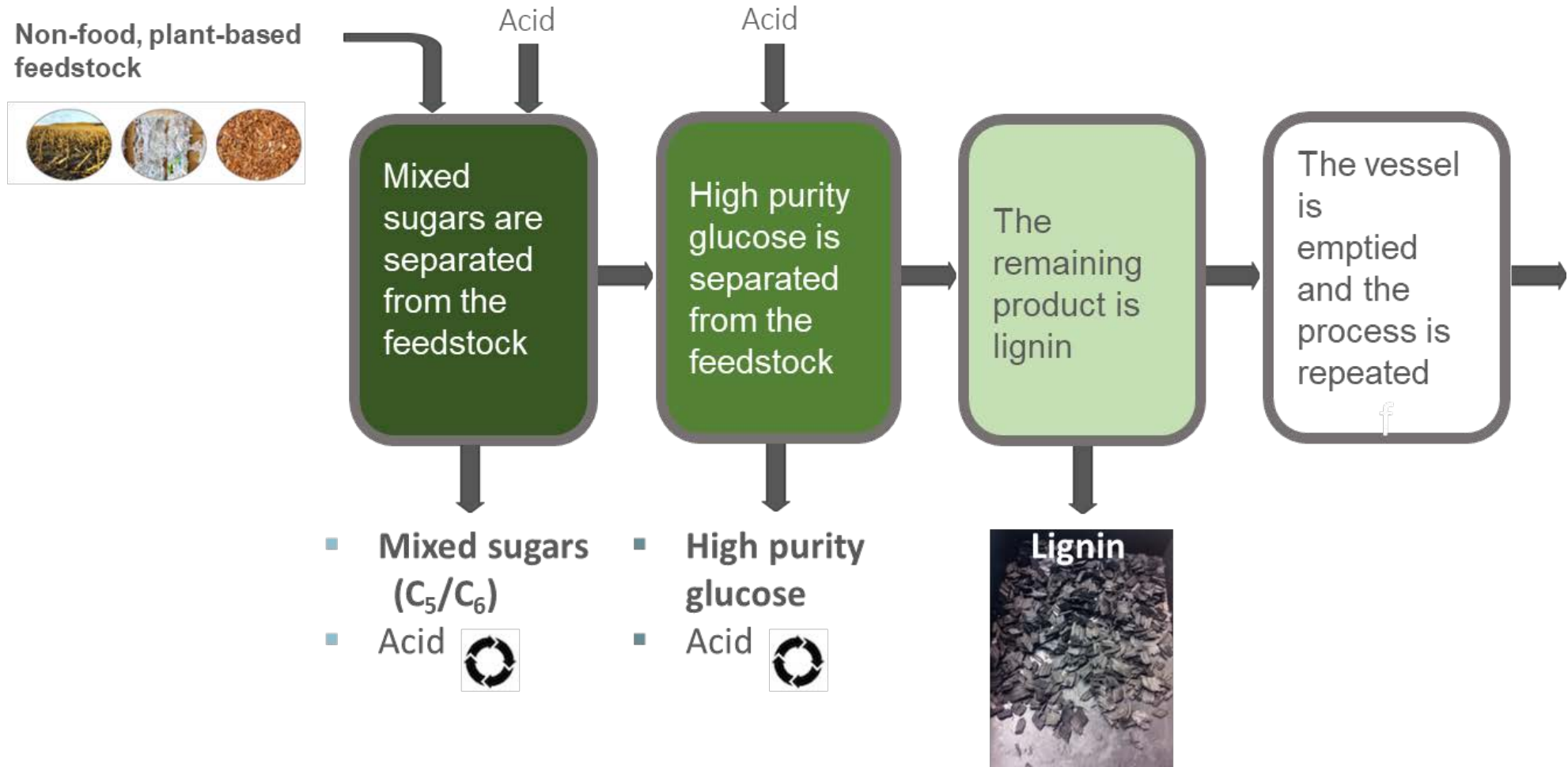
# Aims of the CHAPLIN XL project

- Test the use of Avantium Dawn Technology lignin in a test road
- Constructing several test roads with lignin replacing bitumen up to 50% in various asphalt layers
- Gaining experience with the combination of recycled asphalt/bitumen and fresh lignin in test roads
- Determining the technical lifetime of various biobased asphalt constructions
- Investigating Health and Safety aspects during production of biobased asphalt
- Detailed assessment of techno-economic performance, environmental impacts and circularity of biobased asphalt



# Use of Kraft and Avantium Dawn technology lignin

More than one tonne of Avantium Dawn Technology lignin was produced by the Avantium pilot plant in Delfzijl





# Avantium Dawn technology lignin

The Avantium Dawn Lignin was extensively tested, and (after drying) dried and applied in a pilot road in Siddeburen, Groningen





Amongst others:

- AC Surface, Base en Bind mixtures with relatively high recycled content and application of kraft lignin;
- SMA mixtures for replacement of bitumen by Dawn lignin (Avantium) and Kraft lignin (Stora Enso)

For various asphalt structures, the technical lifetime was estimated based on functional type test and fall weight deflection test (VGD) measurements

Based on the various laboratory tests, it was concluded that asphalt layers containing up to 50% lignin perform equally in terms of loading capacity as 100% bitumen-based asphalt





# Design of total asphalt structures for 5 test roads

Maltaweg, North Sea Port, Vlissingen (Flushing) Nov. 2020. First road with all 3 asphalt layers containing kraft lignin. The middle and base layer additionally contained recycled asphalt



N987, Siddeburen, Groningen, May 2021  
First road ever with both Kraft lignin and Avantium dawn lignin in 250 m long top layer sections



Univers



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Contents lists available at ScienceDirect

# Science of the Total Environment

journal homepage: [www.elsevier.com/locate/scitotenv](http://www.elsevier.com/locate/scitotenv)



## Kraft lignin as a bio-based ingredient for Dutch asphalts: An attributional LCA



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<sup>a</sup> Utrecht University, Copernicus Institute of Sustainable Development, Utrecht, the Netherlands

<sup>b</sup> Wageningen Food & Biobased Research, Wageningen, the Netherlands

<sup>c</sup> Roelofsgroep, Den Ham, the Netherlands

### HIGHLIGHTS

- An environmental life cycle assessment of Dutch bio-based asphalts is presented.
- Kraft lignin was considered as a bio-based ingredient for asphalts.
- A comparison was conducted for various types of asphalts and kraft lignins.
- Climate change benefits can be achieved using lignin-based asphalts to replace current Dutch asphalts.

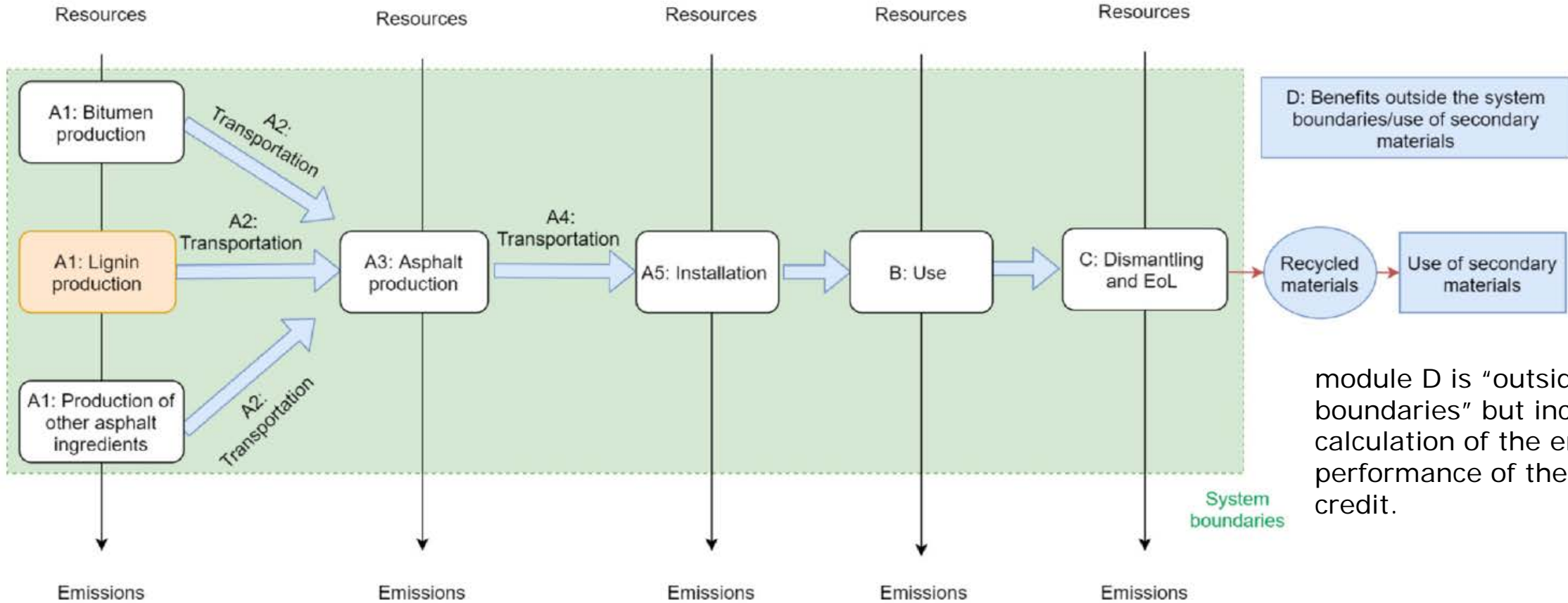
### GRAPHICAL ABSTRACT







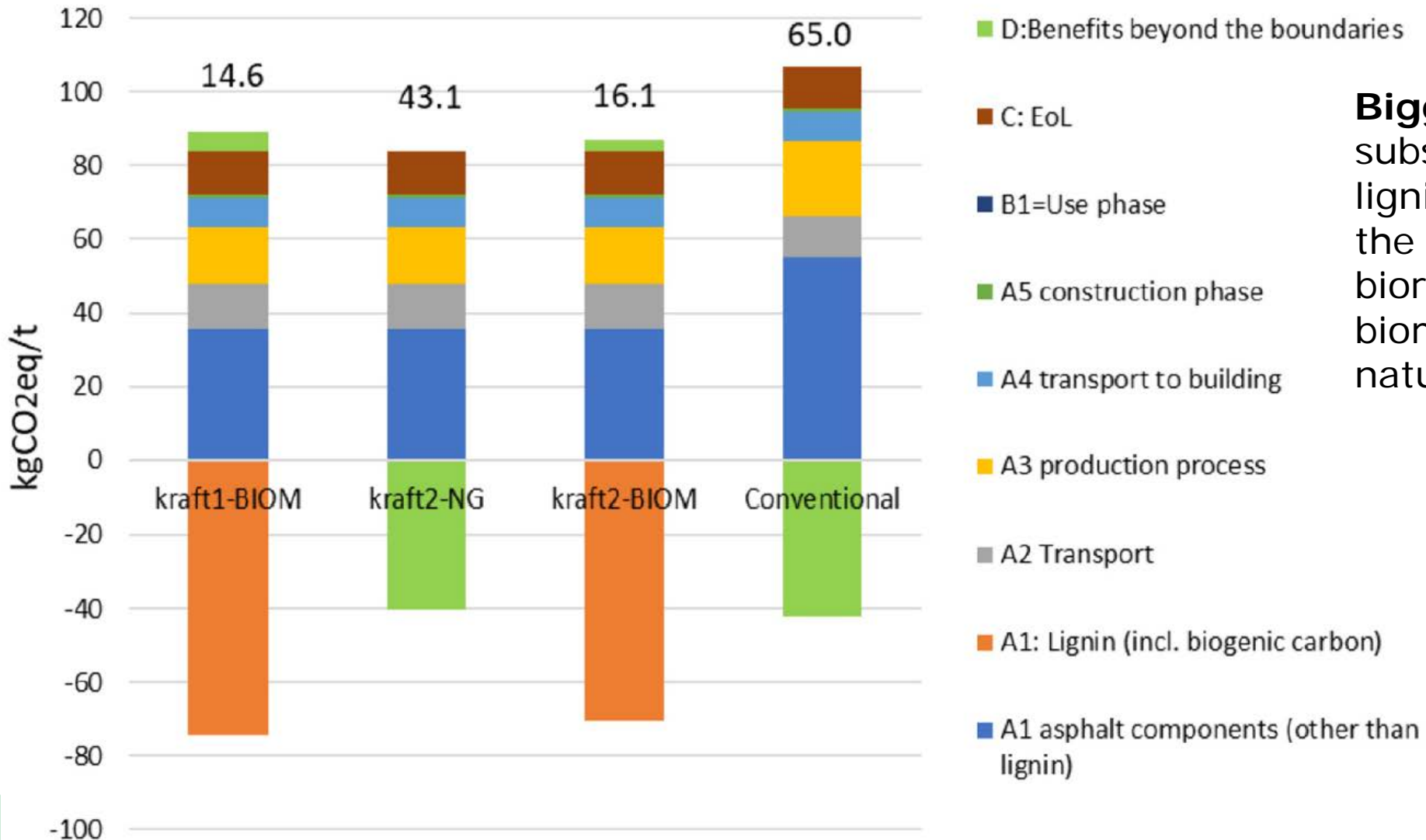
# System boundaries



module D is "outside the system boundaries" but included in the calculation of the environmental performance of the asphalt as credit.



## Cradle-to-grave Global Warming Potential of SMA asphalt



**Biggest issue:**  
 substitution effects of lignin displacement at the pulp & paper mill / biorefinery: low quality biomass (hog fuel) or natural gas?



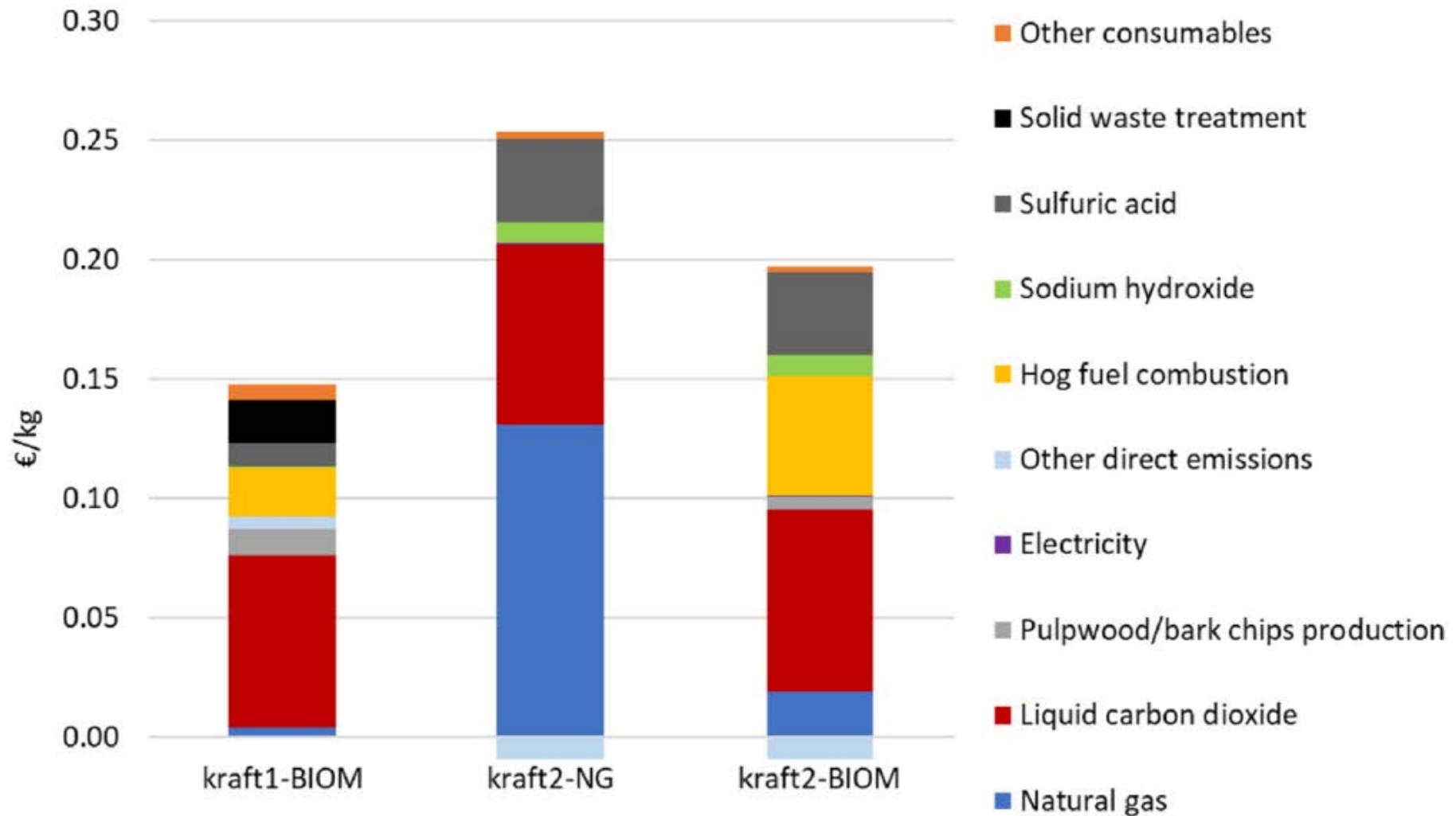


# Environmental Impact categories included

Impact category	Unit	Weighting factor
Abiotic depletion	kg Sb eq	0.16 €/kg
Abiotic depletion (fossil fuels)	MJ	7.7E-05 €/MJ
Global warming (GWP100a)	kg CO <sub>2</sub> eq	0.05 €/kg
Ozone layer depletion (ODP)	kg CFC-11 eq	30.0 €/kg
Human toxicity	kg 1,4-DB eq	0.09 €/kg
Freshwater aquatic ecotoxicity	kg 1,4-DB eq	0.03 €/kg
Marine aquatic ecotoxicity	kg 1,4-DB eq	0.0001 €/kg
Terrestrial ecotoxicity	kg 1,4-DB eq	0.06 €/kg
Photochemical oxidation	kg C <sub>2</sub> H <sub>4</sub> eq	2.0 €/kg
Acidification	kg SO <sub>2</sub> eq	4.0 €/kg
Eutrophication	kg PO <sub>4</sub> --- eq	9.0 €/kg



# MKI\* scores of 1 kg of lignin *per process*

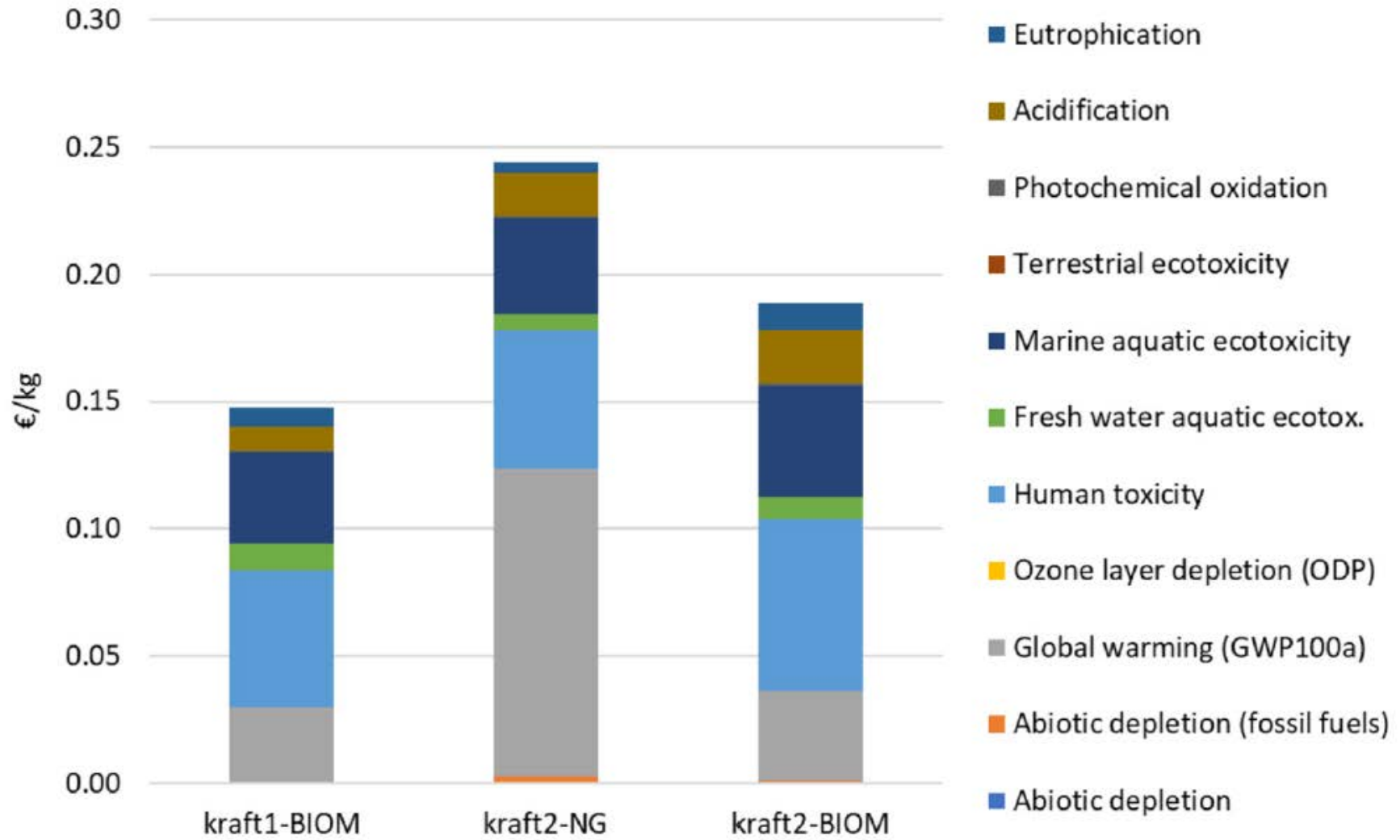


\*) Milieu Kosten Indicator, Dutch single-score indicator system for environmental impacts





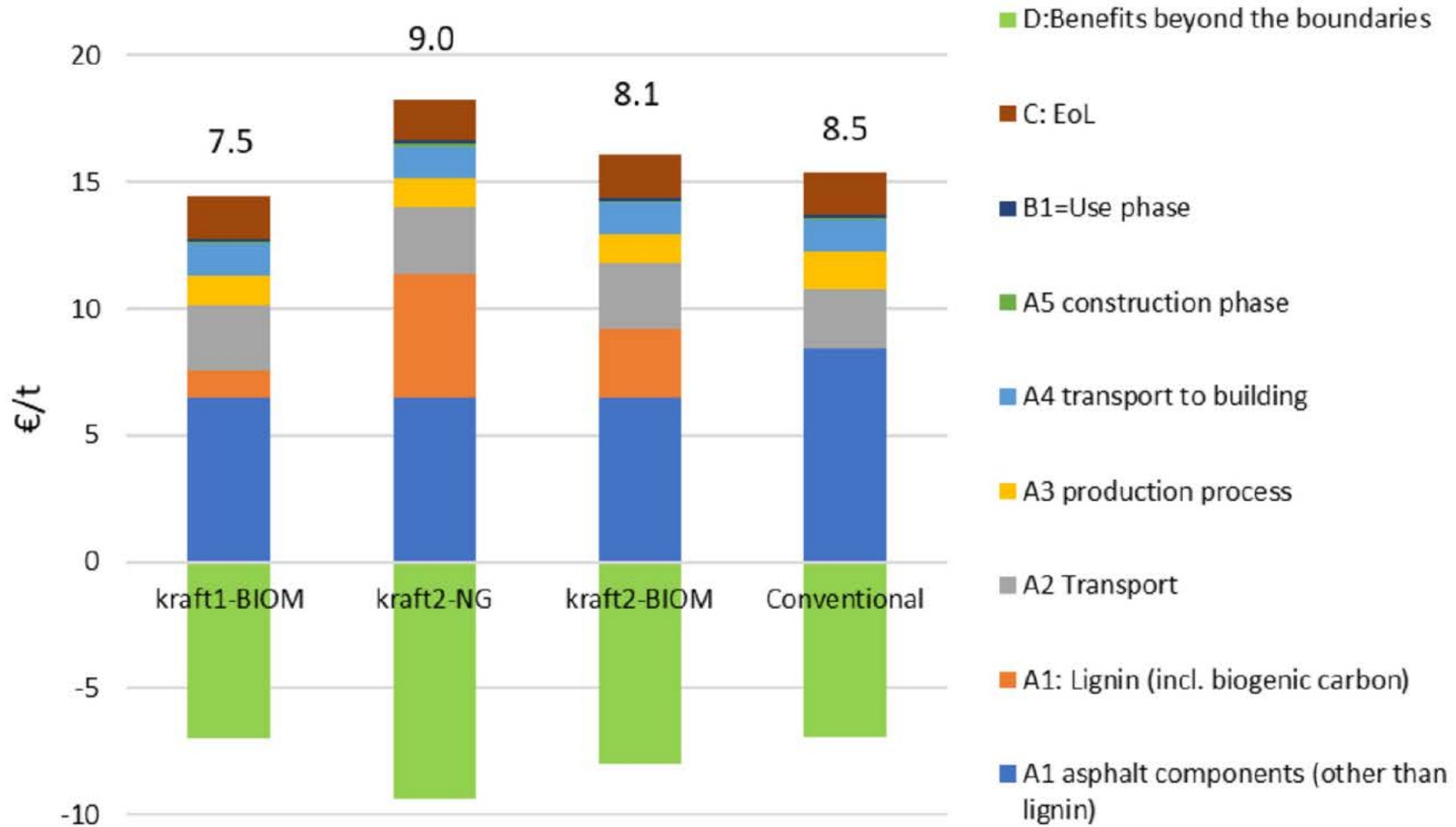
# MKI\* scores of 1 kg of lignin *per impact category*



\*) Milieu Kosten Indicator, Dutch single-score indicator system for environmental impacts



# MKI\* scores of 1 t of SMA asphalt



\*) Milieu Kosten Indicator, Dutch single-score indicator system for environmental impacts

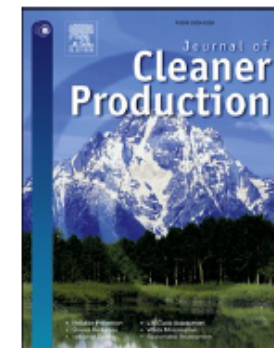


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Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

## Journal of Cleaner Production

journal homepage: [www.elsevier.com/locate/jclepro](http://www.elsevier.com/locate/jclepro)



# Using lignin from local biorefineries for asphalts: LCA case study for the Netherlands

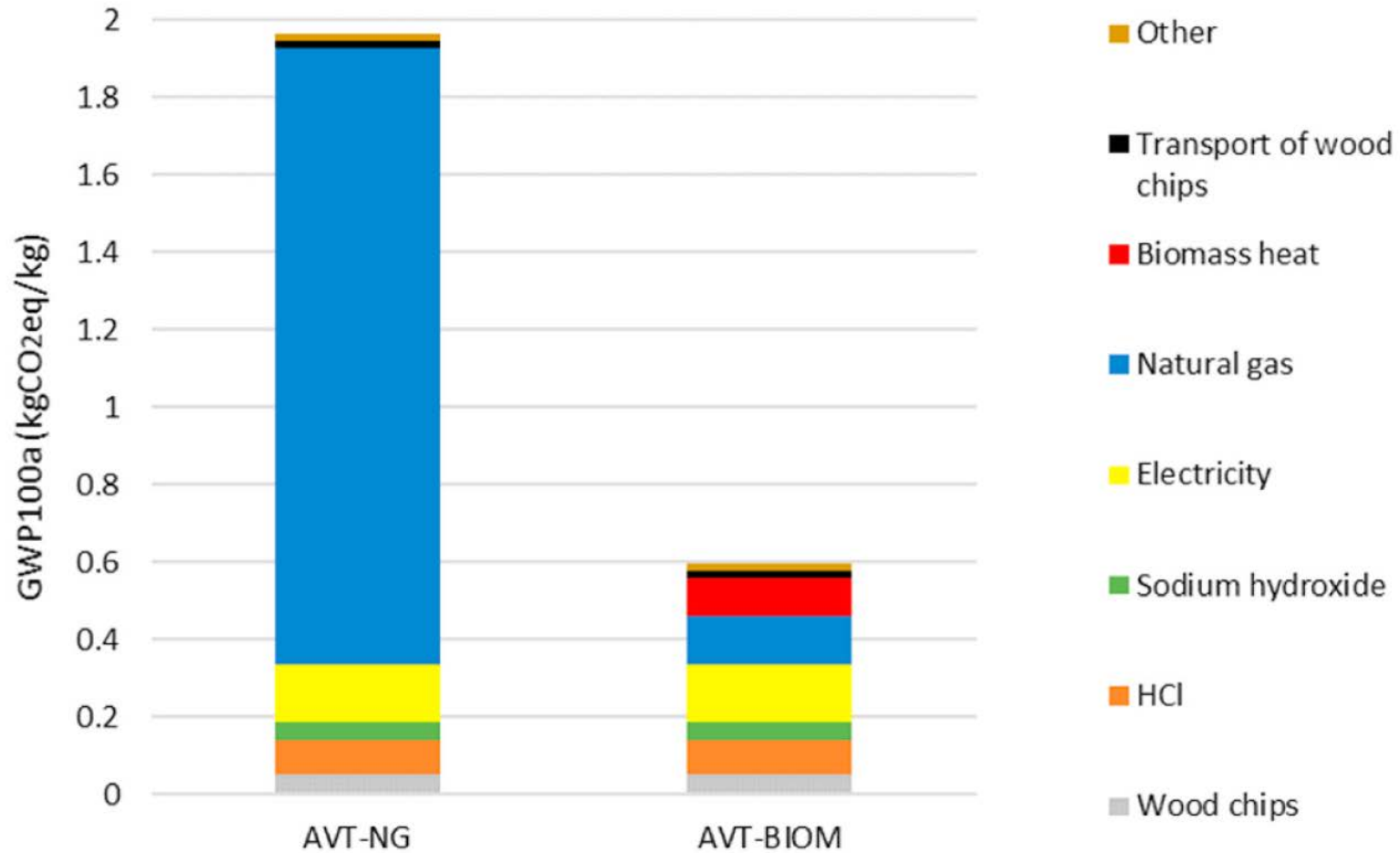
Christian Moretti <sup>a,\*</sup>, Ric Hoefnagels <sup>a</sup>, Marco van Veen <sup>a</sup>, Blanca Corona <sup>a</sup>,  
Svetlana Obydenkova <sup>b</sup>, Scott Russell <sup>c</sup>, Anna Jongerius <sup>c</sup>, Iris Vural-Gürsel <sup>d</sup>, Martin Junginger <sup>a</sup>





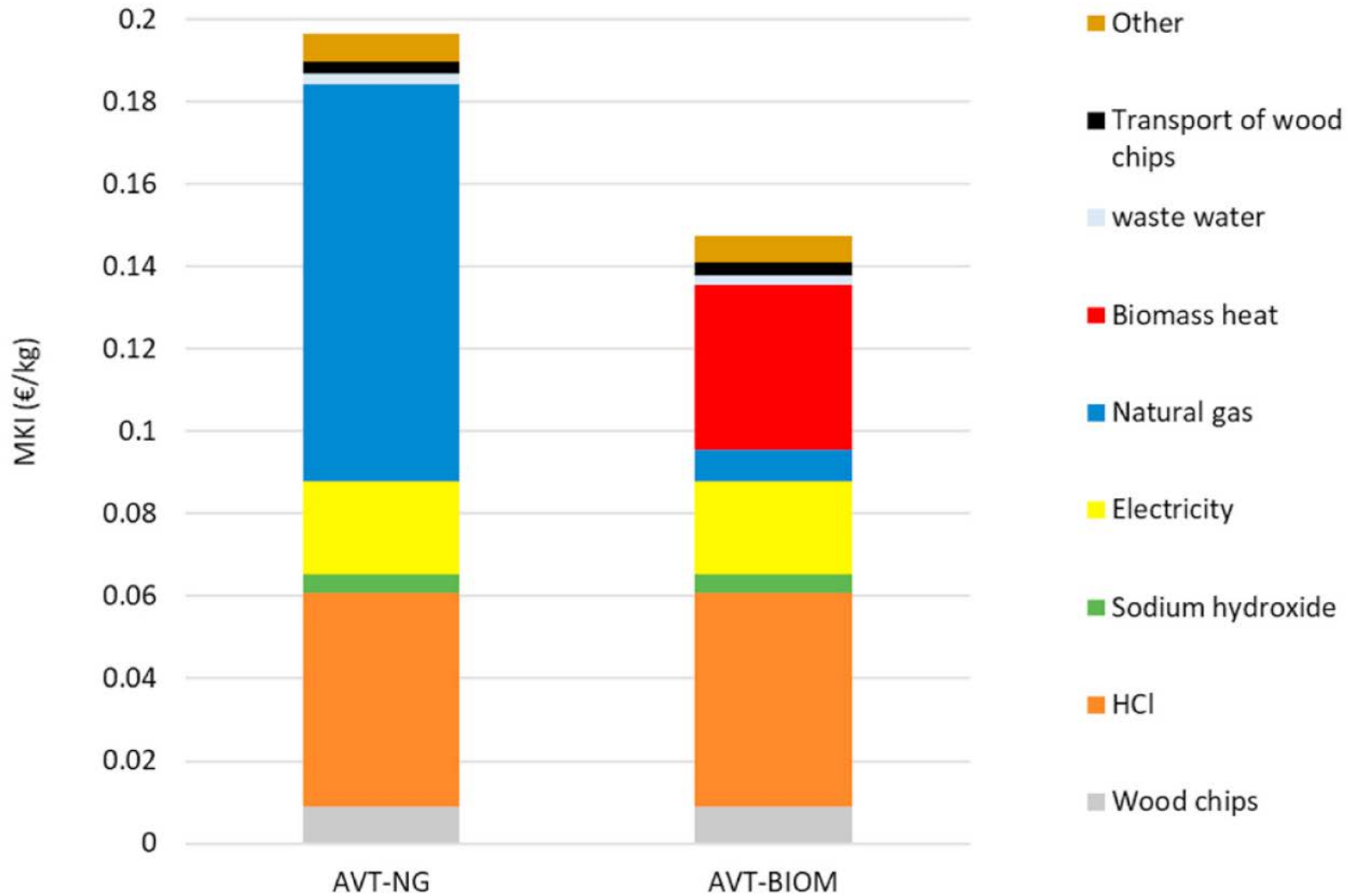


# Cradle-to-gate GWP of 1kg AVT lignin





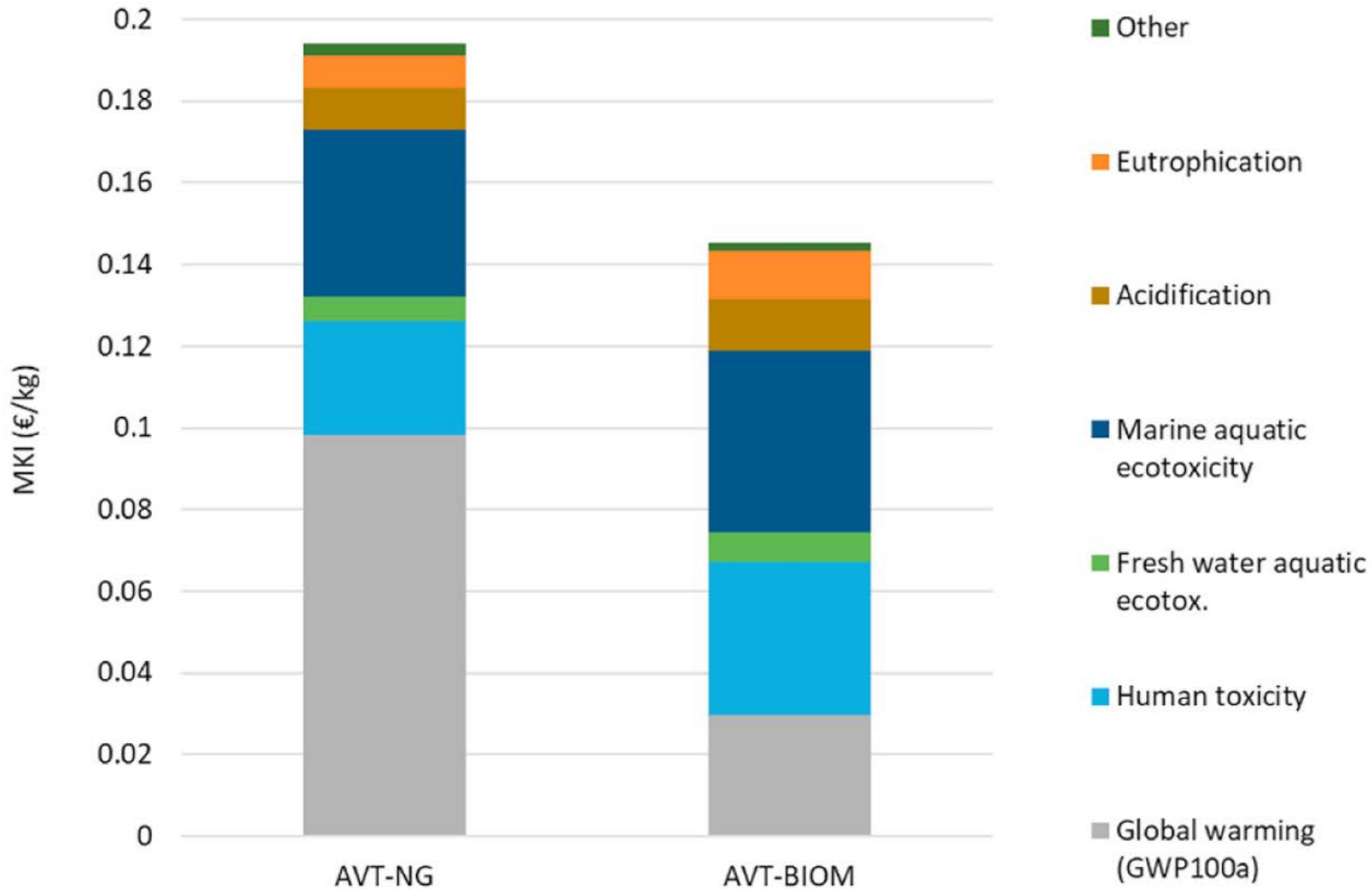
# MKI\* scores of 1 kg of lignin *per process*



\*) Milieu Kosten Indicator, Dutch single-score indicator system for environmental impacts



# MKI\* scores of 1 kg of lignin *per impact category*

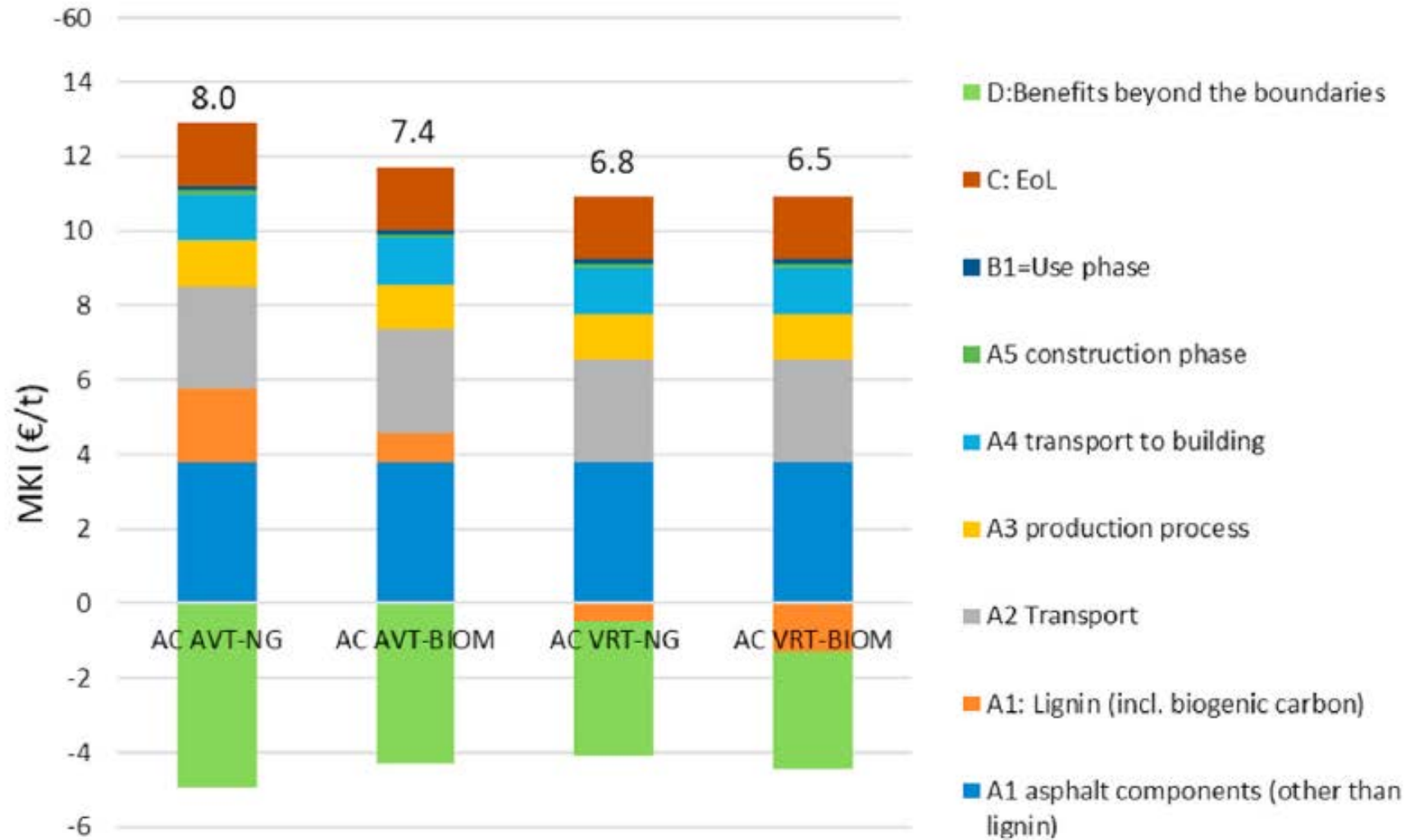


\*) Milieu Kosten





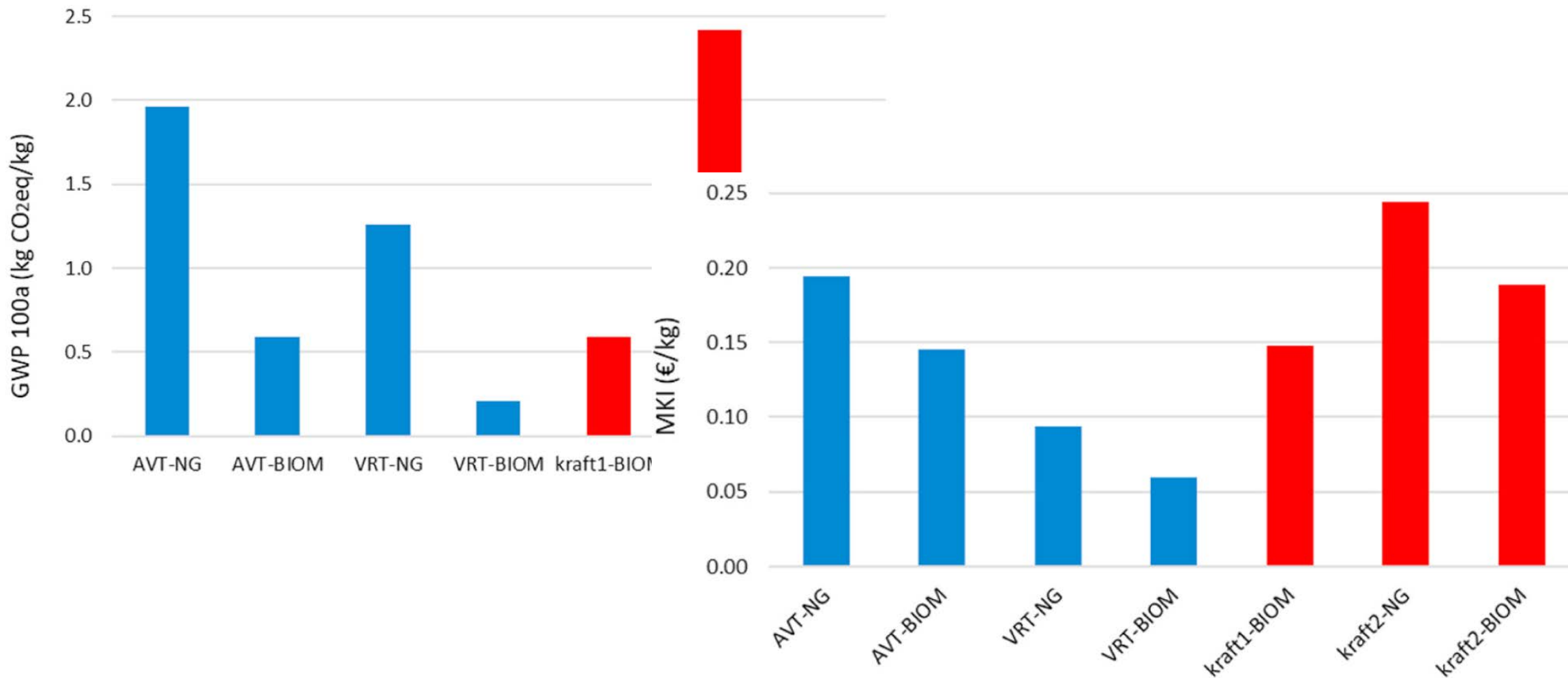
# MKI\* scores of 1 t of top layer asphalt



\*) Milieu Kosten Indicator, Dutch single-score indicator system for environmental impacts



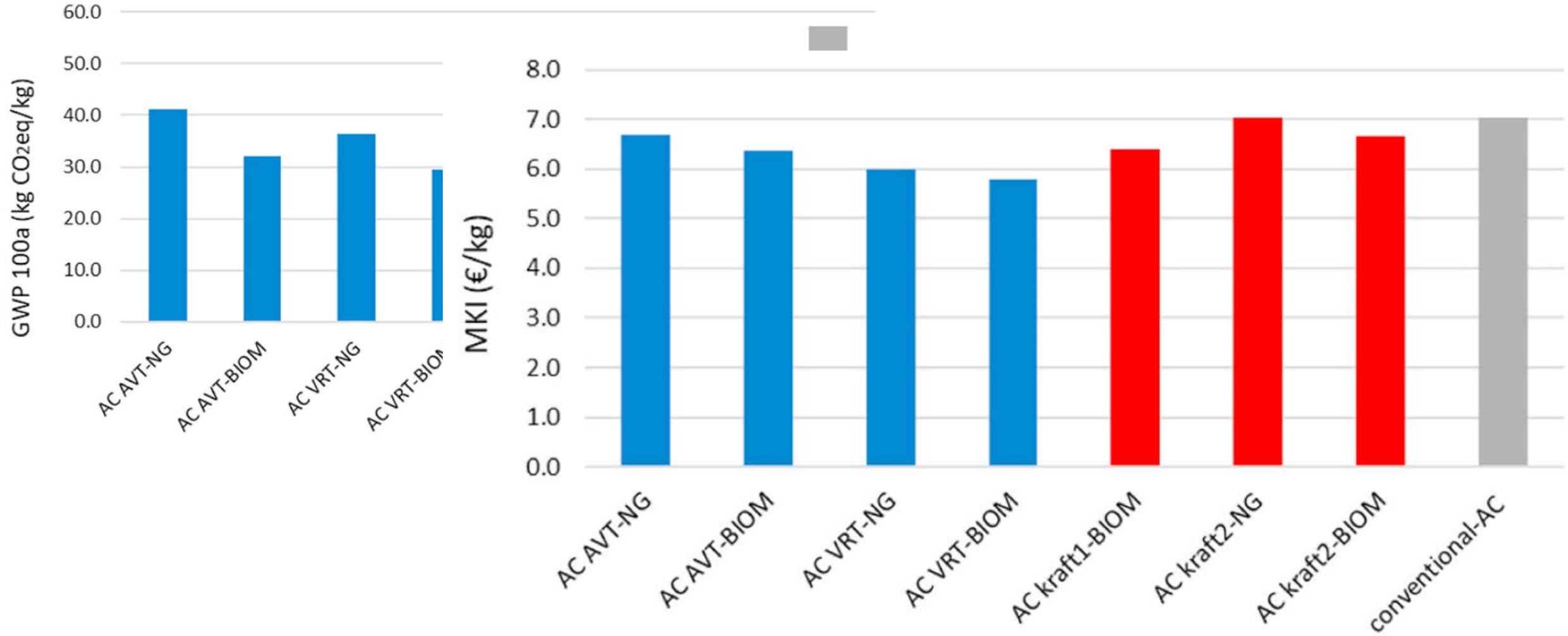
# Comparing lignins...



\*) Milieu Kosten Indicator, Dutch single-score indicator system for environmental impacts



# Comparing asphalts

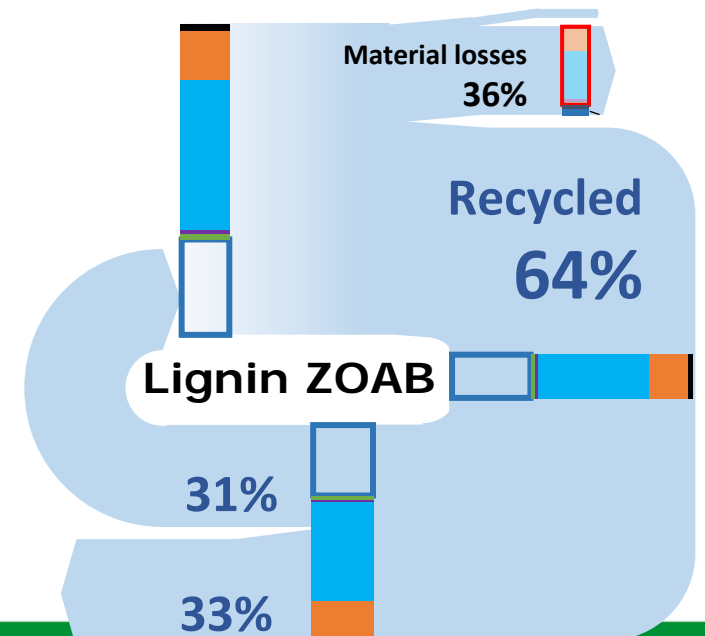
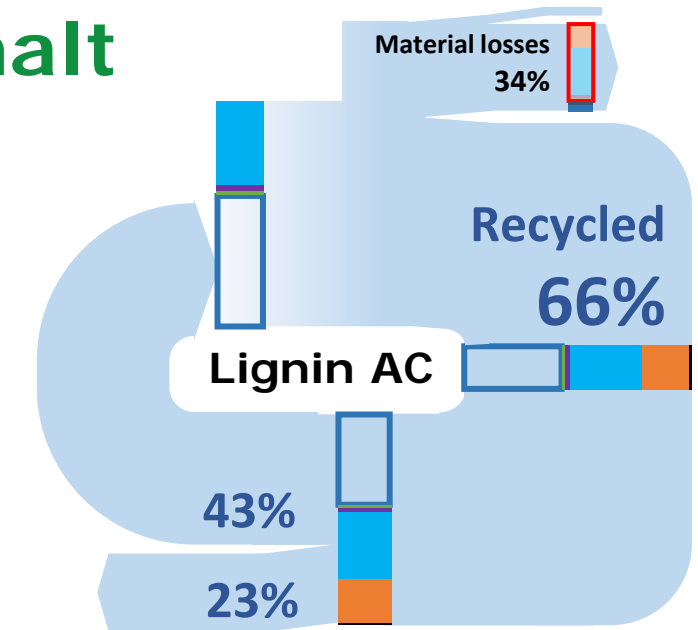
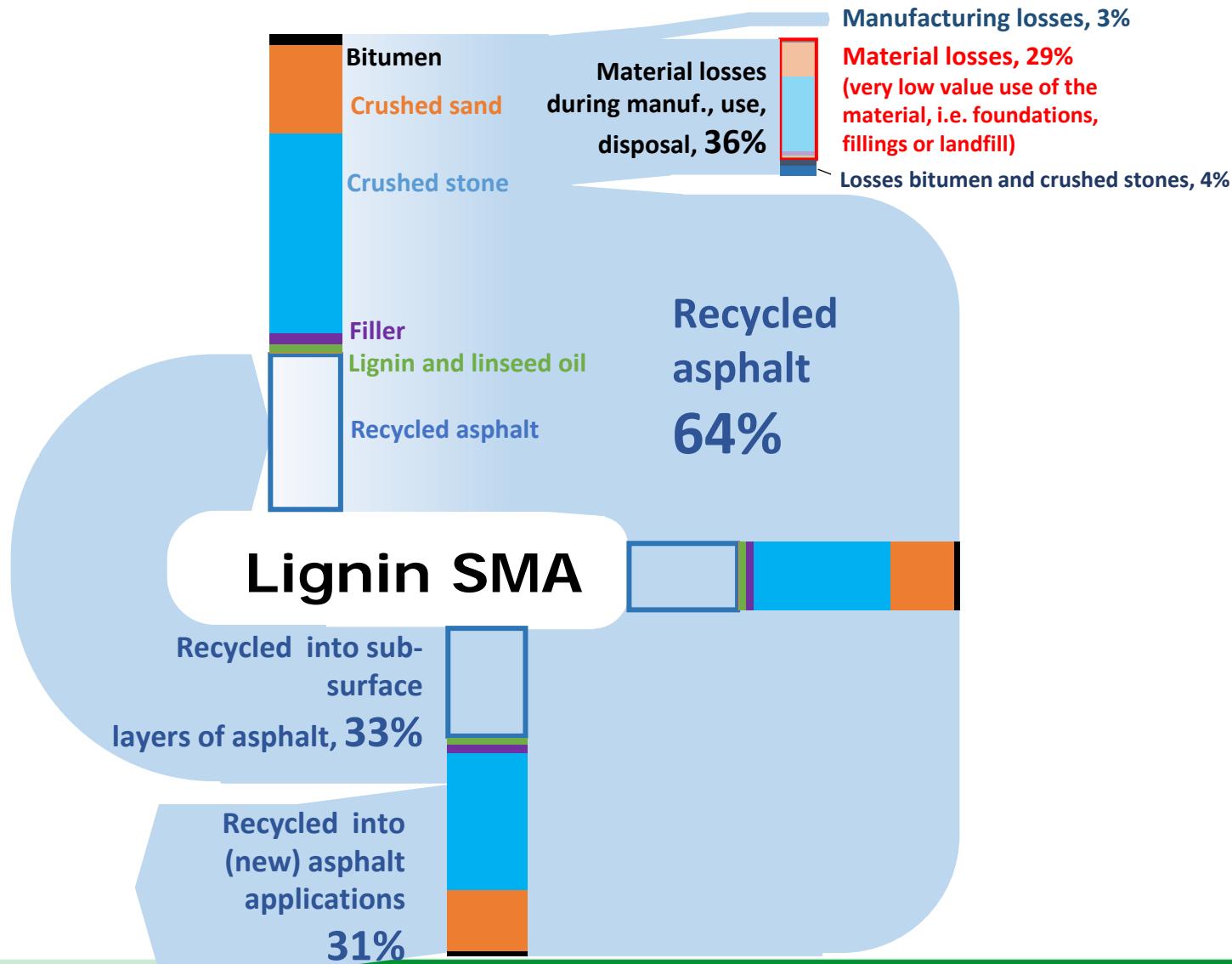


\*) Milieu Kosten Indicator, Dutch single-score indicator system for environmental impacts





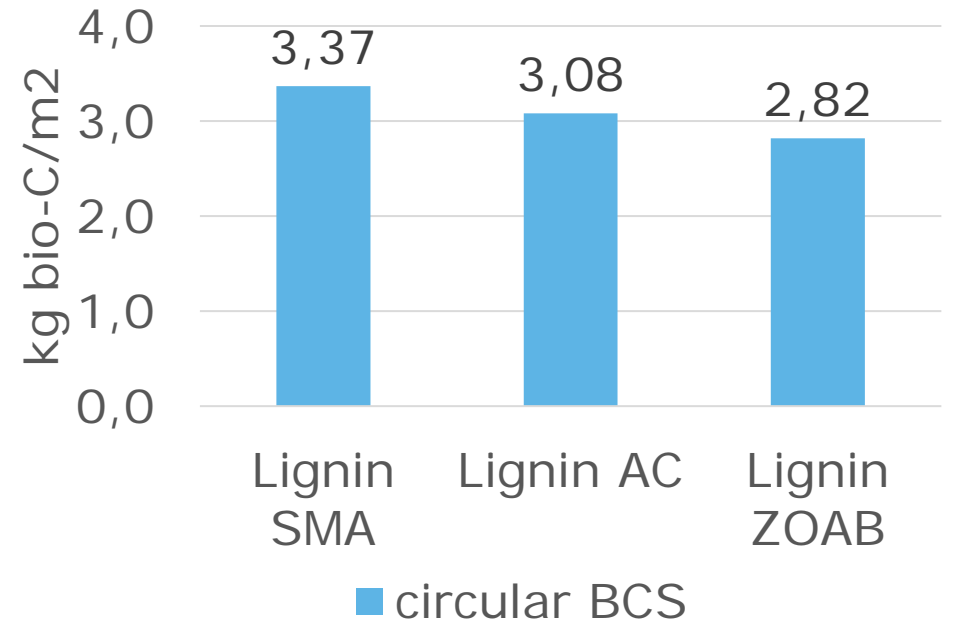
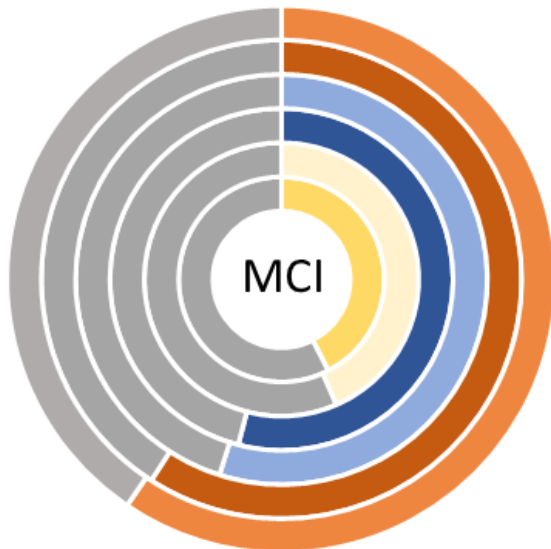
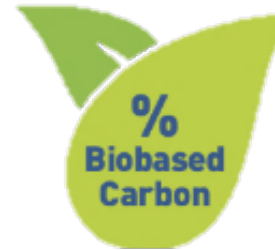
# Material flow diagram lignin-asphalt





# Circularity

- Both the material circularity index (MCI) and the newly developed index Circular Biogenic Carbon Storage (c-BCS) were investigated
- Important insights in trade-offs between circularity, biogenic carbon storage and emissions. Win-win interventions: increase recycling content, extend road lifetime, increase biobased content of binder.





- Lignin in asphalts could reduce GWP over their life cycle substantially (30-75%; depending on the type lignin, type of asphalt and layer considered).
- There are trade-offs in other impact categories (especially toxicity), which is the case for most lignin-based applications
- Advantages in terms of GWP and MKI score mainly depend on how process heat is produced replacing lignin/black liquor in the pulp mill or biorefinery (natural gas or biomass hog fuel).
- Results also strongly depend on allocation methods (and weights) chosen
- Biggest limitation: no primary data from kraft lignin producers obtained, ex ante LCA for biorefineries



## Further research:

- Better data for kraft lignin
- Better inclusion of the sue phase - long-term monitoring!
- Development of new asphalt structures for a variety of climatic / European asphalt conditions!
- Achieving higher biobased content (up to 100%)!
- Further upscaling & improving techno-economic conditions
- Ultimately achieving TRL 9

## Market:

- European and global demand for asphalt increasing (global growth of 4% /year expected)
- Assuming economic viability, demand for lignin in NL could be:
  - 2 - 7 kt/y by 2030
  - 12 - 34 kt by 2040
  - 61 - 121 kt/y by 2050
- Up to a few biorefineries at commercial size could supply these volumes. Lignin could provide an important source of income





## Conclusions

- Lignin is a very promising candidate for the partial substitution of bitumen, showing identical technical performance as 100% bitumen-based roads and no H&S issues identified
- Lignin in asphalts could reduce life cycle climate change impacts substantially (between 30% and 75%), but there are trade-offs in other impact categories
- MKI scores are (in most cases) lower (i.e. better!) compared to conventional asphalts. However, the net difference does not (yet) make up for the higher cost of lignin-based asphalt over its life cycle
- Slightly higher circularity than bitumen-based asphalt
- It is a large volume application at much more profitable prices for biorefineries (> 2x) than combustion



## Review

# Review of life cycle assessments of lignin and derived products: Lessons learned



Christian Moretti <sup>a,\*</sup>, Blanca Corona <sup>a</sup>, Ric Hoefnagels <sup>a</sup>, Iris Vural-Gürsel <sup>b</sup>, Richard Gosselink <sup>b</sup>, Martin Junginger <sup>a</sup>

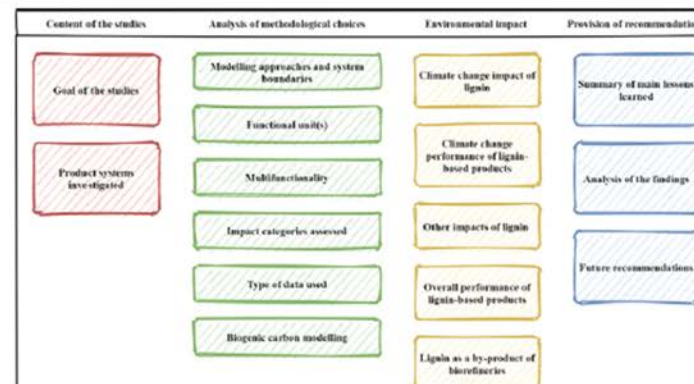
<sup>a</sup> Utrecht University, Copernicus Institute of Sustainable Development, Utrecht, Netherlands

<sup>b</sup> Wageningen Food & Biobased Research, Wageningen, the Netherlands

### HIGHLIGHTS

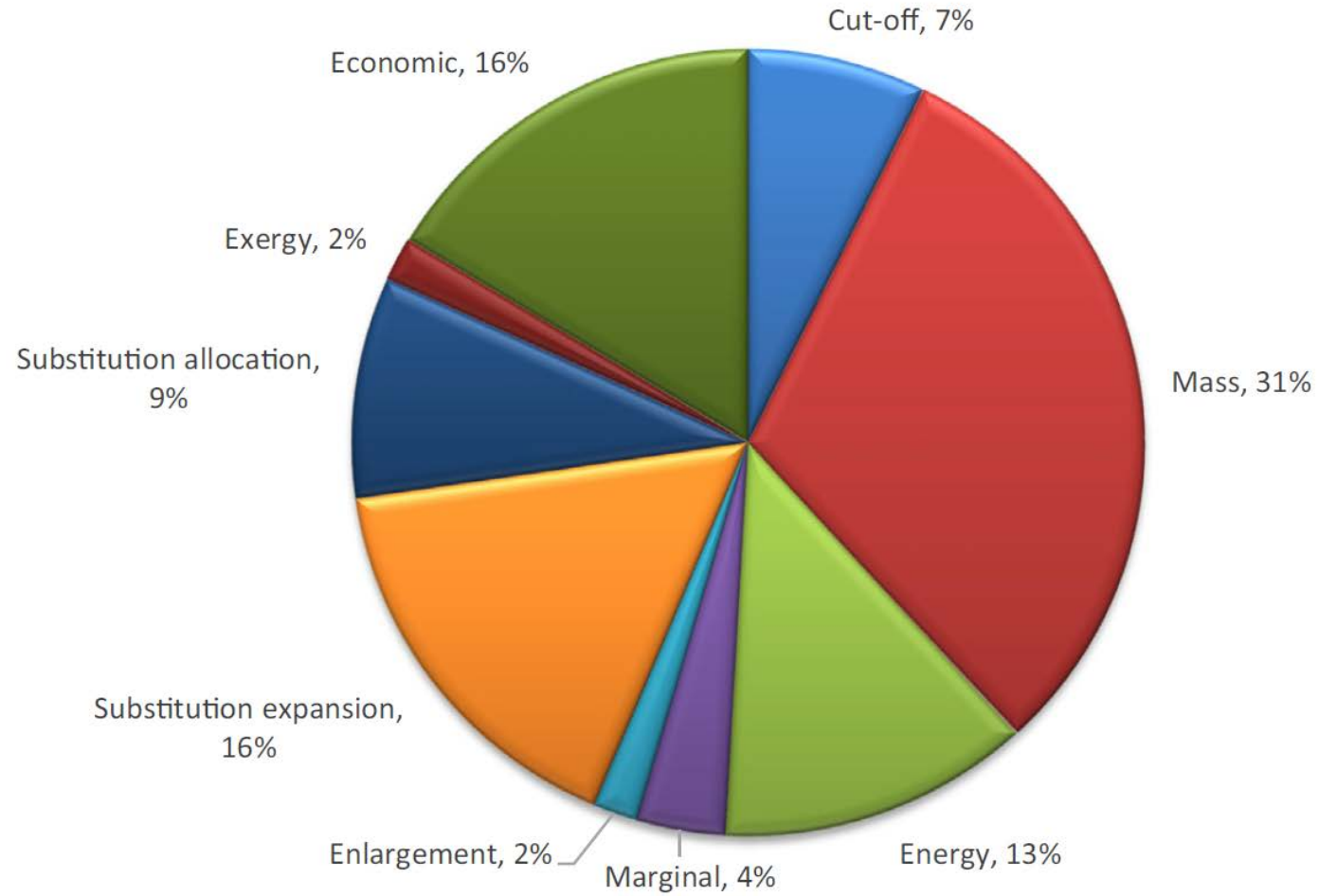
- A first review of peer-reviewed LCAs of lignin and lignin-based products was conducted.
- Most of lignin-based applications showed promising climate change performances but trade-offs in other impact categories.
- The lack of harmonization in the application of LCA methodology hinders direct comparative analyses.
- Recommendations to increase consistency were provided.

### GRAPHICAL ABSTRACT





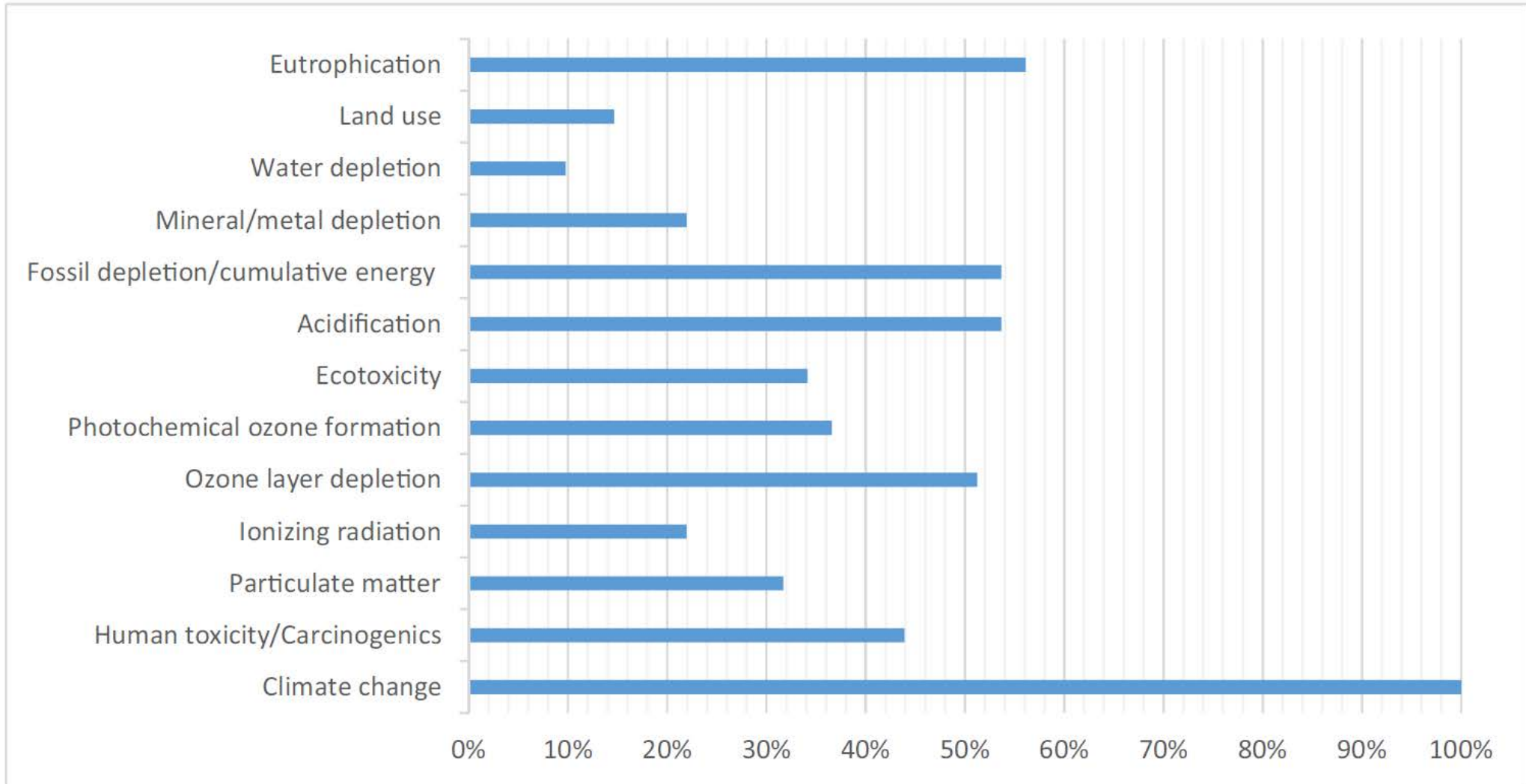
# Dealing with allocation...



**Fig. 4.** Summary of the adopted multifunctionality practices in the selected 42 LCAs.



# Impact categories included







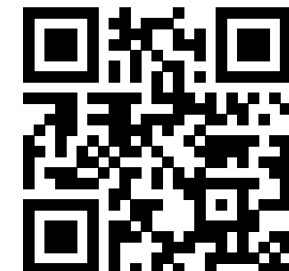
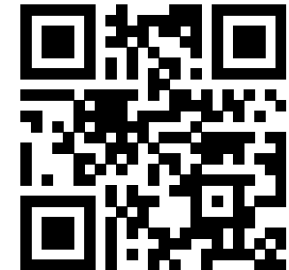
## Other issues identified

- Only few studies considered the use phase and end of life of the product
- 78% of the LCAs did not explicitly specify the type of modeling approach followed i.e. attributional or consequential
- Most of the studies adopted a simple functional unit e.g. based on a mass basis -> this does not state how well each product fulfills the function of the system
- In almost all LCAs (especially of biorefineries), data were mainly obtained from laboratory and process modeling. Few studies used primary (actual) data for kraft lignin production. These studies were also the main sources used in the LCAs that relied on secondary data
- Biogenic carbon dioxide is treated differently in the studies: either treated as carbon-neutral or accounted as carbon storage



## More information

- CHAPLIN XL Public Final report (in Dutch).  
<https://circularbiobaseddelta.nl/app/uploads/2022/01/CHAPLIN-XL-Openbaar-eindrapport-FINAL-28-3-2224.pdf>
- Christian Moretti, Ric Hoefnagels, Marco van Veen, Blanca Corona, Svetlana Obydenkova, Scott Russell, Anna Jongerius, Iris Vural-Gürsel, Martin Junginger (2022) Using lignin from local biorefineries for asphalts: LCA case study for the Netherlands. Journal of Cleaner Production. 343, 131063,  
<https://doi.org/10.1016/j.jclepro.2022.131063>
- Christian Moretti, Blanca Corona, Ric Hoefnagels, Marco van Veen, Iris Vural-Gürsel, Tobias Strating, Richard Gosselink, Martin Junginger (2022) Kraft lignin as a bio-based ingredient for Dutch asphalts: an attributional LCA. Science of the Total Environment, Volume 806, Part 1, 1 February 2022, 150316,  
<https://doi.org/10.1016/j.scitotenv.2021.150316>
- Christian Moretti, Blanca Corona, Ric Hoefnagels, Iris Vural-Gürsel, Richard Gosselink, Martin Junginger (2021) Review of Life Cycle Assessments of lignin and derived products: lessons learned. Science of the Total Environment, 770(2021) 144656 <https://doi.org/10.1016/j.scitotenv.2020.144656>







# Thank you for your attention

And thanks to all contributors: Richard Gosselink, Blanca Corona, Ric Hoefnagels, Marco van Veen, Christian Moretti, Iris Vural-Gürsel, Ted Slaghek, Paul Landa, Hendrik Post, Annelie Jongerius, Ed de Jong, Joop Groen, Albertus Steenberg, Martijn Verschuren & Dave van Vliet

This project was carried out with subsidy of the Dutch Ministry of Economic Affairs & Climate, Nationale regelingen EZ-subsidies, Topsector Energie, executed by Rijksdienst voor Ondernemend Nederland.





# Determining Health and Safety (H&S) aspects

- H&S aspects were investigated during production, processing and application of biobased asphalt, for the various lignins and asphalt structures
- The H&S methods applied followed standard industrial measurement protocols for both closed and open asphalt plants
- The measurements showed that at the recommended asphalt temperatures there was very limited odour development
- In all tests the formaldehyde concentration never exceeded legal thresholds







- Anticipated cost of bio-based asphalt produced in Dutch biorefineries (Avantium, Vertoro\*) appeared to be more expensive than conventional asphalt **at 2020/21 price levels**
- This could well change with amongst other scaling up of production and use of lignin in asphalt plants, the increasing cost and scarcity of fossil bitumen and a higher valuation of the GHG benefits of bio-based asphalt in public procurement

### Production cost of asphalt with various binders (€/t)

	Bitumen	Avantium dawn lignin	Vertoro lignin
Top layer SMA	€76	€125	€80
Top Layer AC	€51	€84	€57
Top Layer Very open AC	€59	€110	€66
Middle layer (all)	€40	€42	€42
Base layer (all)	€40	€55	€44

\* Vertoro is member of CHAPLIN and active participant in the CHAPLIN TKI project



# Public recognition

Nieuws / 05/11/2021

## CHAPLIN wint WOW prijs 2021



Geen reacties



**"En de winnaar van de WOW Juryprijs voor Beste Samenwerking is...CHAPLIN! In dit programma werken bedrijven, overheden en kennisinstellingen samen om de grondstof in asfalt, bitumen, te vervangen door lignine. Daarmee levert men een belangrijke bijdrage aan het vergroenen van de wegenbouw industrie en CO2 reductie."**

Met trots maken we bekend dat ons programma [#CHAPLIN](#) de tweejaarlijkse juryprijs van het [Platform WOW](#) heeft gewonnen!. Een enorme eer om gekozen te worden tot het meest inspirerende en innovatie samenwerkingsprogramma in de weg- en waterbouw van 2021. De geldprijs die [Circular Biobased Delta](#) programmamanager [Joop Groen](#), [Martin Junginger](#) van [Universiteit Utrecht](#) en [Jeroen Nagel](#) van [Rijkswaterstaat](#) op de foto in ontvangst nemen wordt goed besteed aan de doorontwikkeling van lignine gebaseerd asfalt om de wegenbouw te vergroenen en CO2 te reduceren.

Met dank aan de organisatie en de jury en vooral alle deelnemers die dit mede mogelijk hebben gemaakt: Naast Universiteit Utrecht, Rijkswaterstaat en Circular Biobased Delta zijn dat: [Wageningen University & Research](#), [TNO](#), [Q8 Research](#), [Asfalt Kennis Centrum B.V.](#), [Avantium](#), [LXP Group](#), [LATEXFALT B.V.](#), [Vertoro](#), [H4A](#), [Roelofs](#), [NTP](#), [TWW | Negam | Dostal](#), [Boskalis](#), [Dura Vermeer](#), [Biondoil](#), [North Sea Port](#), [Prj Industries](#), [Provincie Noord-Brabant](#), [Provincie Zeeland](#),

Praised for

- collaboration amongst a variety of stakeholders form industry, academia and policy arenas
- innovation
- sustainability



# Press coverage

<https://www.dvhn.nl/economie/Wereldprimeur-in-Siddeburen-Eerste-weg-van-biologisch-asfalt-26858105.html>  
<https://www.rtvnoord.nl/nieuws/823451/Uniek-tussen-Siddeburen-en-Wagenborgen-rij-je-over-duurzaam-bio-asfalt>  
<https://klazienaveen.nu/avantium-kondigt-s-werelds-eerste-wegtest-aan-met-op-lignine-gebaseerd-asfalt-chemical-engineering/>  
<https://economie.groningen.nl/nieuws/een-wereldprimeur-in-groningen-s-werelds-eerste-weg-van-biologisch-asfalt>  
<https://www.provinciegroningen.nl/actueel/nieuws/nieuwsartikel/testweg-met-bioasfalt-aangelegd-tussen-siddeburen-en-wagenborgen/>  
<https://www.chemieparkdelfzijl.nl/actueel/2020/04/867051-avantium-ontvangt-financiering-voor-ontwikkeling-van-bio-based-asfalt>  
<https://www.groningen-seaports.com/nieuws/avantium-en-roelofs-leggen-s-werelds-eerste-testweg-aan-met-in-nederland-geproduceerde-lignine/e24xswxeayzehm/>  
<https://www.chemport.eu/news/article/dutch-plant-based-lignin-is-replacing-bithumen-in-test-road-by-roelofs-and-avantium-co2-reduction-of-road-construction/>

## **Internationaal**

<https://www.biofuelsdigest.com/bdigest/2021/06/06/lignin-leads-the-way-worlds-first-lignin-bio-asphalt-road-lignins-array-of-applications-and-more/>  
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<https://industry-update.com/avantium-announces-worlds-first-road-test-using-lignin-based-asphalt-chemical-engineering/32920/>  
<https://www.dailyadvent.com/news/e31888463ded30dd009be94982db51f6-Avantium-announces-worlds-first-road-test-using-ligninbased-asphalt>  
<https://www.plantmachineryvehicles.com/80633-test-road-under-construction-in-the-netherlands-will-determine-if-plant-based-lignin-could-be-used-as-a-substitute-for>  
<https://www.newsbreak.com/news/2268768065724/avantium-n-and-roelofs-construct-the-world-s-first-test-road-with-lignin-produced-in-the-netherlands>  
<https://indiaeducationdiary.in/utrecht-university-the-worlds-first-test-road-with-lignin-produced-in-the-netherlands/>  
<https://www.bioeconomia.info/2021/06/09/comenzo-en-holanda-la-construccion-de-la-primera-carretera-pavimentada-con-bioasfalto/>  
<https://vfb.be/artikel/avantium-en-roelofs-leggen-s-werelds-eerste-testweg-aan-met-in-nederland-geproduceerde-lignine-03-06-2021>  
<https://www.ipsnews.be/artikel/nederland-test-snelweg-van-plantaardig-materiaal>

**Industry Europe**, [Avantium & Roelofs construct first test road with Dutch lignin](#)

**Chemical Engineering**, [Avantium announces world's first road test using lignin-based asphalt](#)

**Bioplastics News**, [Avantium builds bio asphalt test road](#)

**Advanced Biofuels USA**, [Lignin Leads the Way – World's First Lignin Bio-Asphalt Road, Lignin's Array of Applications and More](#)

**Polymerist**, [Rust Belt Riders Are Building Their Green Future One Bucket At A Time](#)

## **Vakbladen/-sites**

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