Life Cycle Assessment (LCA) of a Thin Bonded Concrete Overlay (BCOA) of Asphalt Project in Woodland, California

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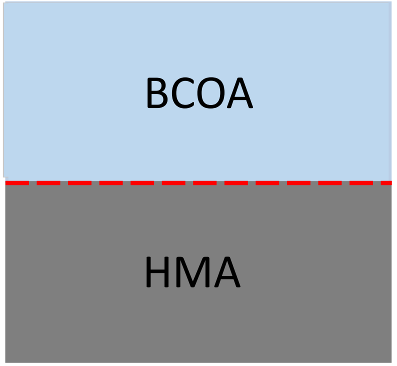
Introduction

- Thin bonded concrete overlay of asphalt (BCOA), or thin whitetopping:
    - a rehabilitation alternative consisting of a 100 to 175 mm concrete overlay on an existing flexible or composite pavement

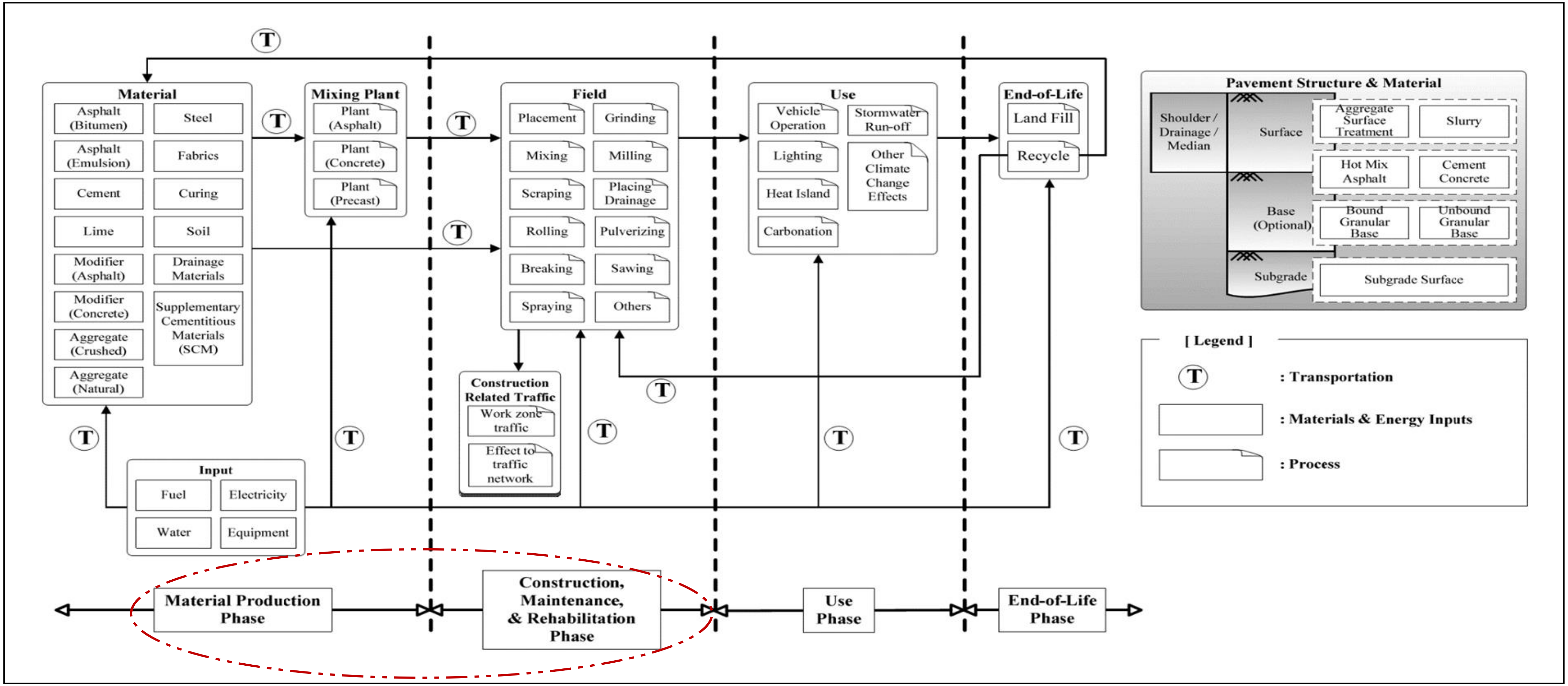
- Thin BCOA has been used as a 20-year design life rehabilitation alternative for asphalt pavements in fair to good condition under low and intermediate traffic levels.



- During the life of the BCOA pavement, the materials and construction stages of thin BCOA result in significant environmental impacts, in terms of
    - energy use,
    - material resource consumption,
    - emissions

- This paper demonstrates the use of LCA to quantify and evaluate the environmental impacts of alternative materials, construction and designs for a BCOA pilot project that has been implemented in Woodland, California.

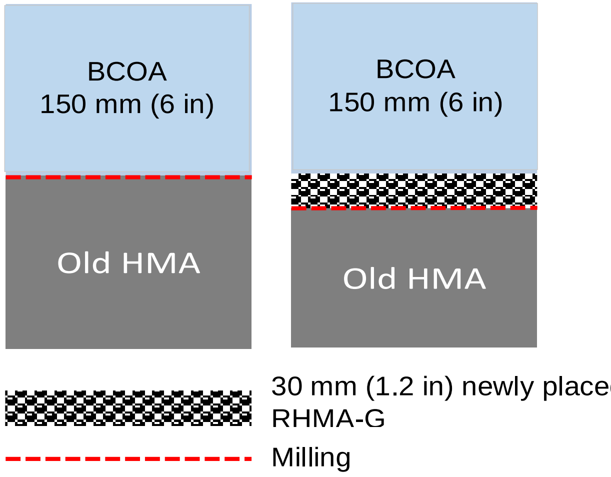
Introduction- Life Cycle Assessment



UCPRC LCA framework- Major life-cycle stages of a pavement (Harvey et al. 2016)

Goal and scope

- The goal of this study was to quantify the potential environmental impacts due to material and construction stages of thin BCOA.
- The LCA analysis is focused on a thin BCOA pilot project built in Woodland, California, in 2018-2019.
- The considered layer includes
  - 150 mm PCC overlay on top of a new rubberized hot mix asphalt (RHMA), and
  - 150 mm PCC overlay on top of a milled old asphalt.
- The mix designs used in the pavement layers of the project, includes
  - PCC Type III used for the HVS test sections with 4 hours opening time (OT) ,
  - PCC Type II/V used for the Woodland project with 24 hours OT, and
  - Normal strength PCC Type II/V used by Caltrans with the 10 days OT,
  - RHMA mix design



A cross-section of the Woodland pilot thin BCOA in SR 113

Scope

- The scope of this study was limited to “cradle-to-laid” for Woodland pilot project in which the materials and construction stages as well as transportation of materials in the life cycle of the pavements were considered.
    - The use stage and end-of-life were not included in this study’s scope.
- The functional unit defined for this study is construction of 1 lane-km of pavement surface.
- The material stage includes
    - extraction of raw materials from the ground,
    - transportation to processing plants, and the plant processing,
    - transportation of the materials from the plant to the site.
- The intended audience of the study includes
    - local governments,
    - pavement researchers and practitioners,
    - pavement designers

Life Cycle Inventories (LCI)

Different considered BCOA cases

	Case Number	Material	Concrete Thickness mm (inch)	RHMA Thickness mm (inch)
6 in PCC Layer	1-A (PCC on top of old HMA)	HVS PCC Type III (4-hr OT)+ Tie Bar	150 (6)	---
	1-B	HVS PCC Type III (4-hr OT)+ Tie Bar+ RHMA	150 (6)	30 (1.2)
	2-A (PCC on top of old HMA)	Woodland PCC Type II/V (24-hr OT)+ Tie Bar	150 (6)	---
	2-B	Woodland PCC Type II/V (24-hr OT)+ Tie Bar+ RHMA	150 (6)	30 (1.2)
	3-A (PCC on top of old HMA)	Caltrans normal strength PCC Type II/V (10-day OT)+ Tie Bar	150 (6)	---
	3-B	Caltrans normal strength PCC Type II/V (10-day OT)+Tie Bar+ RHMA	150 (6)	30 (1.2)
5 in PCC Layer	4-A (PCC on top of old HMA)	HVS PCC Type III (4-hr OT)+ Tie Bar	125 (5)	---
	4-B	HVS PCC Type III (4-hr OT)+ Tie Bar+ RHMA	125 (5)	30 (1.2)
	5-A (PCC on top of old HMA)	Woodland PCC Type II/V (24-hr OT)+ Tie Bar	125 (5)	---
	5-B	Woodland PCC Type II/V (24-hr OT)+ Tie Bar+ RHMA	125 (5)	30 (1.2)
	6-A (PCC on top of old HMA)	Caltrans normal strength PCC Type II/V (10-day OT) + Tie Bar	125 (5)	---
	6-B	Caltrans normal strength PCC Type II/V (10-day OT)+Tie Bar+ RHMA	125 (5)	30 (1.2)

- The LCI database created by the UCPRC was used in this study including the details of model development, data sources, and the assumptions.

Energy Input for 1 kg of PCC

Electricity	0.00618 MJ
Natural Gas	0.000122 m^3
Diesel	2.54E-007 m^3

Energy Input for 1 kg of RHMA

Electricity	0.0076319 MJ
Natural Gas	0.0103261 m^3

Life Cycle Impact Assessment (LCIA)

The life cycle impact assessment categories selected to be reported in this study includes

- Global Warming Potential (GWP): in kg of CO2e.
- Photochemical Ozone Creation Potential (POCP): in kg of O3e (a measure of smog formation).
- Human Health Particulate Matters (PM2.5): in kg of PM2.5 (particulate matters smaller than or equal to 2.5 micrometers in diameter).
- Renewable Primary Energy Demand (PED-R) used as fuel from renewable resources (net calorific value excluding feedstock energy): in MJ.
- Non-renewable Primary Energy Demand (PED-NR) used as fuel from nonrenewable re-sources (net calorific value excluding feedstock energy): in MJ.
- Feedstock Energy (PED-FS) is Primary Energy Demand used as a material from nonrenewable resources (also called PED (non-fuel)): in MJ.
  - Feedstock energy is a primary energy demand stored in the construction materials (such as asphalt) that is not consumed.

LCI data

PCC and RHMA Mix Designs, and Number of Tie bars in BCOA layers

HVS PCC Mix Design Type III (4-hour OT)			*Woodland PCC Type II/V Mix Design (24-hour OT)*			*Normal Strength PCC Type II/V Mix design (10-day OT)*			*RHMA Mix Design*	
Material	*Mass per Volume (lb/yd3)*	*% by mass*	*Material*	*Mass per Volume (lb/yd3)*	*% by mass*	*Material*	*Mass per Volume (lb/yd3)*	*Percentage by mass*	*Material*	*% by mass*
Accelerator	37. 436	0.89	Accelerator	0.00	0.00	Accelerator	76	1.62	Crushed	92.50
Flyash	0.00	0.00	Flyash	101	2.55	Flyash	704.153	15.00	Natural	0
Crushed Aggregate	1787	31.86	Crushed Aggregate	1200	30.34	Crushed Aggregate	1350	28.76	Bitumen	6.00
Natural Aggregate	1348	42.23	Natural Aggregate	1787	45.18	Natural Aggregate	1875	39.94	Extender oil	0.15
Type III Portland Cement	799	18.88	Type II/V Portland Cement	574	14.51	Type II/V Portland Cement	429	9.14	Crumb Rubber Modifier (CRM)	1.35
Retarder	4	0.095	Retarder	0.897	0.023	Retarder	0.2	0.004	Polymer	0
Water Reducing Admixture	6.25	0.15	Water Reducing Admixture	1.614	0.041	Water Reducing Admixture	2	0.040	RAP	0
Water	250	5.91	Water	291	7.36	Water	258	5.50		
Number of Tie bars										
Number of tie bars per slab (slabs are 6 ft long)						2				
Number of tie bars per 1 km						1094				

LCI and LCIA

Construction Information

Layer	Equipment/ Activity	Engine Power kw(hp)	Hourly Fuel Use m3/hr(gal/hr)	Speed km/h(ft/min)	Time for 1Pass over 1lane-km (hr)	No. of Passes	Fuel Used m3(gal)	Total Fuel Used for 1lane-km m3 (gal)
PCC	Milling for 25 mm (1 in)	522 (700)	0.076 (20)	0.183 (10)	5.47	1	0.41 (109.36)	0.49 (129.05)
	Sweeping (multiple times)	59.66 (80)	0.008 (2)	1.83 (100)	0.55	2	0.01 (2.19)	
	Wetting	59.66 (80)	0.008 (2)	1.83 (100)	0.55	1	0.004 (1.09)	
	Concrete Placement	67.11 (90)	0.011 (3)	0.183 (10)	5.47	1	0.06 (16.40)	
RHMA	Prime coat application	260.995(350)	0.027 (7.2)	0.457 (25)	2.19	1	0.06 (16.40)	0.54 (143.15)
	RHMA placement	186.43(250)	0.040 (10.6)	0.274 (15)	3.65	1	0.15 (39.62)	
	Rolling (vibratory)	111.86(150)	0.031 (8.1)	0.457 (25)	2.19	2	0.13 (34.34)	
	Rolling (static)	111.86(150)	0.031 (8.1)	0.457 (25)	2.19	3	0.2 (52.83)	

LCI and LCIA

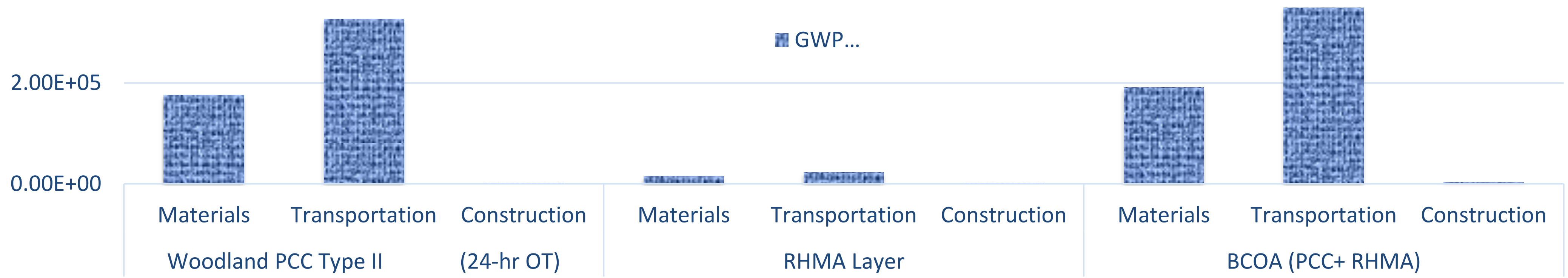
Transportation Information

Material	Transportation	Material in 1lane-km (kg)	No. of trips
PCC Type II	1-way 40 km (25 mile) from plan to the construction field	1,332,000	56
Cement	1-way 692km (430 mile) from cement plant to the mixing plant	193,292	9
RHMA	1-way 56km (35 mile) from plan to the construction field	266,400	12
Bitumen	1-way 435km (270 mile) from refinery to the plant	15,974	1
Crushed Agg.	1-way 40 km (25 mile) from quarry to the plant	246,420	11

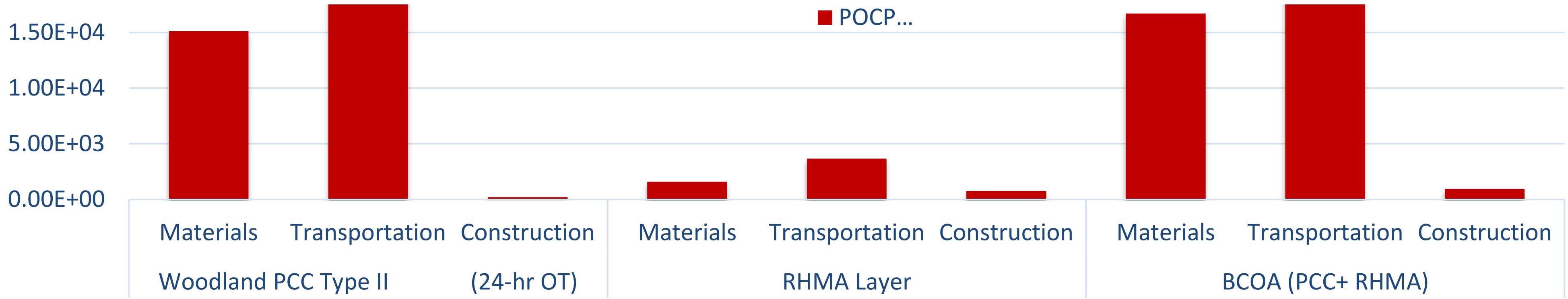
Impacts of Material Functional Unit (1 kg) During Production

Material	Unit	GWP (kg CO2e)	POCP (kg O_3e)	PM2.5 (kg)	PED-R (MJ)	PED-NR (MJ)	PED-FS (MJ)
HVS PCC Type III (4-hr OT)	1kg	1.78E-01	1.50E-02	9.72E-05	2.08E-01	1.08E+00	0.000E+00
Woodland PCC Type II/V (24-hr OT)	1kg	1.296E-01	1.120E-02	8.502E-05	1.418E-01	8.652E-01	0.000E+00
Caltrans Normal Strength PCC Type II/V (10-d OT)	1kg	1.169E-01	8.228E-03	1.183E-04	1.076E-01	8.150E-01	0.000E+00
RHMA	1kg	5.628E-02	5.977E-03	4.036E-05	9.329E-02	3.408E+00	6.487E+00
Tie Bar	Each	3.343E+00	1.667E-01	1.616E-03	1.443E+00	4.147E+01	0.000E+00

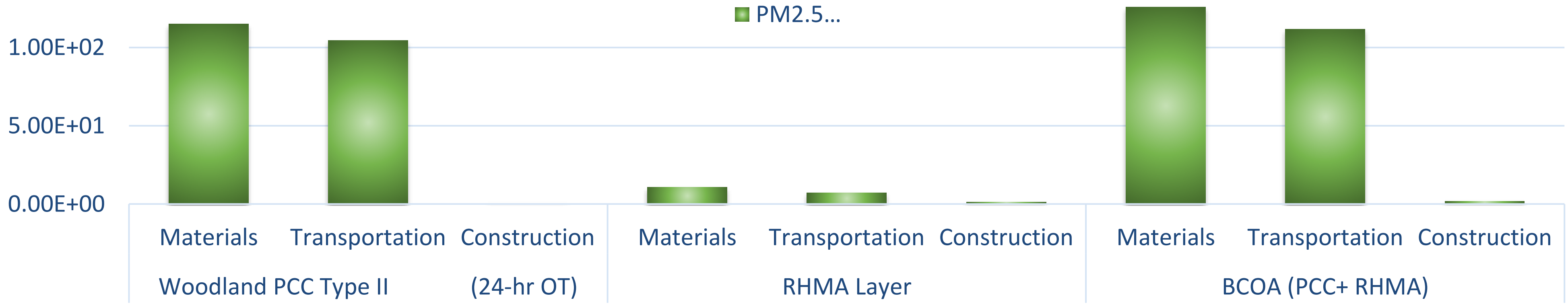
LCIA Results-Emissions



***Global Warming Potential* results per life cycle stage per pavement layer (Woodland case study)**

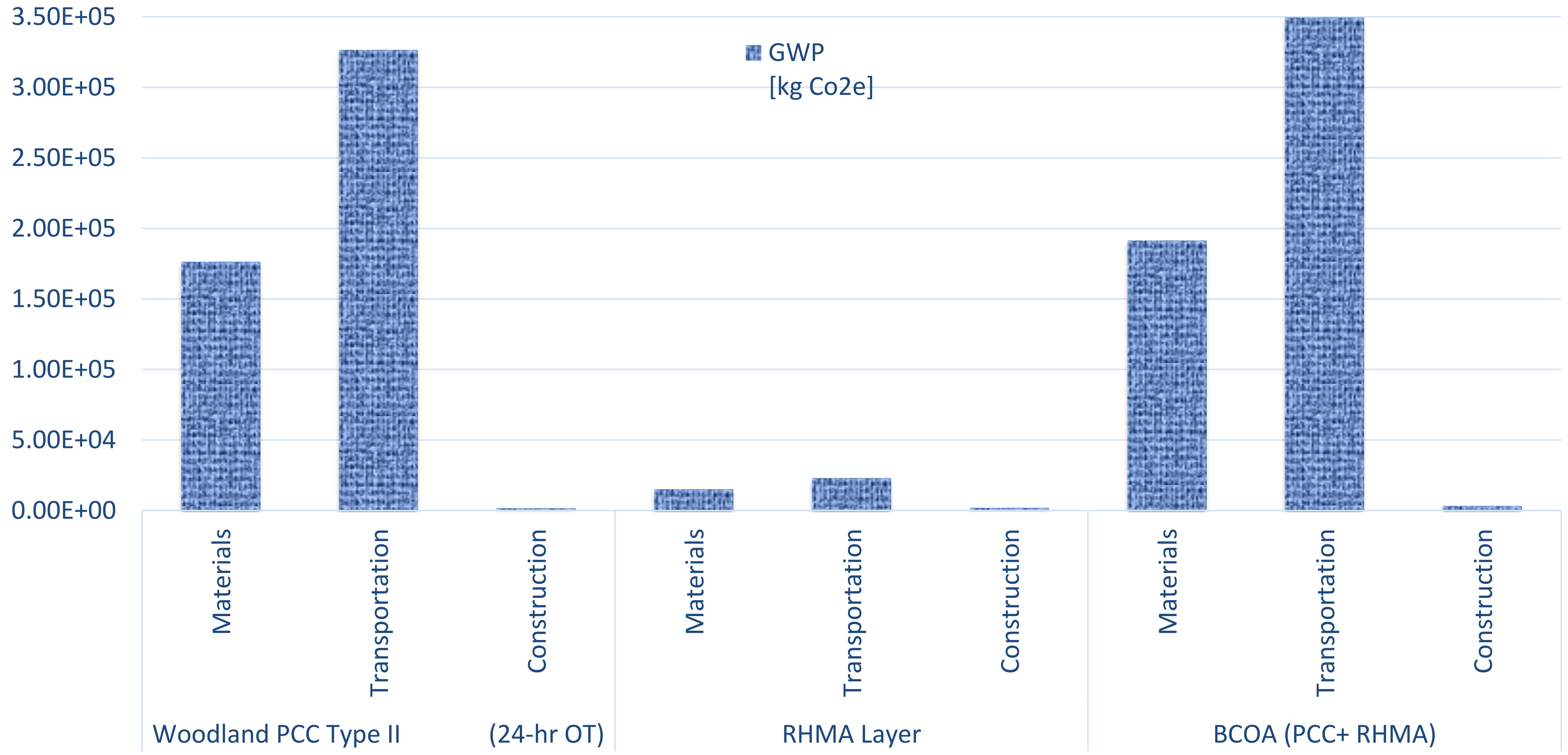


***Smog Formation Potential* results per life cycle stage per pavement layer (Woodland case study)**



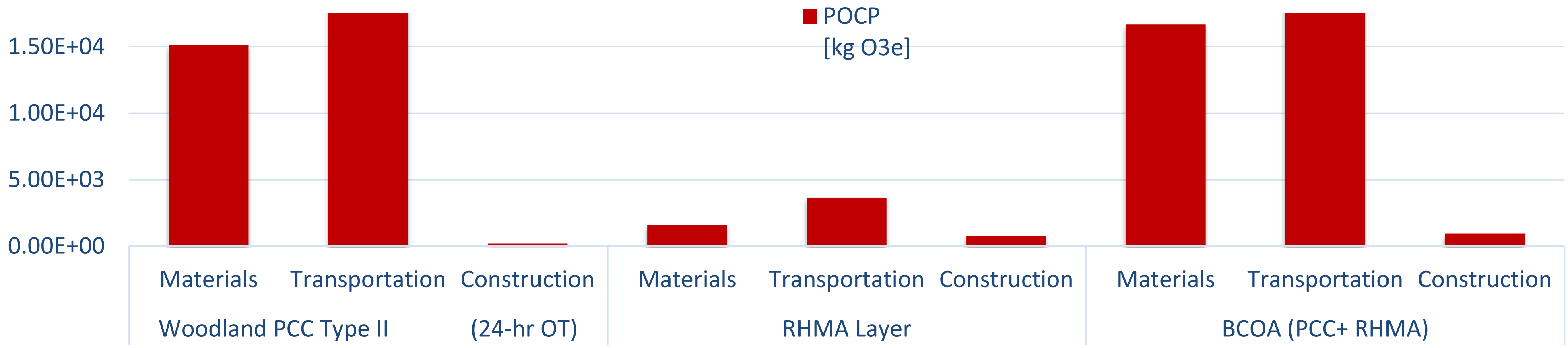
***Human Health Particulate* Effect results per life cycle stage per pavement layer (Woodland case study)**

LCIA Results- Emissions



Global Warming Potential ***results per life cycle stage per pavement layer (Woodland case study)***

LCIA Results-Emissions



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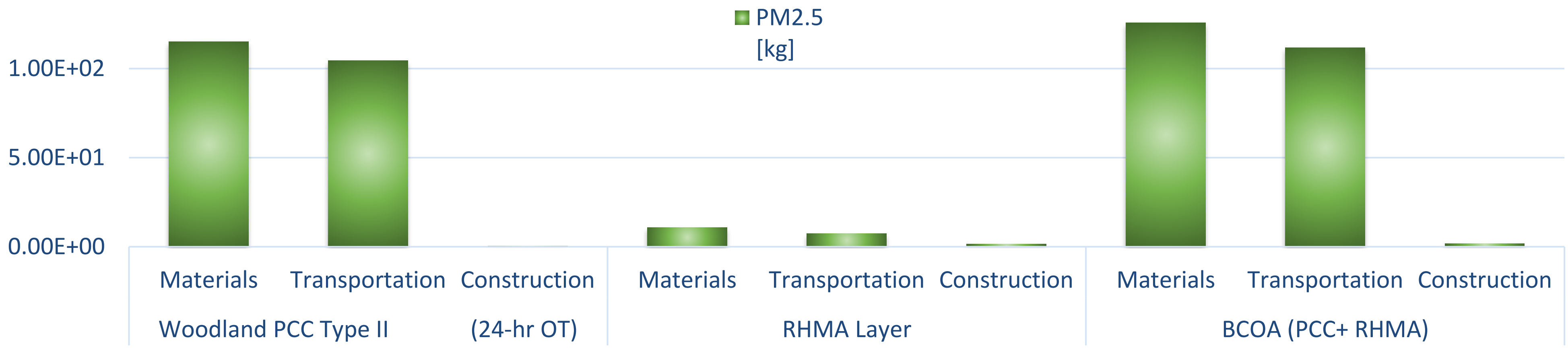

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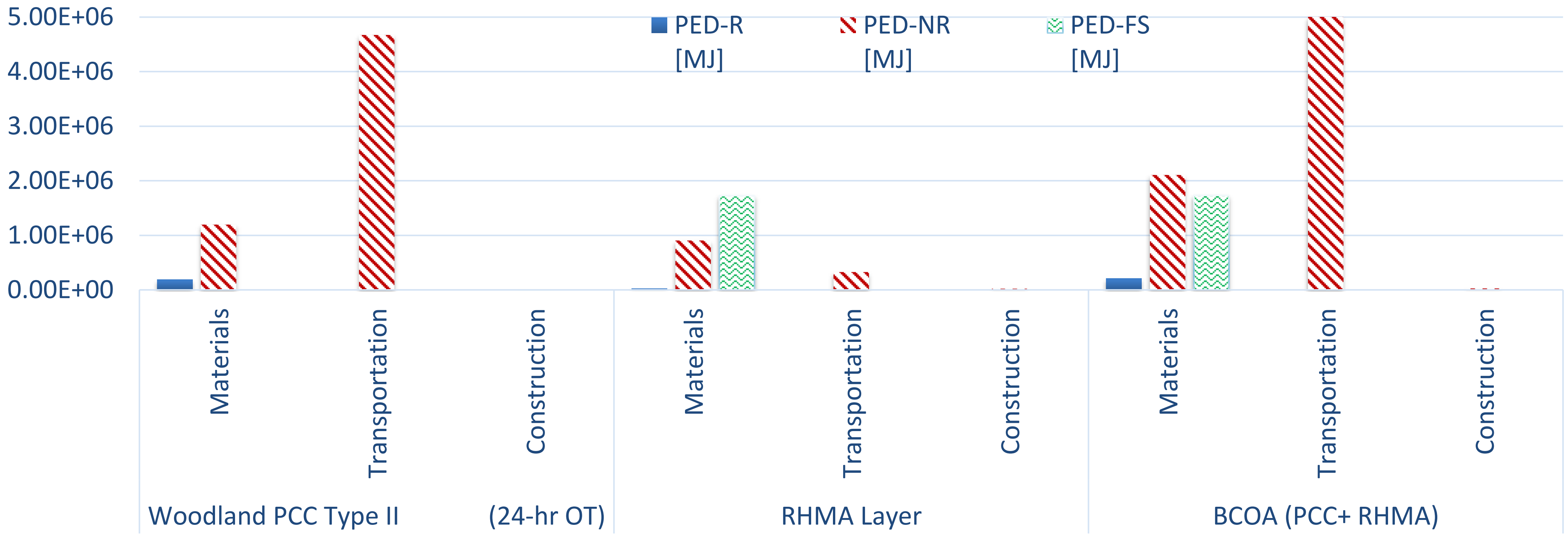
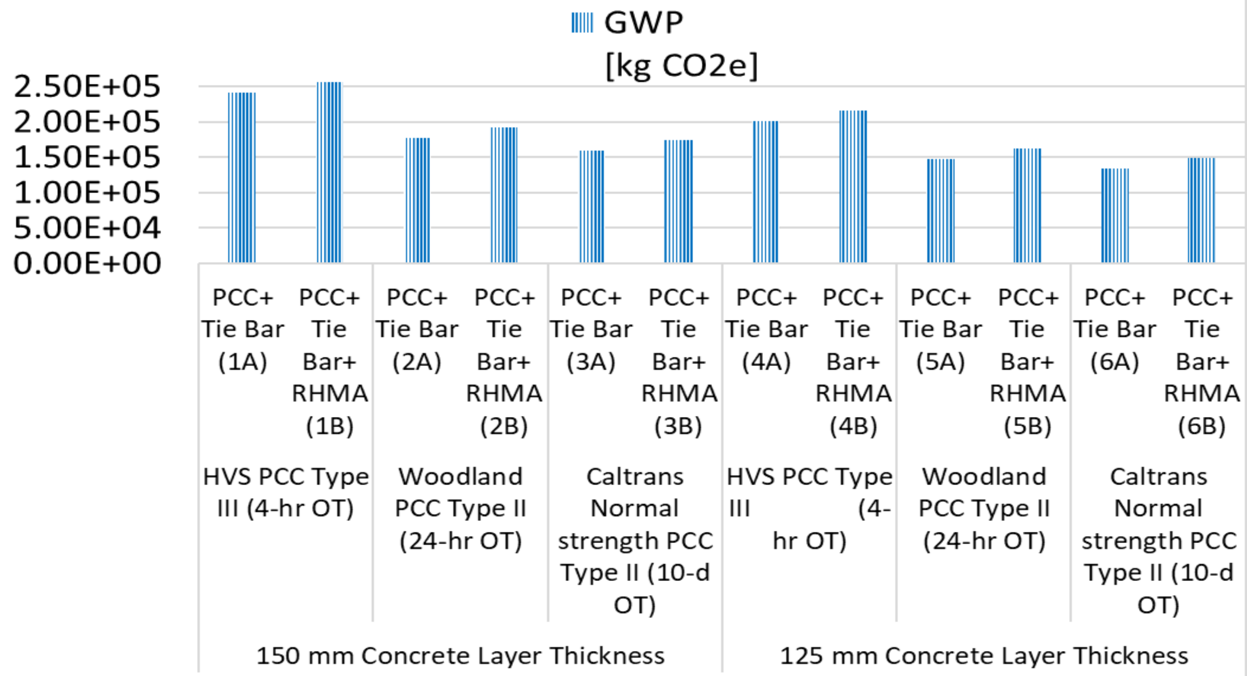
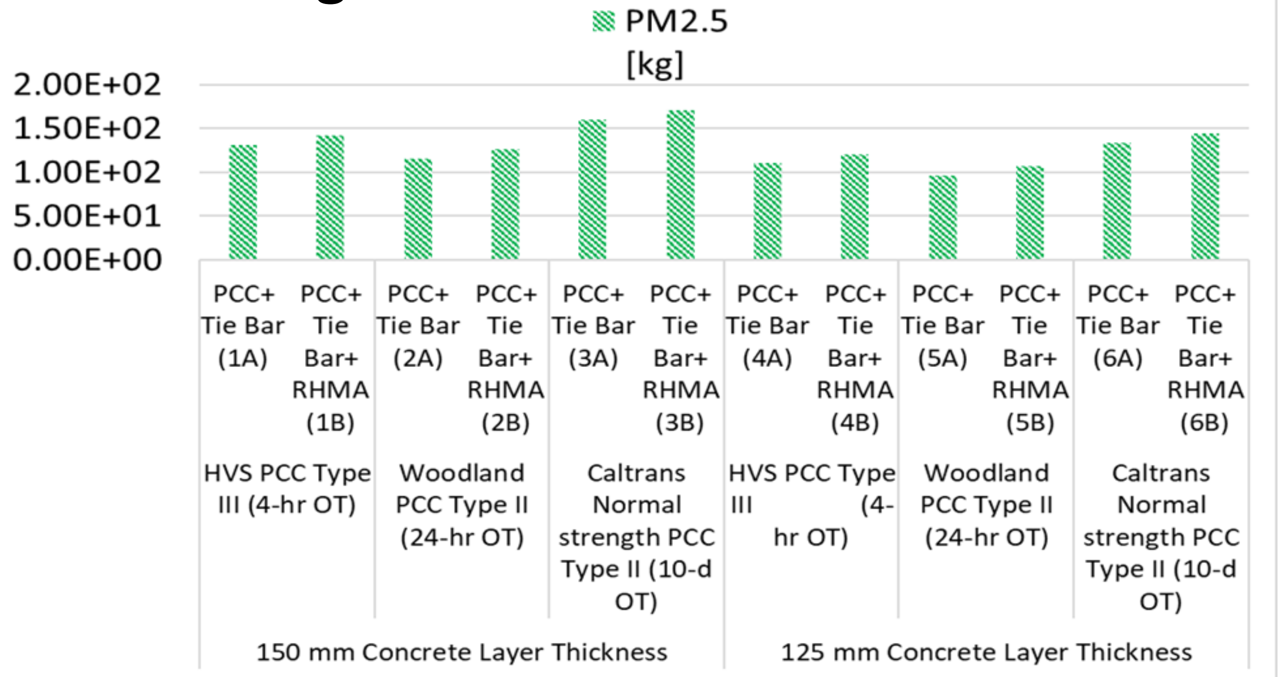
LCIA Results- Energy Consumption

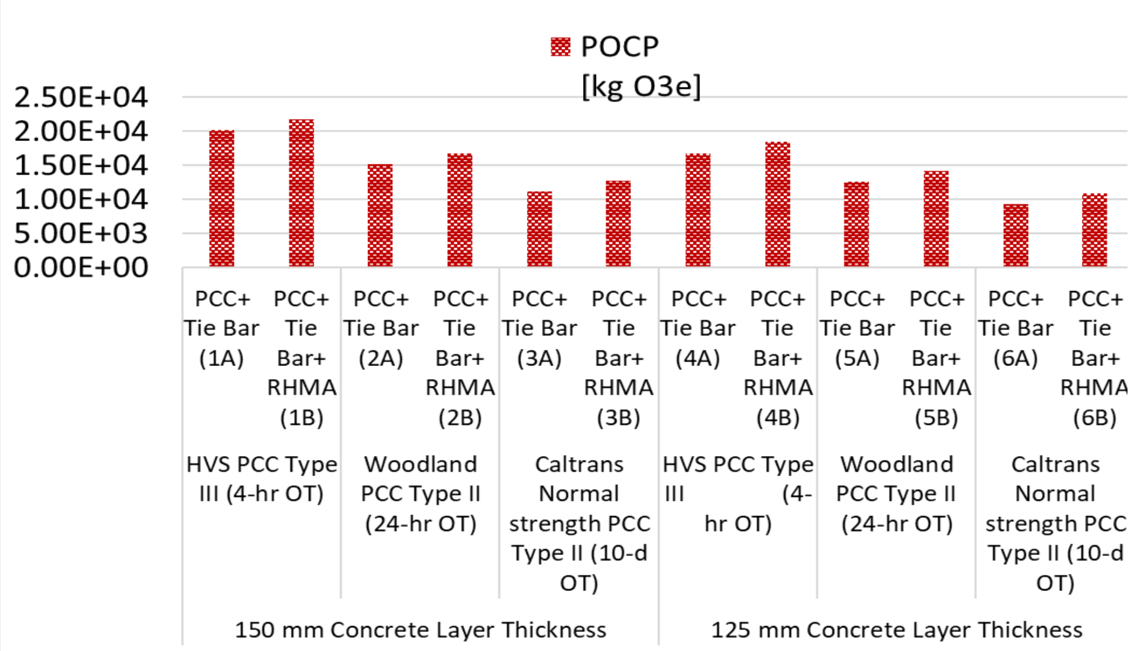


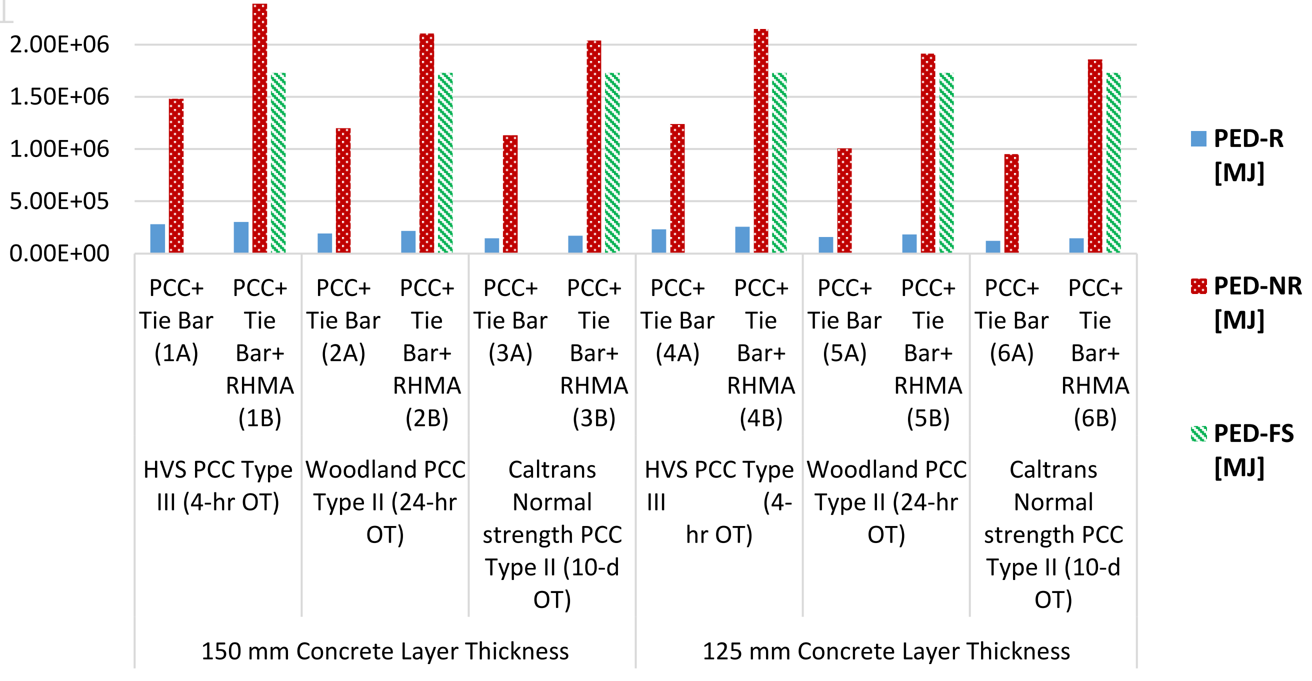
Consumed Energy per life cycle stage per pavement layer (Woodland case study)

Sensitivity Analysis- LCIA results in material stage for different alternatives

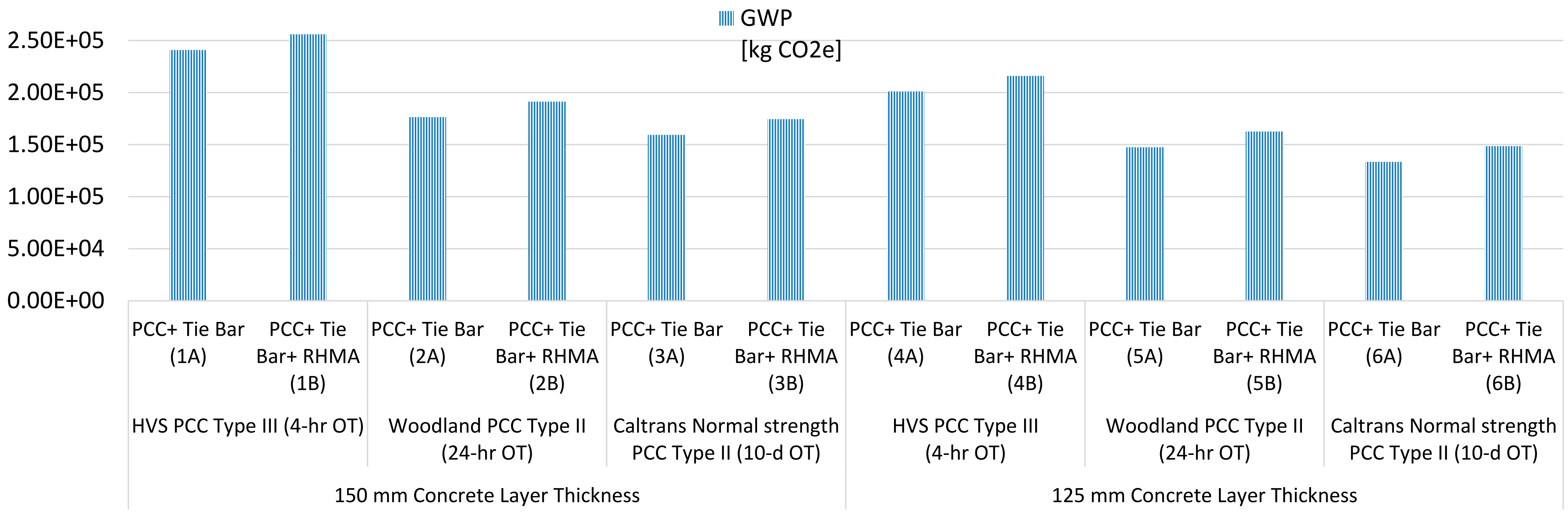






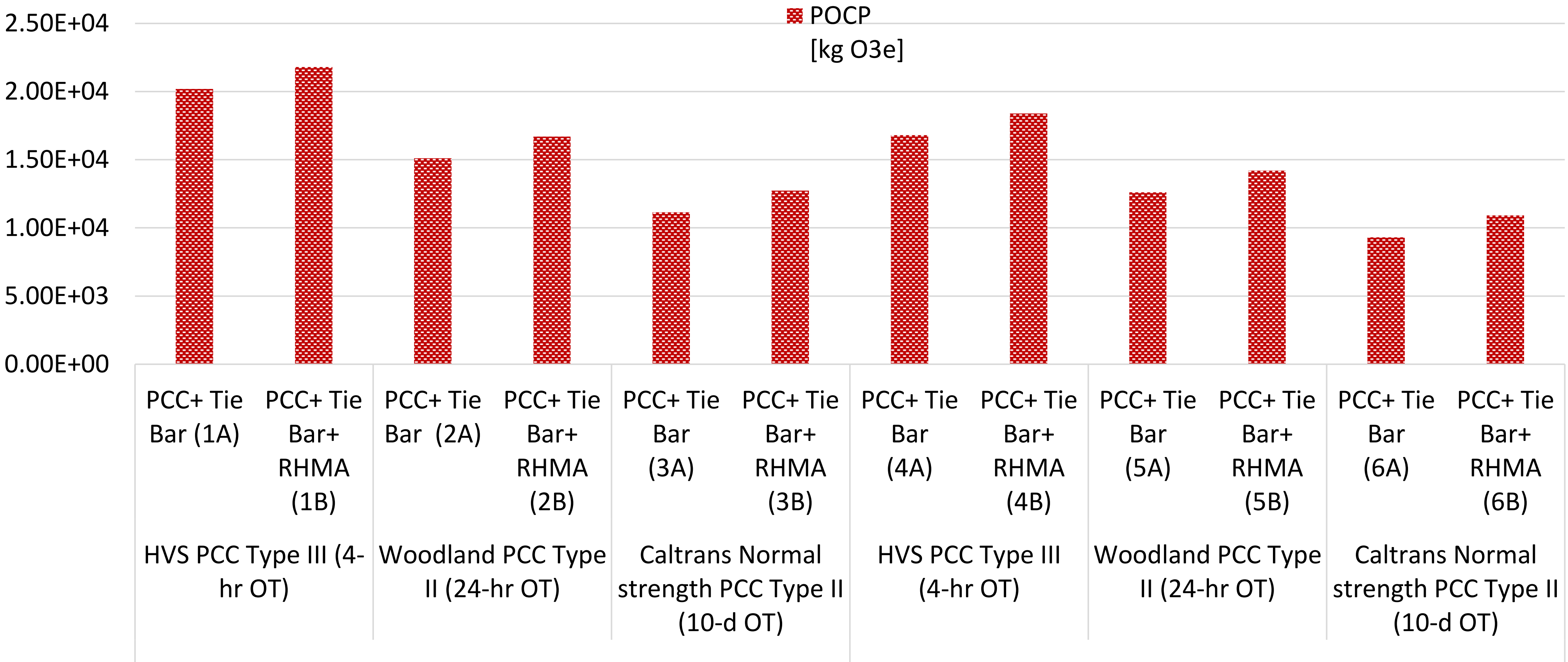


Sensitivity analysis



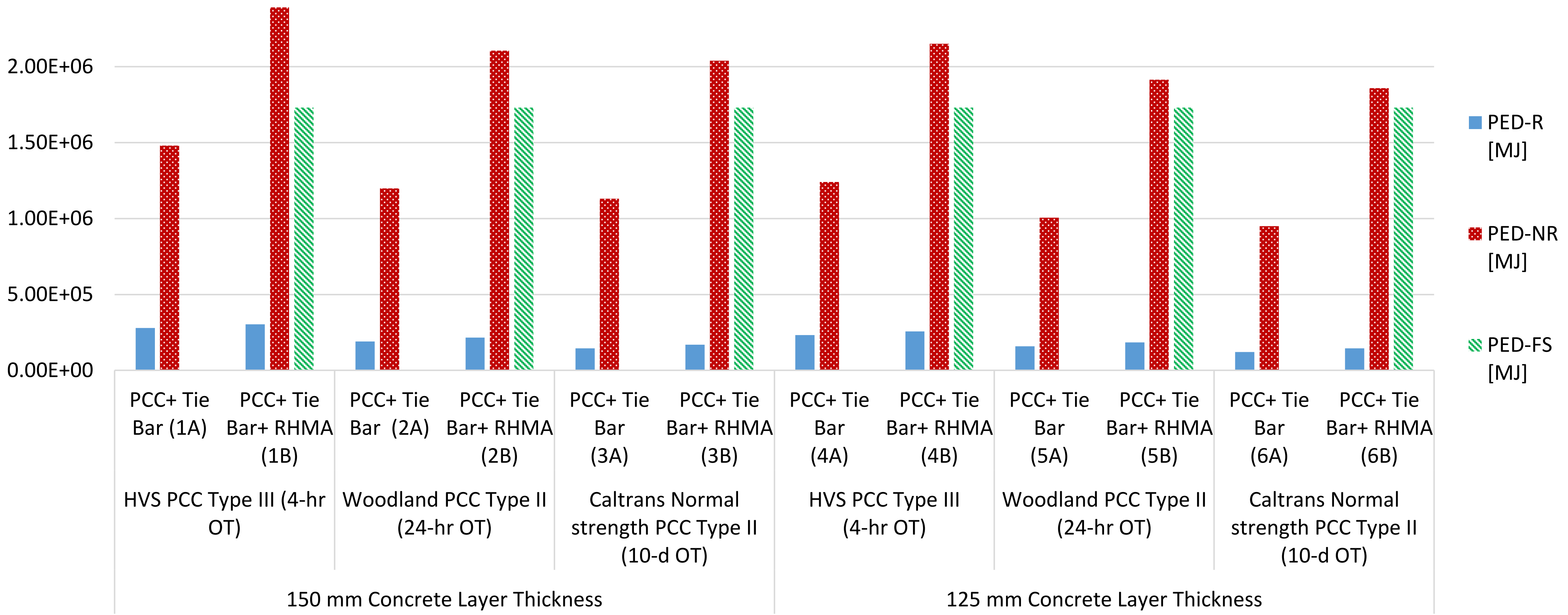
Global Warming Potential results in material stage for different alternatives

Sensitivity analysis



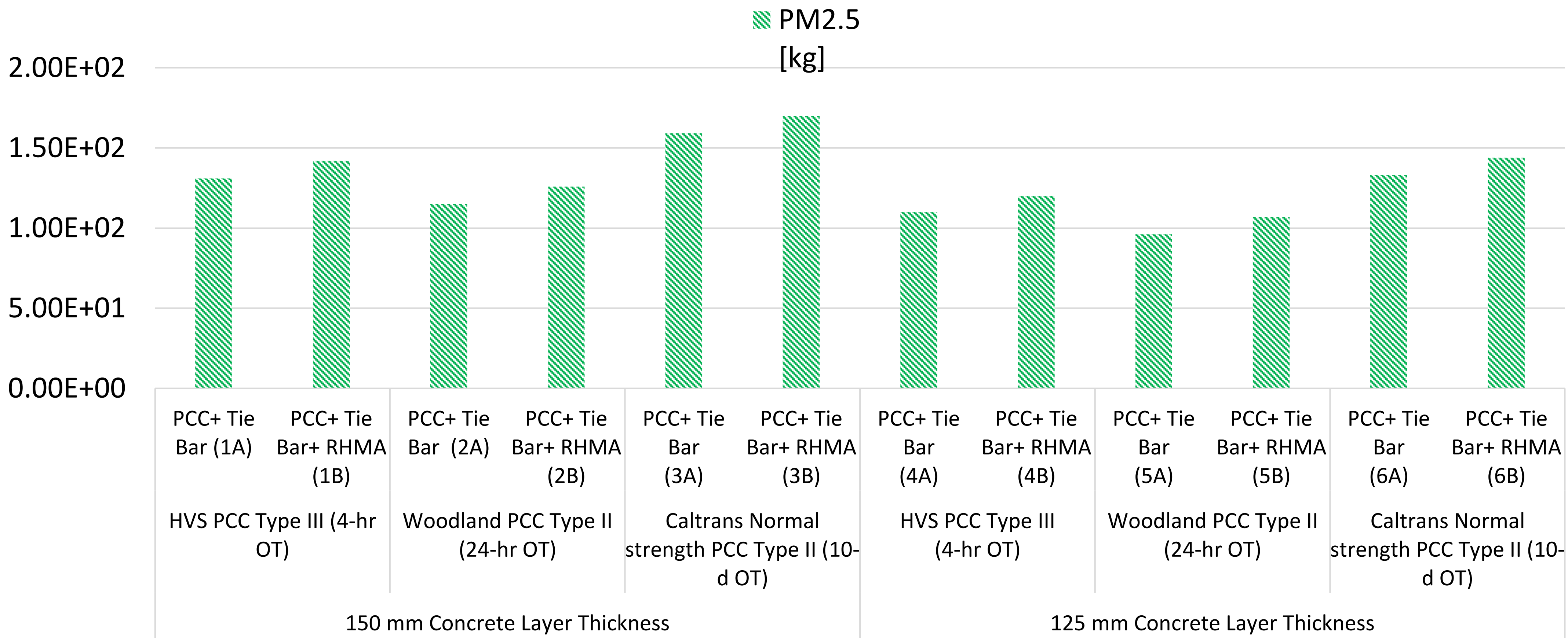
Smog Formation Potential results in material stage for different alternatives

Sensitivity analysis



Energy consumptions result in material stage for different alternatives

Sensitivity analysis



Human Health Particulate Effect results in material stage for different alternatives

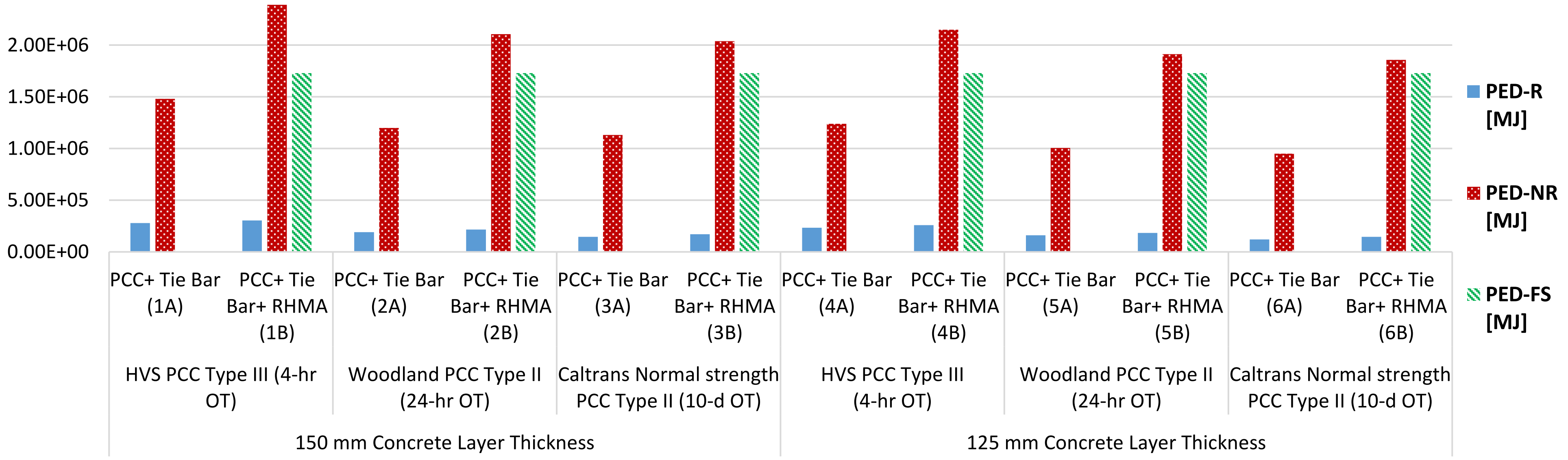
Interpretation

The important factors leading to major changes in the environmental emissions and energy consumptions in the material stage:

✓ Thickness of the surface layer.

✓ The new RHMA layer under the surface rigid layer compared to old HMA under the PCC layer.

- ➢ The results show the increase of 8%-13% in GWP, POCP, PM2.5, and PED-R.
- ➢ The sharp increase in PED-NR (75%) can also be seen.



Interpretation

The difference in the concrete mix designs:

✓ HVS PCC Type III mix with 4 hours OT has the highest environmental impacts and energy consumption followed by PCC Type II/V mix designs.

- ➢ Finer grinding of Type III PC as well as the higher amount of cement in Type III PC compared to Type II/V PC result in the higher environmental impacts.

✓ Caltrans normal strength mix has a slightly lower impacts in terms of GWP, POCP, and energy consumption compared to the Woodland mix. However, the Caltrans normal strength mix has the highest impacts in terms of PM2.5.

- ➢ This might be because of the higher amount of flyash in this mix compared to the other mixes.

This paper demonstrates the use of LCA to quantify and evaluate the environmental impacts of alternative materials, construction and designs for a pavement structure.

ACKNOWLEDGMENT

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Questions?