Life Cycle Assessment of Pavements under a Changing Climate

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Pavement LCA Symposium 2017

Motivation

Climate Change → *influences* / *deterioration* → Pavement → *generates* / *large amounts* → GHG

- For pavements, climate stressors such as temperature, precipitation, wind speed, solar radiation, and groundwater table have strong influence on performance

- Current Pavement LCA methodology typically assumes static climate (or past climate), which may not be suitable for long-term planning into the future

Goals

- Develop a framework to incorporate climate change in pavement LCA.
- Using climate change informed LCA, identify how decisions during the design portion of pavement infrastructure can affect life cycle impacts and costs.
- Investigate the impacts and costs associated with different pavement maintenance and rehabilitation strategies.

Methodology

Input data collection

- Traffic
- Climate Information
- Pavement Structure
- Material Properties

Baseline Design

- Emulate Current design (New Hampshire I-95)

Pavement ME

- Perform evaluation
- Distress
- IRI

Operation spreadsheet

- Relate pavement roughness to fuel consumption
- Material quantity

SimaPro and PaLATE

- Life cycle inventory
- Calculate GWP
- Energy Consumption
- Costs

Pavement Alternatives

- Vary Layer thickness
- Amount of RAP
- Rehab trigger in terms of IRI

Climate Downscaling

CMIP5

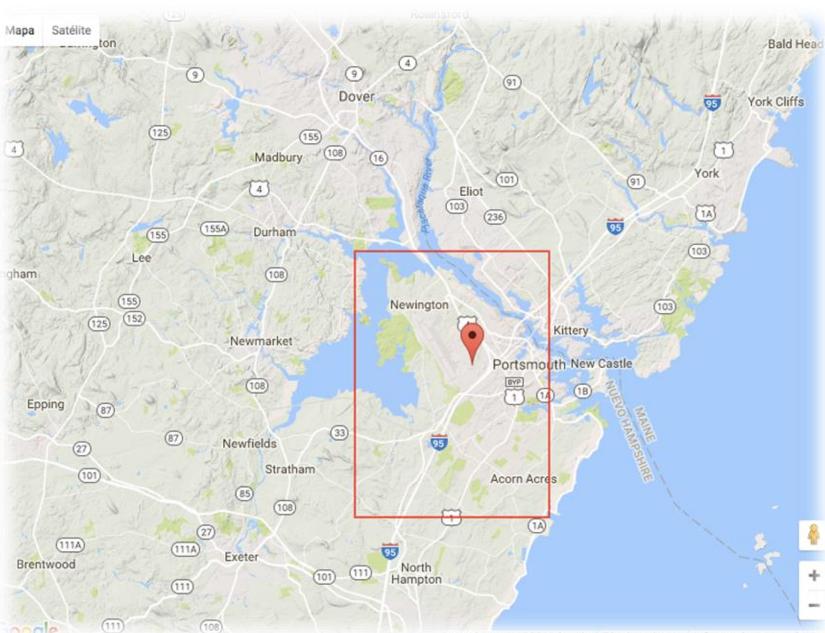
Variables: - Precipitation
- Max. & Min. temperature

Coverage: - 1950-2099

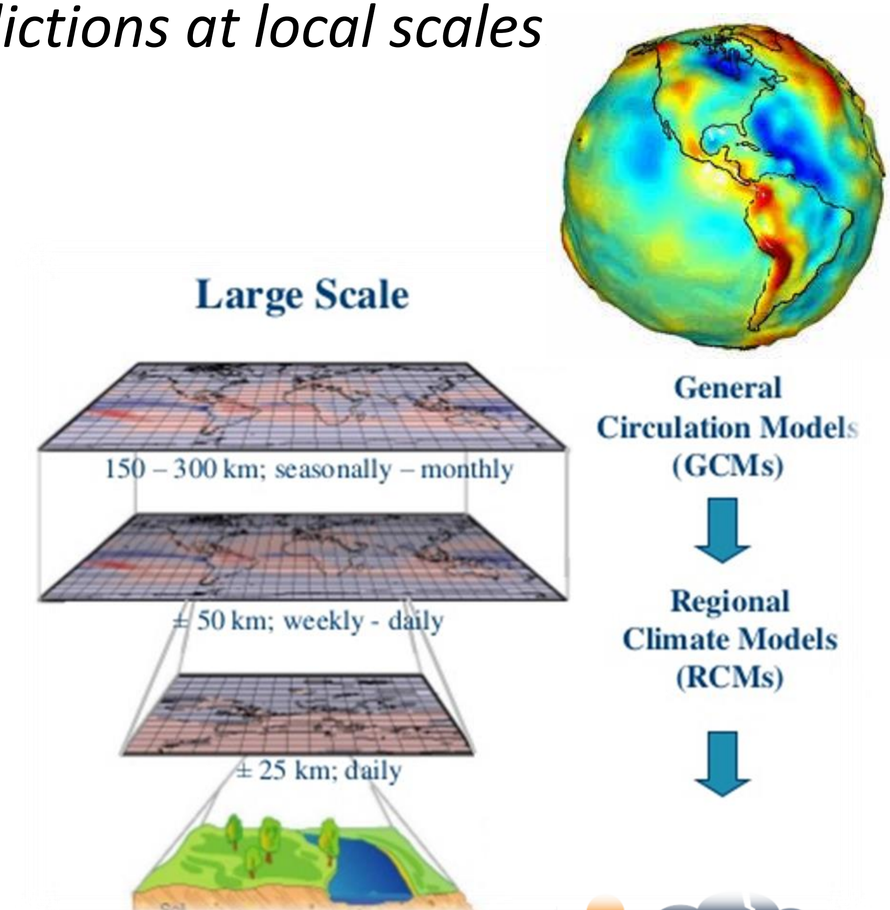
Resolution: - Daily

Space: - NLDAS

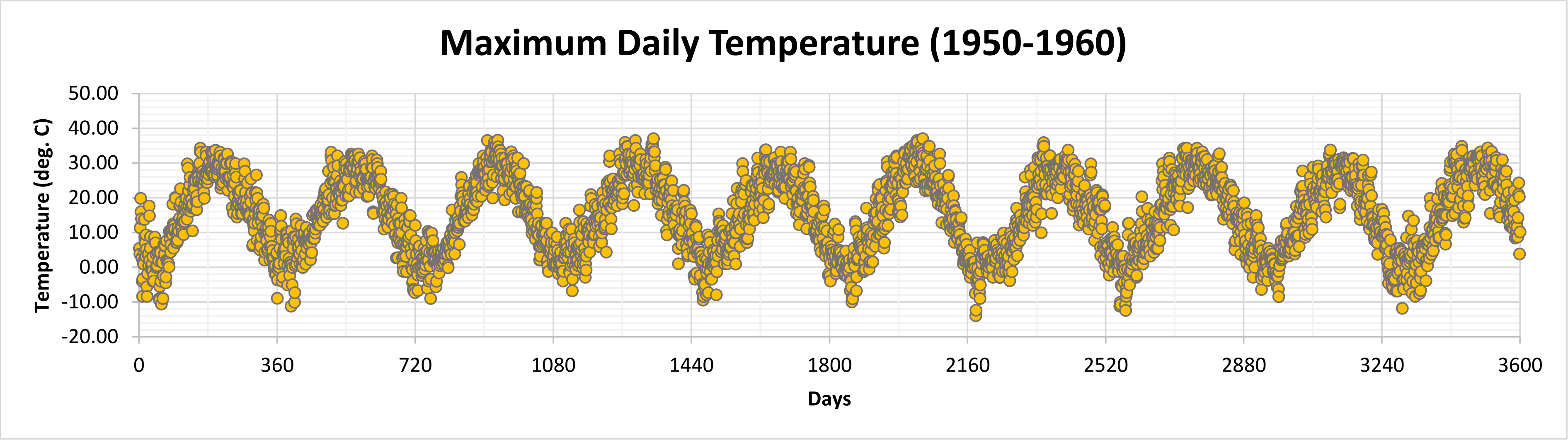
Resolution: - 12km X 12 km

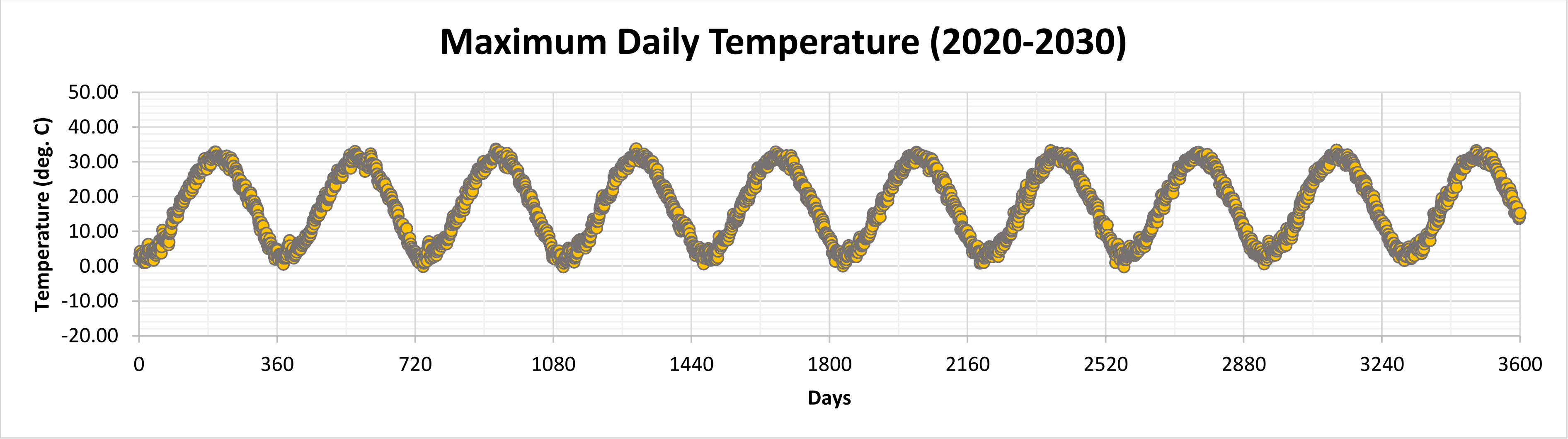


Downscaling is the general name for a procedure to take information known at large scales to make predictions at local scales



Climate Downscaling: RCP 8.5 Scenario





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Pavement ME Climate Inputs

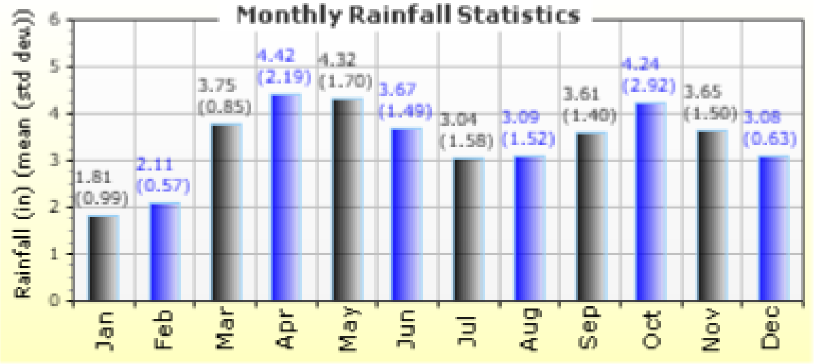
Climate Inputs

Climate Data Sources:

Climate Station Cities:	Location (lat lon elevation(ft))
ROCHESTER, NH	43.27800 -70.92200 330

Annual Statistics:

Mean annual air temperature (°F)	47.56
Mean annual precipitation (in)	40.83
Freezing index (°F - days)	776.52
Average annual number of freeze/thaw cycles:	85.56



Water table depth (ft) 10.00

Monthly Climate Summary:

Year	Month	Day	Precip (mm)	0	1	2	3	4	5
2020	1	1	1.72	(5.84)	(6.77)	(7.58)	(8.25)	(8.75)	(9.05)
2020	1	2	3.45	(4.09)	(4.90)	(5.61)	(6.20)	(6.64)	(6.90)
2020	1	3	1.90	(4.39)	(5.24)	(5.99)	(6.60)	(7.06)	(7.34)
2020	1	4	2.54	(4.62)	(5.54)	(6.34)	(7.01)	(7.50)	(7.80)
2020	1	5	1.73	(5.75)	(6.77)	(7.67)	(8.40)	(8.94)	(9.28)
2020	1	6	2.92	(6.20)	(7.18)	(8.03)	(8.73)	(9.25)	(9.57)
2020	1	7	4.88	(3.67)	(4.41)	(5.05)	(5.58)	(5.97)	(6.22)
2020	1	8	4.94	(4.64)	(5.30)	(5.88)	(6.36)	(6.71)	(6.93)
2020	1	9	2.69	(6.13)	(6.92)	(7.62)	(8.19)	(8.61)	(8.87)
2020	1	10	4.55	(6.29)	(7.13)	(7.86)	(8.47)	(8.91)	(9.19)
2020	1	11	2.85	(6.69)	(7.64)	(8.48)	(9.17)	(9.68)	(10.00)
2020	1	12	1.44	(6.49)	(7.48)	(8.35)	(9.07)	(9.60)	(9.92)
2020	1	13	3.16	(5.24)	(6.19)	(7.01)	(7.69)	[illegible]	(8.50)
2020	1	14	2.41	(6.27)	(7.32)	(8.24)	(8.99)	[illegible]	(9.90)
2020	1	15	3.36	(4.74)	(5.62)	(6.39)	(7.02)	[illegible]	(7.78)
2020	1	16	1.80	(6.35)	(7.41)	(8.34)	(9.10)	(9.67)	(10.02)
2020	1	17	2.53	(7.50)	(8.62)	(9.61)	(10.42)	(11.02)	(11.39)
2020	1	18	4.01	(6.38)	(7.34)	(8.19)	(8.89)	(9.40)	(9.72)
2020	1	19	1.52	(7.85)	(8.97)	(9.95)	(10.75)	(11.35)	(11.71)
2020	1	20	3.88	(7.13)	(8.14)	(9.03)	(9.76)	(10.30)	(10.64)
2020	1	21	2.51	(5.29)	(6.18)	(6.95)	(7.59)	(8.06)	(8.35)
2020	1	22	1.89	(4.79)	(5.74)	(6.56)	(7.24)	(7.75)	(8.06)
2020	1	23	1.45	(4.57)	(5.57)	(6.44)	(7.15)	(7.68)	(8.01)
2020	1	24	1.97	(2.70)	(3.70)	(4.57)	(5.28)	(5.82)	(6.14)
2020	1	25	2.23	(3.87)	(4.72)	(5.46)	(6.07)	(6.52)	(6.80)
2020	1	26	2.92	(2.99)	(3.80)	(4.50)	(5.08)	(5.51)	(5.78)
2020	1	27	4.84	(3.92)	(4.85)	(5.67)	(6.34)	(6.84)	(7.15)
2020	1	28	1.93	(6.30)	(7.21)	(8.01)	(8.66)	(9.15)	(9.45)

CMIP5-CLIMATE DATA

General)

```
Sub fecha()
    Dim x As Integer

        ActiveCell.Range("A1").Select
        Selection.NumberFormat = "mm"
        ActiveCell.Offset(0, 1).Range("A1").Select
        ActiveCell.FormulaR1C1 = "=RC[-1]"
        Selection.NumberFormat = "dd"
        ActiveCell.Offset(0, 1).Range("A1").Select
        ActiveCell.FormulaR1C1 = "=RC[-2]"
        Selection.NumberFormat = "yyyy"
        ActiveCell.Offset(1, -2).Range("A1").Select

        Do Until IsEmpty(ActiveCell.Offset(0, 1))
        For x = 0 To 23 Step 1
        ActiveCell.Value = x
        ActiveCell.Offset(1, 0).Select
        Next x
            ActiveCell.Range("A1:F1").Select
            Selection.Insert Shift:=xlDown
            ActiveCell.Select
```

VBA ROUTINE

Durham_RCP 4.5: Bloc de notas

Archivo Edición Formato Ver Ayuda

```
20200101-20401231
-70.922,43.278,330,10,10,10,10,10,48.54,100,39.18,66.1,64.8,62.9,61.4,68.3,74,75.6,75.8,75.2,72,67.2,6
1 1 2020 4.74 19.26 3760.63
0 20.01 0.13 5 100 10
1 18.44 0 4 100 10
2 17.07 0 4 100 10
3 15.95 0 4 100 10
4 15.12 0 5 100 10
5 14.6 0 4 100 10
6 14.43 0 5 100 10
7 15.12 0 5 25 10
8 17.07 0 5 62.5 10
9 20.01 0 6 100 10
10 23.46 0 10 100 10
11 26.92 0 7 100 10
12 29.85 0 10 25 10
13 31.81 0 8 25 10
14 32.5 0 7 50 10
15 32.33 0 9 100 10
16 31.81 0 7 100 10
17 30.98 0 6 100 10
18 29.85 0 3 0 10
19 28.48 0 5 25 10
20 26.92 0 7 75 10
21 25.23 0 0 100 10
```

CUSTOMIZED - CLIMATE FILE

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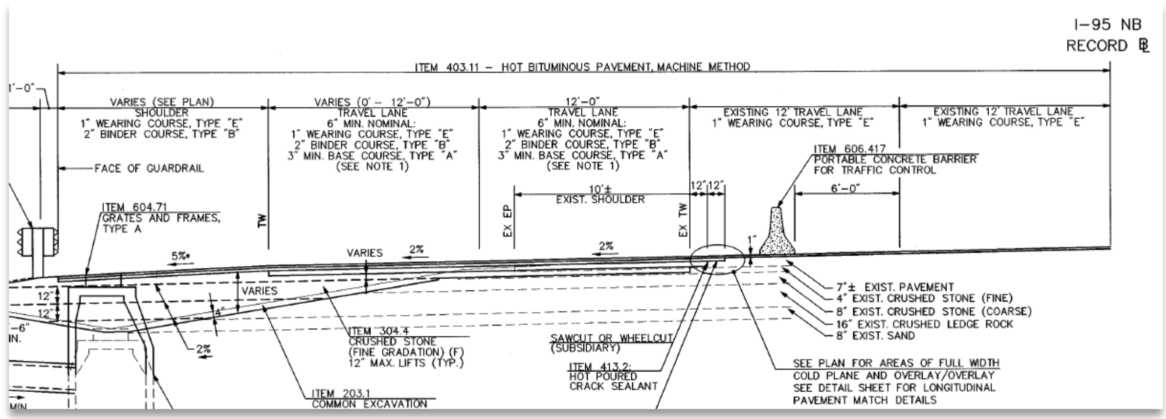
Impact Inputs (Pavement LCA Inventory)

Impact Input	Units	Value	Source
Production			
Asphalt Concrete	MJ/ton	641.00	SimaPro
Asphalt Concrete	kg CO_2 eq/ton	84.70	SimaPro
Gravel	MJ/ton	265.00	SimaPro
Gravel	kg CO_2 eq/ton	14.10	SimaPro
Sand	MJ/ton	61.80	SimaPro
Sand	kg CO_2 eq/ton	4.25	SimaPro
Transportation			
Dump Truck Transportation	MJ/ton*mile	5.13	SimaPro
Dump Truck Transportation	kg CO_2 eq/ton*mile	0.32	SimaPro
Construction			
Asphalt Paving (Productivity)	ton/hr	10.00	PaLATE
Asphalt Rolling – Tandem (Productivity)	ton/hr	395.00	PaLATE
Unbound Material Compaction (Productivity)	ton/hr	1,832.00	PaLATE
Construction Machine Operation	MJ/hr	10,816.00	SimaPro
Construction Machine Operation	kg CO_2 eq/hr	72.00	SimaPro
Maintenance			
Asphalt Milling	MJ/yd^3	6.23	SimaPro
Asphalt Milling	kg CO_2 eq/yd^3	0.40	SimaPro
Operation			
Gasoline	MJ/gal	130.00	EPA
Gasoline	lb CO_2/gal	19.64	EPA
Diesel	MJ/gal	137.00	EPA
Diesel	lb CO_2/gal	22.38	EPA

Test scenario 1: Comparison of Different Pavement Structures and Levels of Recycling

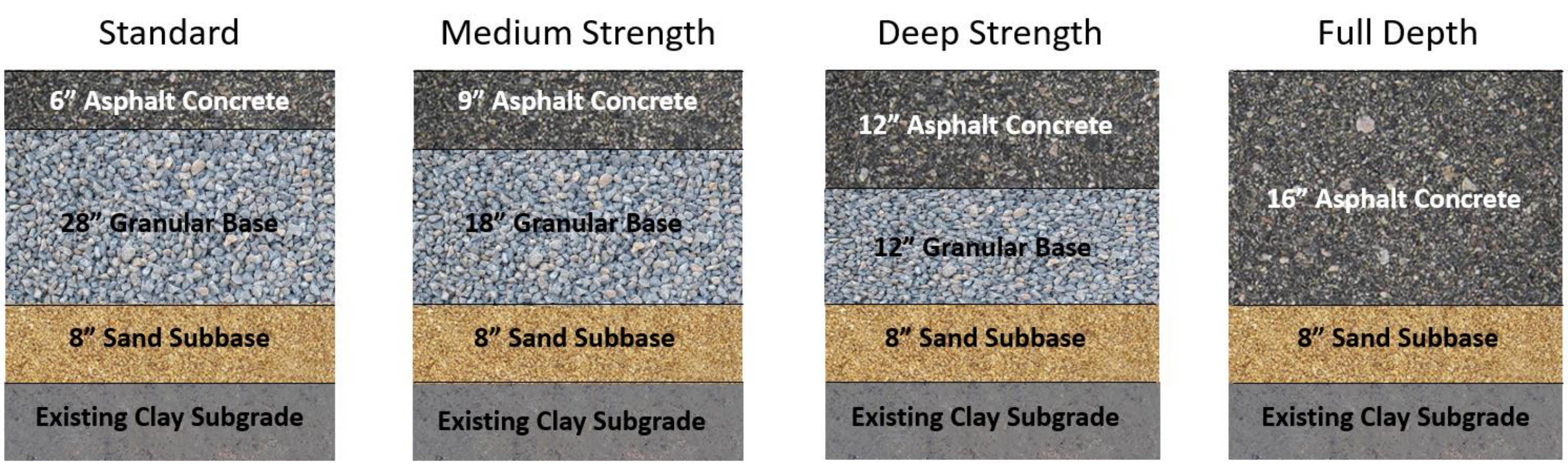
20 YEARS ANALYISIS	
AADT	88,000
% Cars	90
% Trucks	10
Operational Speed (mph)	70
Length (miles)	17
# Lanes/direction	4
Traffic growth rate (%)	0



I-95 CROSS SECTION

- 3 VARIATIONS OF ASPHALT LAYER
- 4 STRUCTURES

12 STRUCTURE - MATERIAL COMBINATIONS



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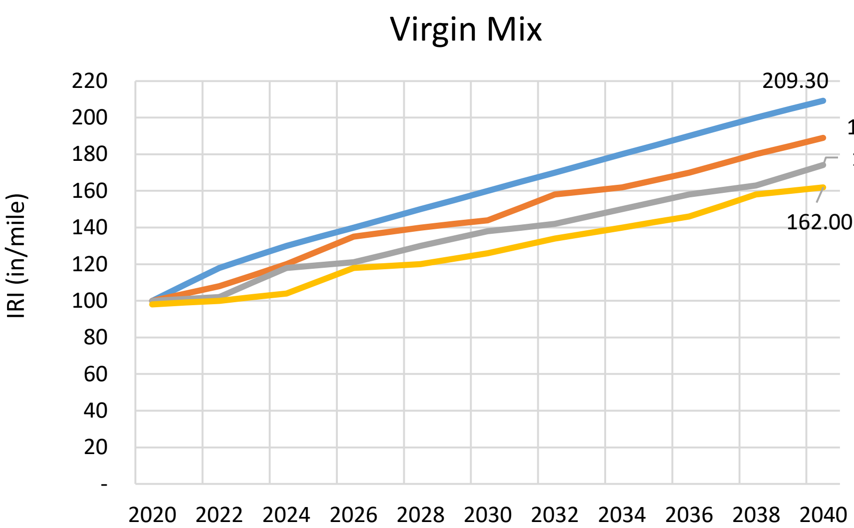
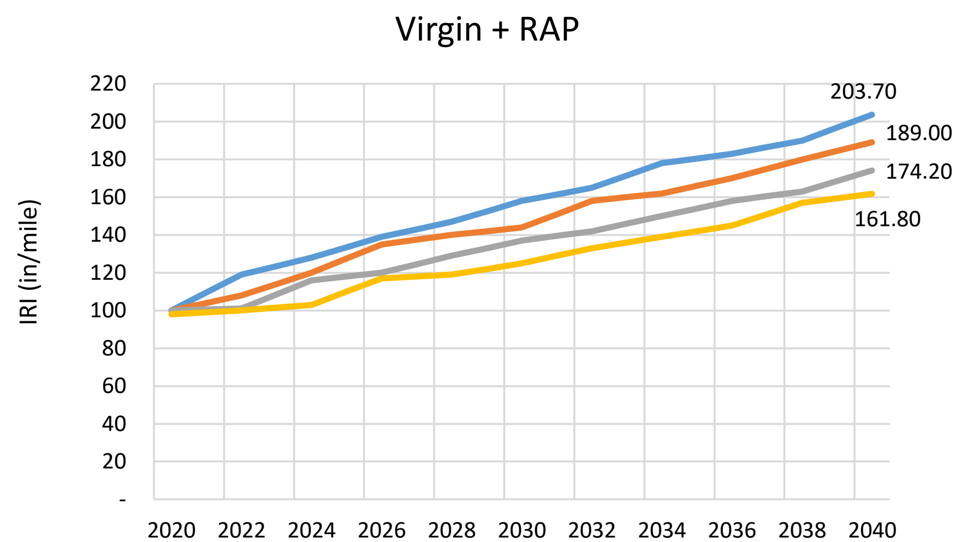
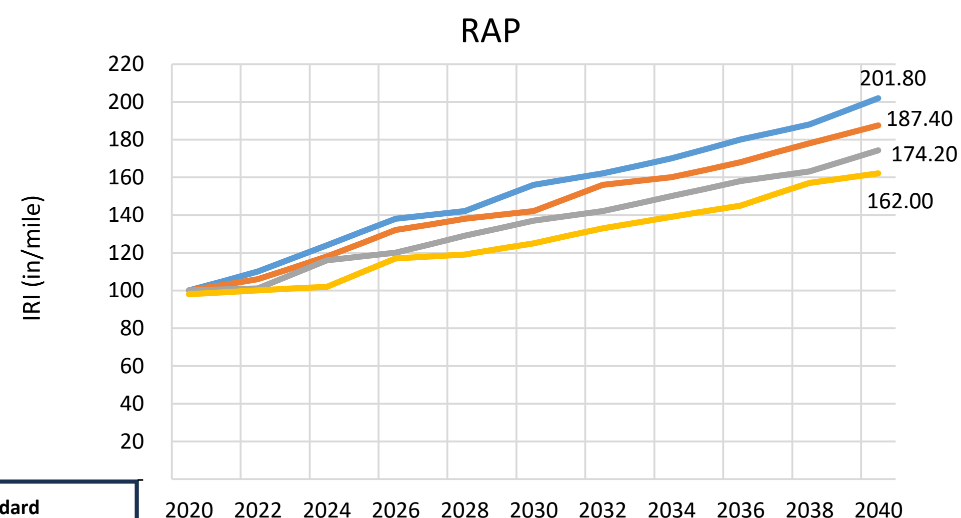
Results Scenario 1

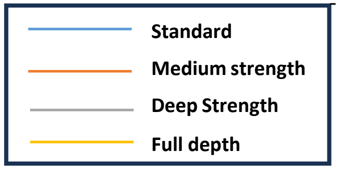
		EXPECTED LIFE	
	Mix Alternatives	**Downscaled CMIP5**	**Rochester Climate Station**
ALL LAYERS VIRGIN ASPHALT MIXTURE (V)	Standard-V	18	21
	Medium Strength-V	22	24
	Deep Strength-V	27	28
	Full Depth-V	33	34
TOP TWO LAYERS VIRGIN MIXTURE, BOTTOM LAYER 40% RAP MIXTURE (V/R)	Standard-V/R	19	21
	Medium Strength-V/R	22	24
	Deep Strength-V/R	27	28
	Full Depth-V/R	34	32
ALL LAYERS 40% RAP ASPHALT MIXTURE (R)	Standard-R	20	21
	Medium Strength-R	23	21
	Deep Strength-R	27	24
	Full Depth-R	33	28



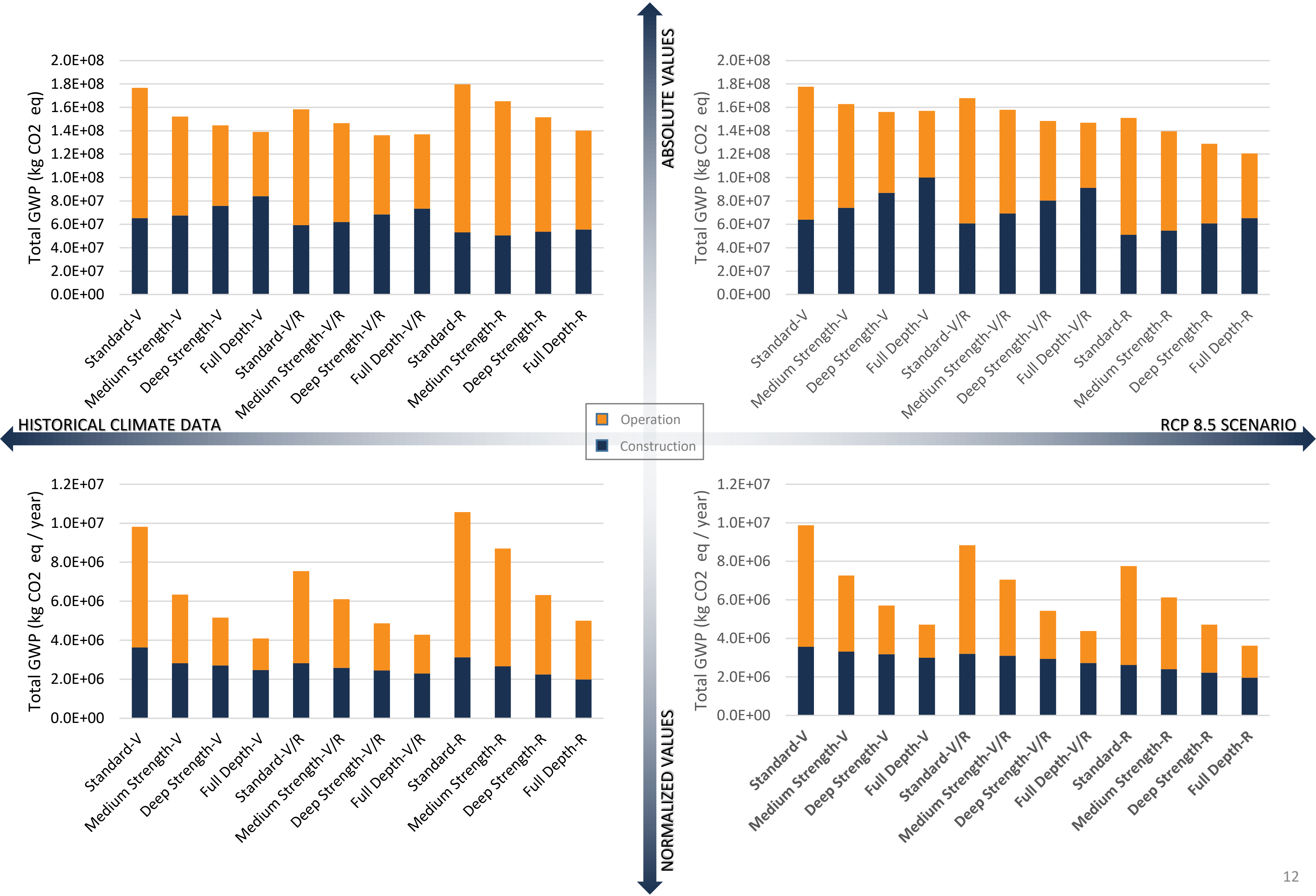


Mix Alternatives	CLIMATE MODEL RCP 8.5	ROCHESTER CLIMA STATION	Δ Terminal IRI
Standard-V	209.30	209.30	-
Medium Strength-V	189.00	187.70	1.30
Deep Strength-V	174.10	173.50	0.60
Full Depth-V	162.00	161.90	0.10
Standard-V/R	203.70	203.40	0.30
Medium Strength-V/R	189.00	187.60	1.40
Deep Strength-V/R	174.20	173.60	0.60
Full Depth-V/R	161.80	161.90	(0.10)
Standard-R	201.80	220.90	(19.10)
Medium Strength-R	187.40	207.00	(19.60)
Deep Strength-R	174.20	191.00	(16.80)
Full Depth-R	162.00	176.20	(14.20)

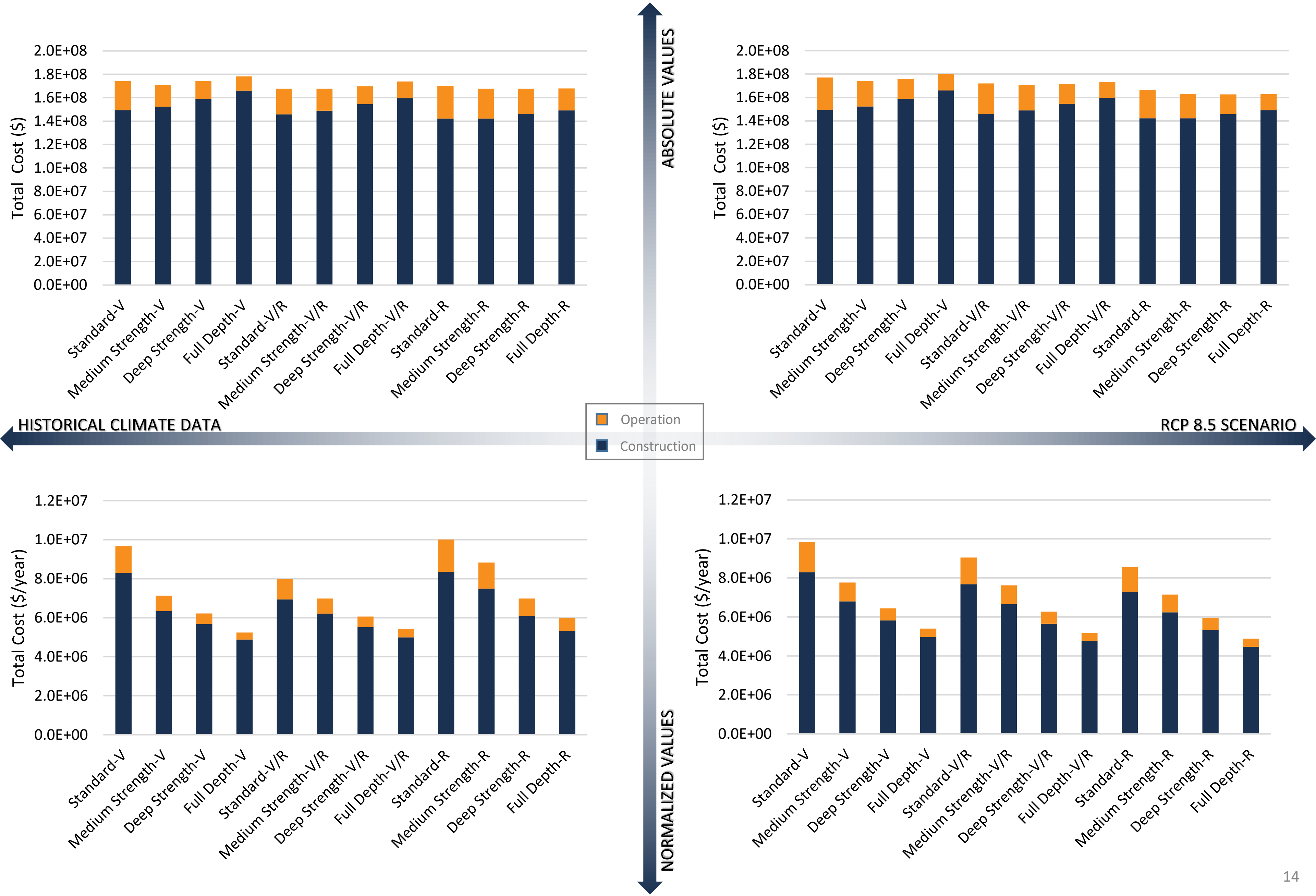




Global Warming Potential



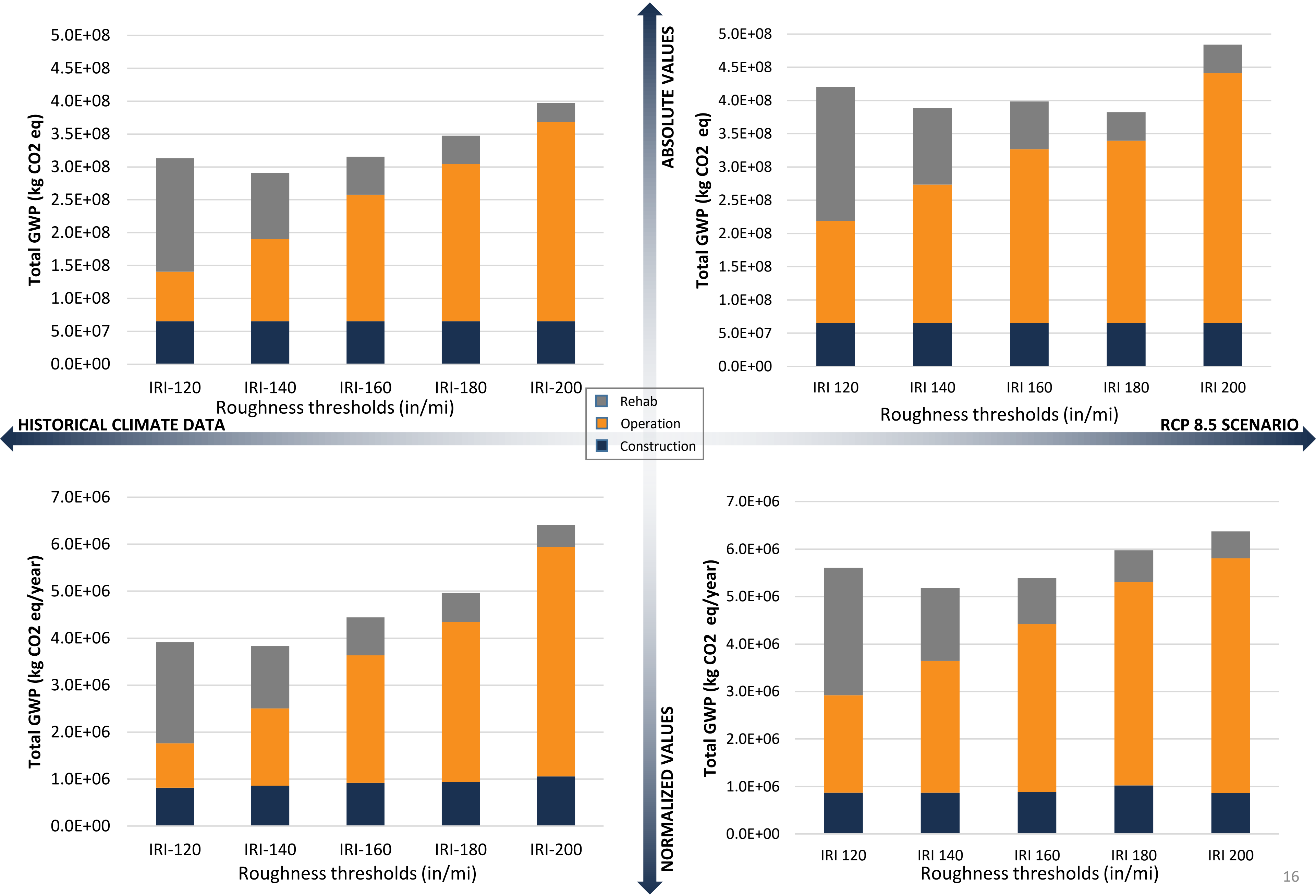
Total Cost


ABSOLUTE VALUES
NORMALIZED VALUES
HISTORICAL CLIMATE DATA
RCP 8.5 SCENARIO
Operation
Construction
Total Cost ($)
Total Cost ($/year)
2.0E+08
1.8E+08
1.6E+08
1.4E+08
1.2E+08
1.0E+08
8.0E+07
6.0E+07
4.0E+07
2.0E+07
0.0E+00
1.2E+07
1.0E+07
8.0E+06
6.0E+06
4.0E+06
2.0E+06
0.0E+00
Standard-V
Medium Strength-V
Deep Strength-V
Full Depth-V
Standard-V/R
Medium Strength-V/R
Deep Strength-V/R
Full Depth-V/R
Standard-R
Medium Strength-R
Deep Strength-R
Full Depth-R

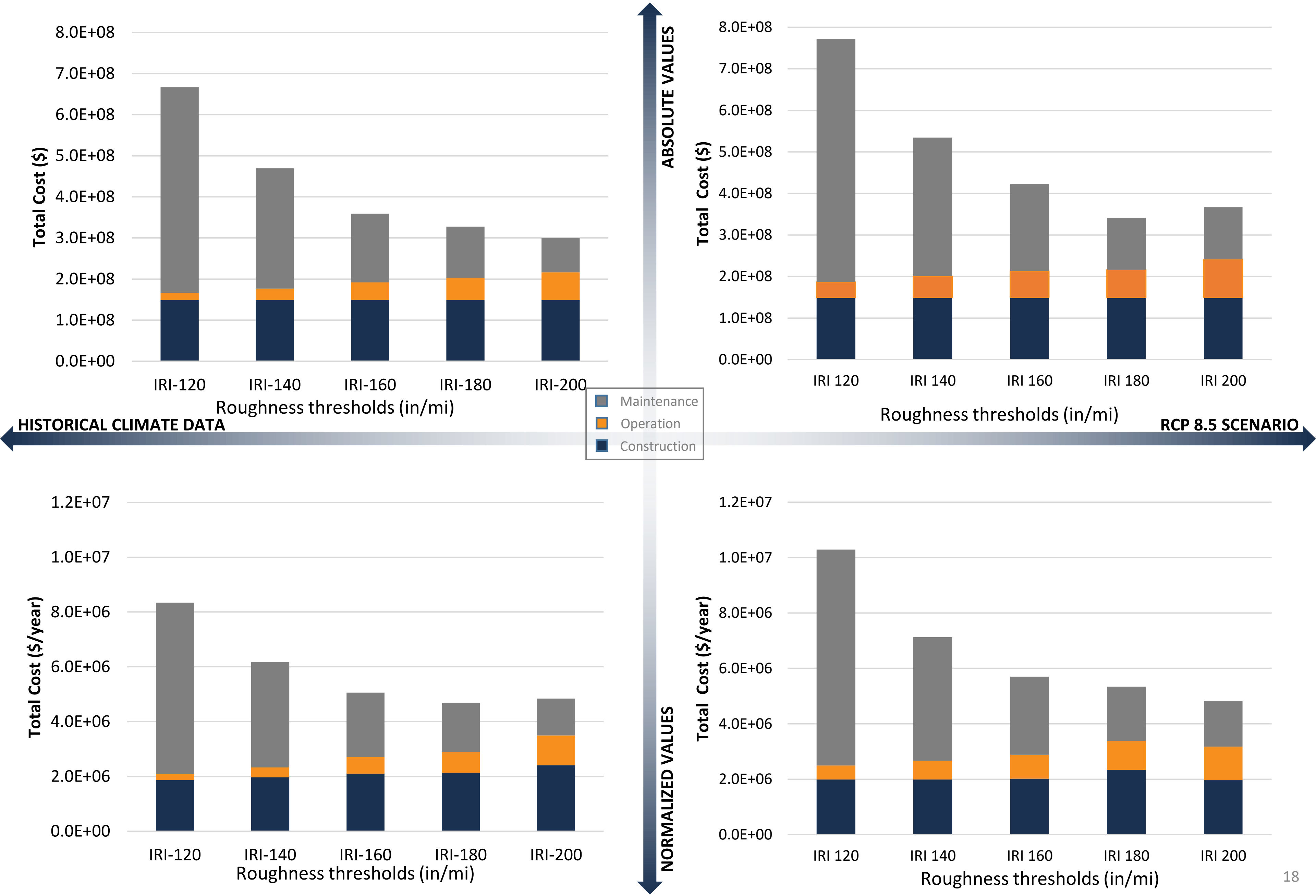
Test scenario 2: Pavement Roughness Threshold for Overlay Rehabilitation

	TOTAL SIMULATION DURATION (Yrs.)		REHABILITATION CYCLES	
Roughness thresholds (in/mi)	**Downscaled CMIP5**	**Rochester Climate Station**	**Downscaled CMIP5**	**Rochester Climate Station**
IRI 120	75	80	14	14
IRI 140	75	76	8	7
IRI 160	74	71	5	4
IRI 180	64	70	3	3
IRI 200	76	62	3	2

Global Warming Potential



Total Cost


ABSOLUTE VALUES
NORMALIZED VALUES
HISTORICAL CLIMATE DATA
RCP 8.5 SCENARIO
Maintenance
Operation
Construction
Total Cost ($)
8.0E+08
7.0E+08
6.0E+08
5.0E+08
4.0E+08
3.0E+08
2.0E+08
1.0E+08
0.0E+00
IRI-120
IRI-140
IRI-160
IRI-180
IRI-200
Roughness thresholds (in/mi)
IRI 120
IRI 140
IRI 160
IRI 180
IRI 200
Total Cost ($/year)
1.2E+07
1.0E+07
8.0E+06
6.0E+06
4.0E+06
2.0E+06
0.0E+00

Summary

- There is a dynamic interaction between climate and pavements.
- LCA findings change drastically with use of future climate information as opposed to historic climate data.
- Framework presented here should be considered for LCA based design and operational guidance for roadways.

Future Work

- PavementME is quite comprehensive, however it requires local calibration. An alternative would be to use pavement performance curves from pavement or asset management systems.
- With changing climate, it is necessary to use reliable future climate projections in LCA process.
  - Emissions and GWP from analysis like the ones presented in this paper have a certain and quantifiable effect on future climate. Extension can take the future climate impact of the comparison alternatives into consideration.
- Effect of climate change on the equipment and vehicle efficiencies need to be accounted to improve reliability of the GWP calculations.

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Thank you !

Acknowledgement:

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