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18-21/05/26

A 10-YEAR CARBON LOOKBACK: A FRAMEWORK TO QUANTIFY GWP SAVINGS FROM PROACTIVE PAVEMENT MAINTENANCE ON IRELAND’S NATIONAL ROAD NETWORK

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20/05/2026

The Irish Road Network

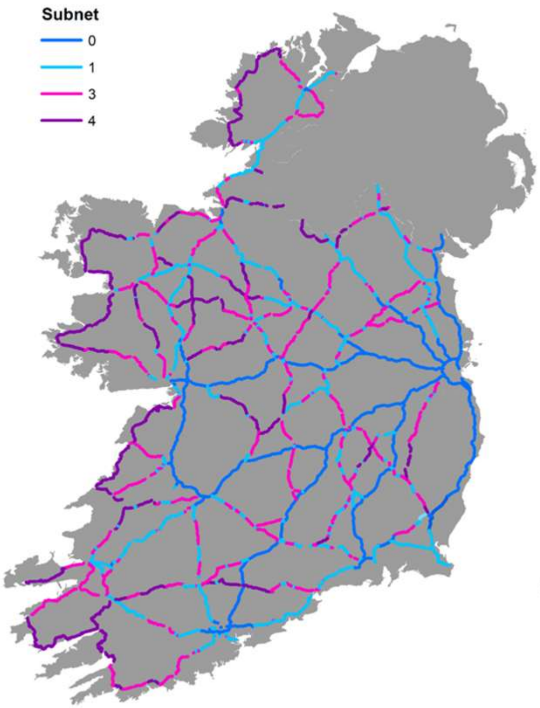
Total network comprises 5400 centreline kilometres. The network is very diverse. There are major variations in:

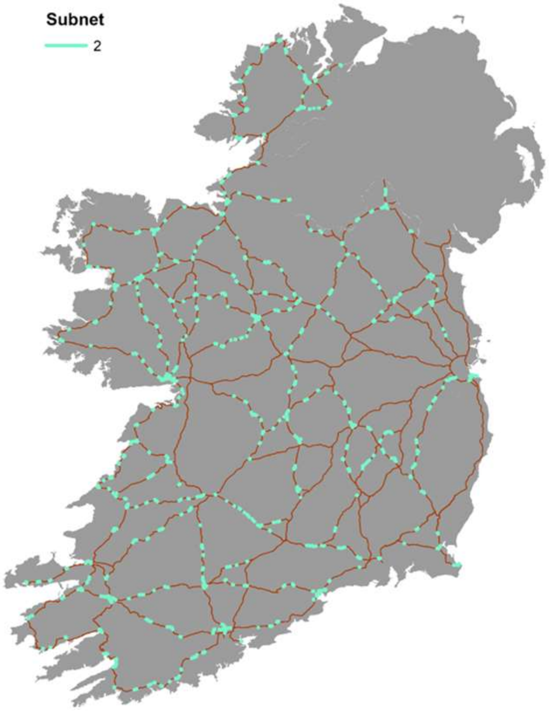
- Pavement Structure
- Traffic Levels
- Alignment
- Drainage Characteristics

TII addressed this by breaking the Overall Network into 5 Subnetworks. Subnetworks display internally consistent characteristics and behaviour.

The Irish Road Network - Subnetworks

Subnet		Classification	Length (km)	% Of Network
0	Motorway + Dual Carriageways	High speed, high volumes pavement, made up of Motorway and Dual Carriageway sections of the network.	1200	23%
1	Engineered Single Carriageway	Typically carry reasonably large volumes of traffic and are identified by the presence of hard shoulders adjacent to the carriageway.	1200	22%
2	Urban Roads	Low to medium speed, typically short sections through towns that are not bypassed, also includes longer sections within the cities and larger towns where National Roads start and end.	700	13%
3	Legacy Pavement - High Traffic	Legacy subnetwork, typically constructed without formal geometric or pavement design. Typically carries traffic volumes less than 10,000 AADT.	1300	24%
4	Legacy Pavement - Low Traffic	Legacy subnetwork, typically constructed without formal geometric or pavement design. Typically carries traffic volumes less than 5000 AADT.	950	18%





The Irish Road Network – Current State

- KPI's employed to monitor and manage the Network include:
  - **International Roughness Index (IRI)**
  - **RUT Depth (RUT)**
  - **Longitudinal Evenness (LPV)**
- Qualitative Descriptors employed: Very Good, Good, Fair, Poor, Very Poor. Parameters are measured annually by TII across the network Target is 95% in Fair or Better for all parameters.

IRI – Roughness/Ride Quality

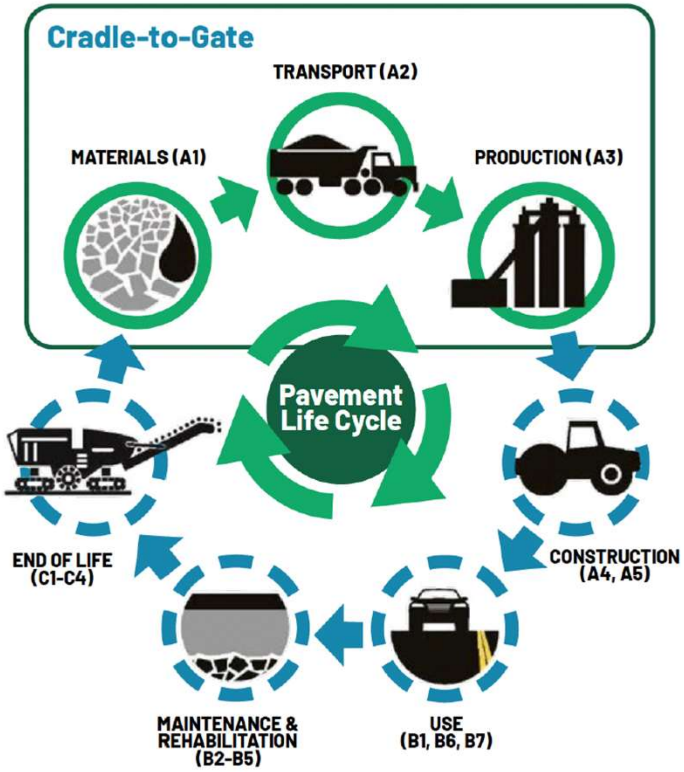
LPV – Bumpiness

Rut Depth – Transverse Profile

Current Network Condition

Why Quantifying GWP Savings from Proactive Pavement Maintenance Matters?

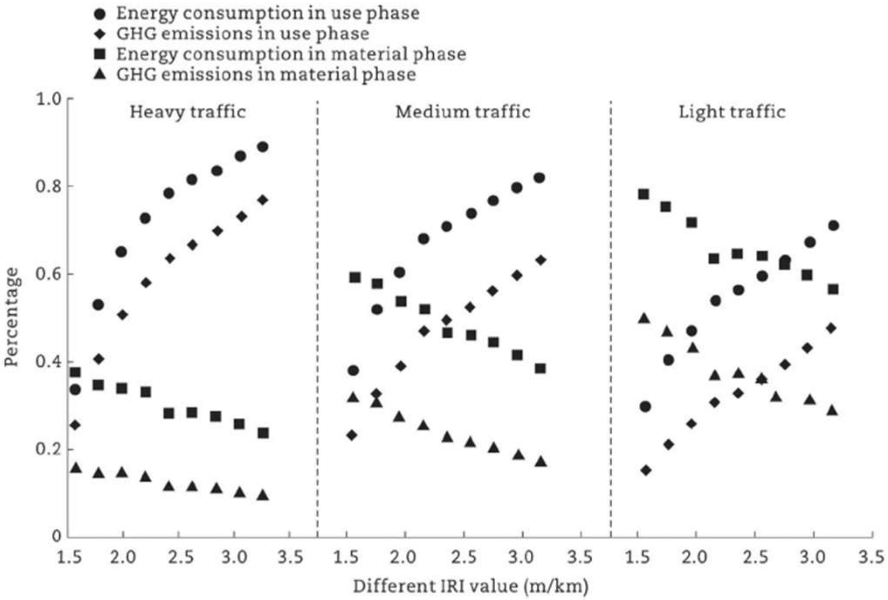
- Transport emissions are not only about vehicles; infrastructure construction, maintenance and rehabilitation also contribute significantly to GHG emissions.
- Pavement management is moving from cost + condition to cost + performance + carbon/GWP
- TII wants a transparent way to quantify the carbon benefits of timely maintenance



Shacat, J., Willis, R., Ciavola, B., The Carbon Footprint of Asphalt Pavements, NAPA, https://www.asphaltpavement.org/uploads/documents/Climate/NAPA-SIP109-TheCarbonFootprintOfAsphaltPavements-March2024.pdf

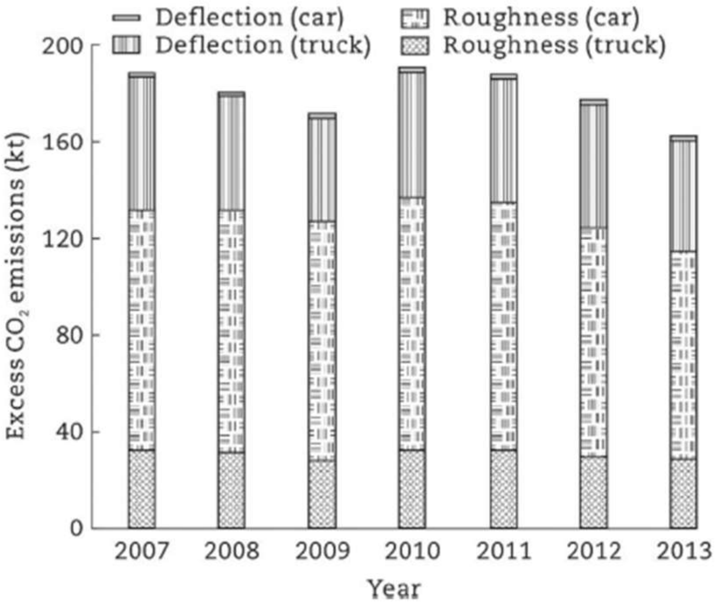
Why Quantifying GWP Savings from Proactive Pavement Maintenance Matters?

Energy Consumption and GHG Emissions with IRI Value



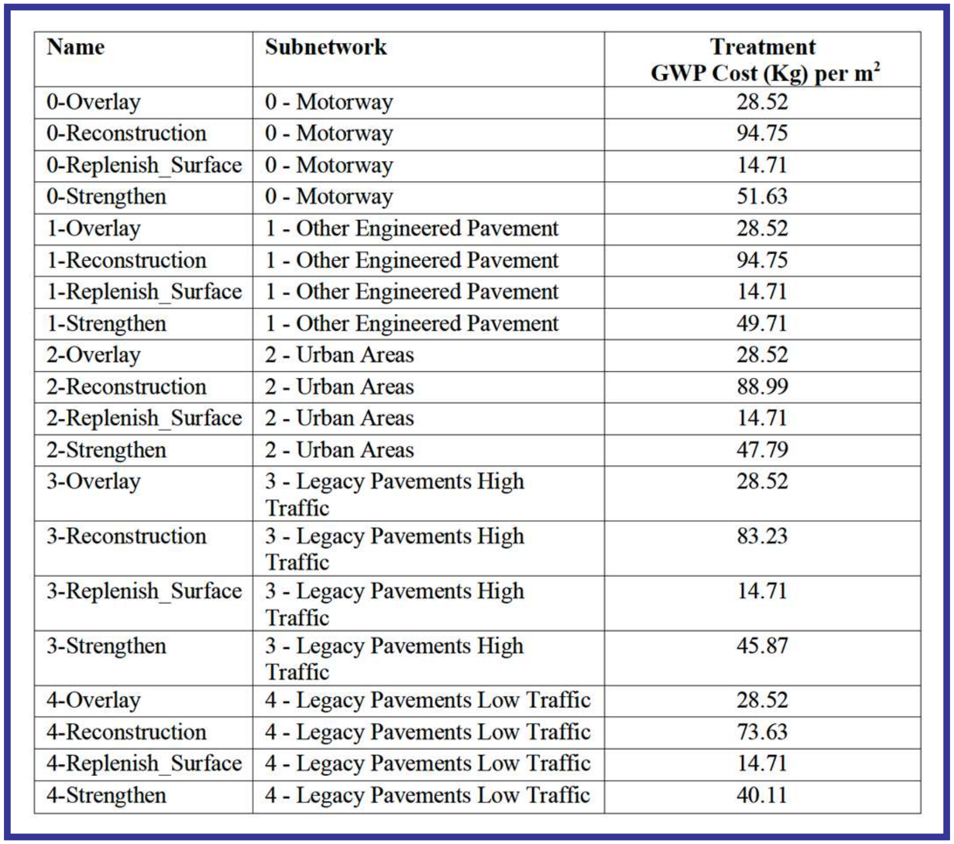
Chong, D., Wang, Y., (2017), Impacts of flexible pavement design and management decisions on life cycle energy consumption and carbon footprint. The International Journal of Life Cycle Assessment 22.

Total Annual Excess CO2 Emissions of Roughness and Deflection



Louhghalam, A., Akbarian, M., Ulm, F.-J., (2017), Carbon management of infrastructure performance: integrated big data analytics and pavement-vehicle-interactions. Journal of Cleaner Production 142.

Network Management – GWP Cost & Productivity



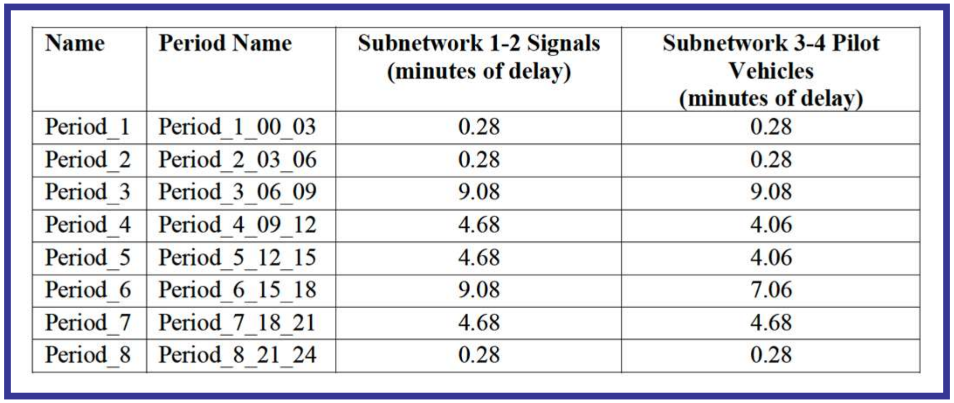
Name	Subnetwork	Treatment GWP Cost (Kg) per m^2
0-Overlay	0 - Motorway	28.52
0-Reconstruction	0 - Motorway	94.75
0-Replenish_Surface	0 - Motorway	14.71
0-Strengthen	0 - Motorway	51.63
1-Overlay	1 - Other Engineered Pavement	28.52
1-Reconstruction	1 - Other Engineered Pavement	94.75
1-Replenish_Surface	1 - Other Engineered Pavement	14.71
1-Strengthen	1 - Other Engineered Pavement	49.71
2-Overlay	2 - Urban Areas	28.52
2-Reconstruction	2 - Urban Areas	88.99
2-Replenish_Surface	2 - Urban Areas	14.71
2-Strengthen	2 - Urban Areas	47.79
3-Overlay	3 - Legacy Pavements High Traffic	28.52
3-Reconstruction	3 - Legacy Pavements High Traffic	83.23
3-Replenish_Surface	3 - Legacy Pavements High Traffic	14.71
3-Strengthen	3 - Legacy Pavements High Traffic	45.87
4-Overlay	4 - Legacy Pavements Low Traffic	28.52
4-Reconstruction	4 - Legacy Pavements Low Traffic	73.63
4-Replenish_Surface	4 - Legacy Pavements Low Traffic	14.71
4-Strengthen	4 - Legacy Pavements Low Traffic	40.11

In determining these values, GWP from various states of a construction project, i.e.:

- material production (kg/m2)
- manufacturing and mixture (kg/m2)
- transportation of material to site (kg/m2)
- placement (kg/m2)
- demolition (kg/m2)
- recycling credit (kg/m2)
- The sample values presented in Table 1 were further nuanced based upon the treatment type e.g. SMA, HRA, Surface Dressing.

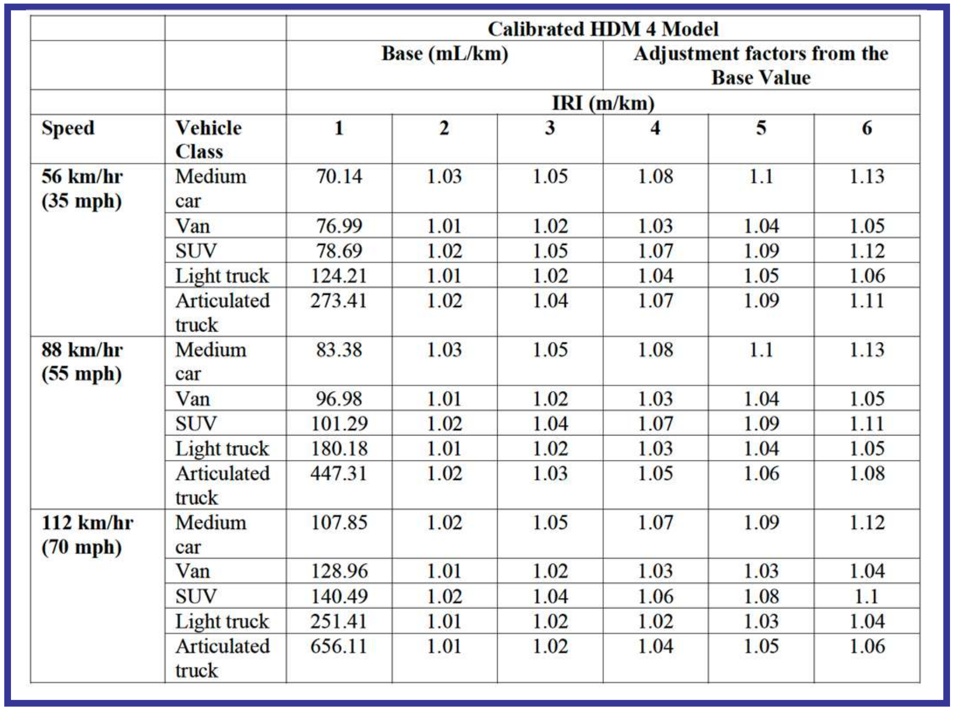
Network Management – GWP Cost & Productivity

Delay Costs – Subnets 1 to 4



Name	Period Name	Subnetwork 1-2 Signals (minutes of delay)	Subnetwork 3-4 Pilot Vehicles (minutes of delay)
Period_1	Period_1_00_03	0.28	0.28
Period_2	Period_2_03_06	0.28	0.28
Period_3	Period_3_06_09	9.08	9.08
Period_4	Period_4_09_12	4.68	4.06
Period_5	Period_5_12_15	4.68	4.06
Period_6	Period_6_15_18	9.08	7.06
Period_7	Period_7_18_21	4.68	4.68
Period_8	Period_8_21_24	0.28	0.28

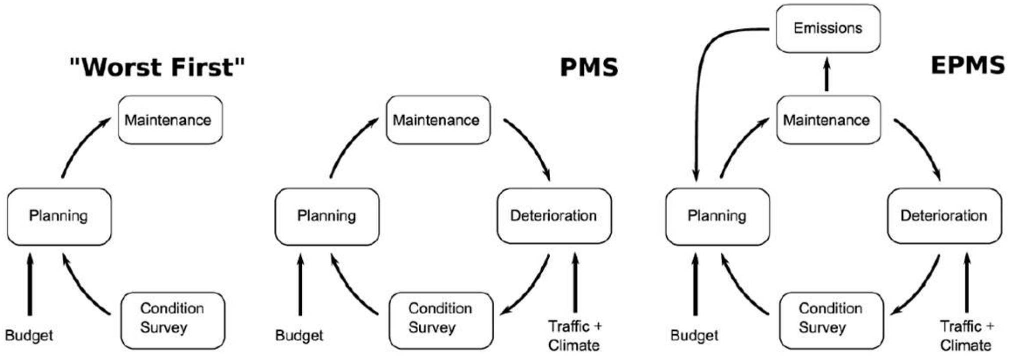
Effect of Roughness on Fuel Consumption (NCHRP 720)



		Calibrated HDM 4 Model					
		Base (mL/km)			Adjustment factors from the Base Value		
		IRI (m/km)					
Speed	**Vehicle Class**	**1**	**2**	**3**	**4**	**5**	**6**
56 km/hr (35 mph)	Medium car	70.14	1.03	1.05	1.08	1.1	1.13
	Van	76.99	1.01	1.02	1.03	1.04	1.05
	SUV	78.69	1.02	1.05	1.07	1.09	1.12
	Light truck	124.21	1.01	1.02	1.04	1.05	1.06
	Articulated truck	273.41	1.02	1.04	1.07	1.09	1.11
88 km/hr (55 mph)	Medium car	83.38	1.03	1.05	1.08	1.1	1.13
	Van	96.98	1.01	1.02	1.03	1.04	1.05
	SUV	101.29	1.02	1.04	1.07	1.09	1.11
	Light truck	180.18	1.01	1.02	1.03	1.04	1.05
	Articulated truck	447.31	1.02	1.03	1.05	1.06	1.08
112 km/hr (70 mph)	Medium car	107.85	1.02	1.05	1.07	1.09	1.12
	Van	128.96	1.01	1.02	1.03	1.03	1.04
	SUV	140.49	1.02	1.04	1.06	1.08	1.1
	Light truck	251.41	1.01	1.02	1.02	1.03	1.04
	Articulated truck	656.11	1.01	1.02	1.04	1.05	1.06

Research Aim

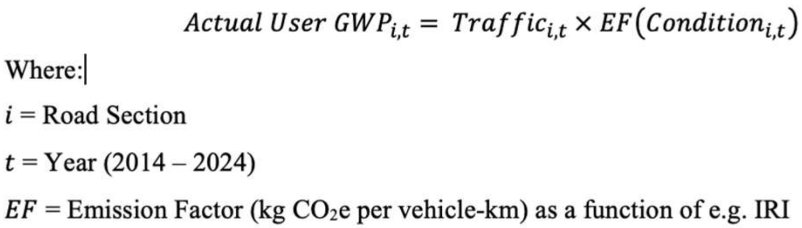
- Develop a framework for a 10-Year Carbon Lookback Analysis
- Compare:
  - **Actual GWP = emissions under real interventions**
  - **Notional GWP = emissions if interventions had not occurred**
- Extend analysis to 2035 to capture long-term benefits of smoother pavements and avoided backlog



Adapted from Gosse, C., Smith, B., Clarens, F., (2013), Environmentally Preferable Pavement Management Systems, ASCE Journal of Infrastructure Systems, 19(3)

METHODOLOGY

- Actual User GWP is the life-cycle CO_2-equivalent emitted by vehicles using the improved sec-tions. It is computed annually by applying emission factors to traffic volumes, adjusted for measured pavement condition:



$$Actual\ User\ GWP_{i,t} = Traffic_{i,t} \times EF(Condition_{i,t})$$

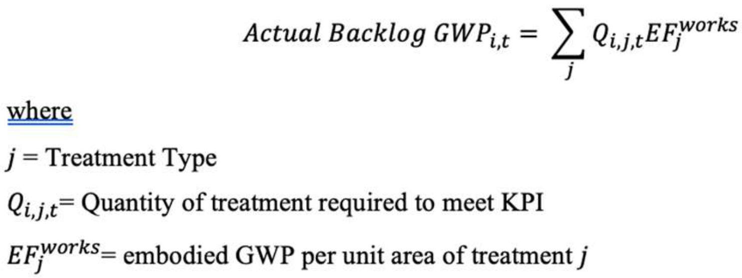
Where:

i = Road Section

t = Year (2014 – 2024)

EF = Emission Factor (kg CO_2e per vehicle-km) as a function of e.g. IRI

- The Actual Backlog GWP quantifies the embedded GWP cost to restore each section to the target condition at a given year:



$$Actual\ Backlog\ GWP_{i,t} = \sum_j Q_{i,j,t} EF_j^{works}$$

where

j = Treatment Type

$Q_{i,j,t}$= Quantity of treatment required to meet KPI

EF_j^{works}= embodied GWP per unit area of treatment j

METHODOLOGY

- Notional User GWP estimates the emissions had no improvement occurred. Baseline condition is taken from the year preceding treatment; deterioration is projected using TII’s Markov models:

$$Notional\ User\ GWP_{i,t} = Traffic_{i,t} \times EF\left(Condition_{i,t}^{notional}\right)$$

$$\begin{aligned} &Notional\ Increased\ Backlog\ GWP_{i,2024} \\ &\qquad = Notional\ Backlog\ GWP_{i,2024} \\ &\qquad - Actual\ Backlog\ GWP_{i,treatment\ year} \end{aligned}$$

- Thus, the historic GWP saving on section i is:

$$\begin{aligned} &GWP\ Savings_{i,2014-2024} \\ &\qquad = (Notional\ User\ GWP - Actual\ User\ GWP) \\ &\qquad + (Notional\ Increase\ Backlog\ GWP_{2024} \\ &\qquad - \ Actual\ Backlog\ GWP_{2024}) \end{aligned}$$

METHODOLOGY

- Thus:

$$Projected\ Actual\ User\ GWP_{i,t} = Traffic_{i,t}^{projected} \times EF\left(Condition_{i,t}^{projected}\right)$$

$$Projected\ Notional\ User\ GWP_{i,t} = Traffic_{i,t}^{projected} \times EF\left(Condition_{i,t}^{notional\ projected}\right)$$

- Then projected backlog in 2035 is computed analogously by comparing to network KPIs. The projected saving is then:

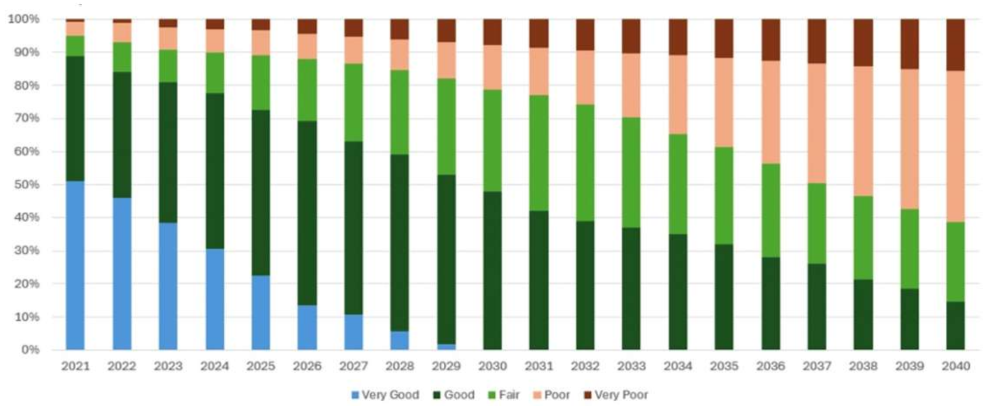
$$\begin{aligned} Projected\ GWP\ Savings_{2025-2035} &= (Projected\ Notional\ User\ GWP - Projected\ Annual\ User\ GWP) \\ &+ (Projected\ Notional\ Backlog\ GWP_{2035} \\ &- Notional\ Backlog\ GWP_{2024}) \\ &- (Projected\ Actual\ Backlog\ GWP_{2035} - Actual\ Backlog\ GWP_{2024}) \end{aligned}$$

- Final Total Savings are calculated as:

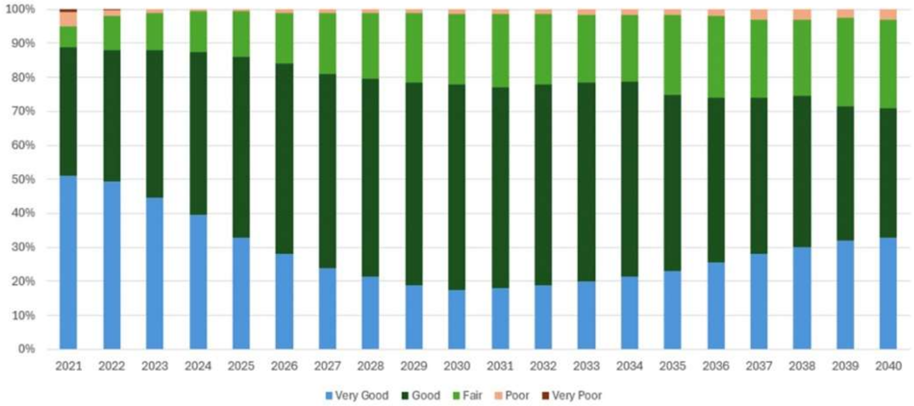
$$Total\ GWP\ Savings_{2014-2035} = GWP\ Savings_{2014-2024} + Projected\ GWP\ Savings_{2025-2035}$$

Traditional Life Cycle Optimisation Results

Considering Cost + Performance:



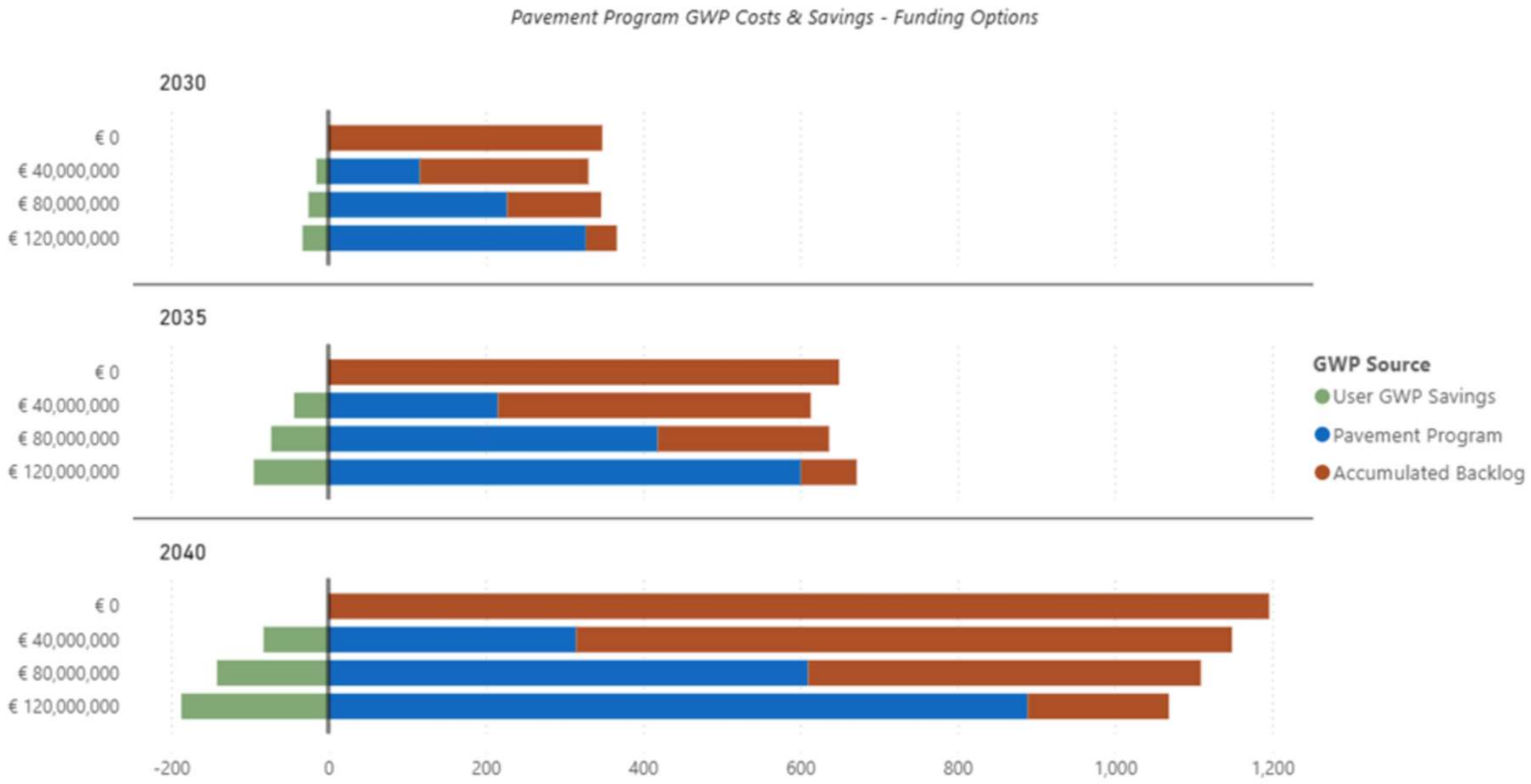
Do Nothing



Optimum €120ml p.a.

Results

Considering Cost + Performance + Carbon/GWP:



Conclusions

- Proactive pavement maintenance can deliver measurable life-cycle carbon savings.
- Benefits arise from:
  - **smoother surfaces reducing user emissions**
  - **avoiding or delaying carbon-intensive rehabilitation**
  - **limiting future backlog growth**
- The framework supports a three-dimensional decision basis:
  - **Cost**
  - **Performance**
  - **Carbon**
- It provides a repeatable network-level method for embedding carbon accounting in pavement asset management.

Thank you for your attention.

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Re-Generation
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