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Table of Contents

List of Figures

List of Tables

List of Abbreviations

Table 1. List of Abbreviations

Abbreviation	Definition
ADEPT	Association of Directors of Environment, Economy, Planning & Transport
BEIS	Department for Business, Energy & Industrial Strategy
BIM	Building Information Modelling
BSI	British Standards Institute
CE	Conformité Européenne (CE marking)
CEDR	Conference of European Directors of Roads
CEI	Circular Economy Index
CIWM	Chartered Institution of Wastes Management
c-PCR	Complementary Product Category Rules
CTI	Circular Transition Indicators
DfT	Department for Transport
DMRB	Design Manual for Roads and Bridges
DPP	Digital Product Passport
EAPA	European Asphalt Pavement Association
EC	European Commission
EPD	Environmental Product Declaration
ESCi	Environmental Sustainability and Circularity indicator
ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
GHG	Greenhouse Gas
HMA	Hot Mix Asphalt
ID	Identifier
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
M&R2	Maintenance and Response framework 2
MCHW	Manual of Contract Documents for Highway Works
MCI	Material Circularity Indicator
MPA	Mineral Products Association
P-AMS	National Highways Pavement Asset Management System
PD	Published Document
PMB	Polymer Modified Binder
QA/QC	Quality Assurance / Quality Control
RA	Reclaimed Asphalt
RFID	Radio Frequency Identification
SDF2	Scheme Delivery Framework 2
SMA	Stone Mastic Asphalt
SRN	Strategic Road Network
WM3	Waste Classification and Assessment - Technical Guidance, 3rd Version
WRAP	Waste and Resources Action Programme

Glossary

Table 2. Glossary

Term	Definition
Aggregate	Granular material of natural, manufactured or recycled origin used in construction [1].
Digital Product Passport	Digital record storing comprehensive, verifiable data about a product's entire lifecycle [2]. It is designed to include and build upon Environmental Product Declarations, using them as a core data source for a broader, dynamic digital record. DPPs include details on origin, supply chain information, materials, environmental impact, and any repair or recycling instructions for end of life. This information is linked via a unique ID.
Downcycling	Refers to those recycling activities that obtain recovered resources with a lower value than initially given [3].
End of life	In the context of asphalt, refers to the point at which asphalt is no longer suitable for its original purpose (e.g., as a road surface) and must be removed, stored, treated, recycled or disposed.
Reuse	Reuse is defined by the Environment Agency [4], as the following: • It is used for the same purpose for which it was designed – the use must not be subordinate or incidental to the original use • the previous holder intended for it to be reused • no repair, or no more than minor repair, is required to it when it is transferred from the previous holder to the new holder, and the previous holder knows this • any necessary repair is going to be done • its use is lawful • it is not managed in a way that indicates that it is waste, for example it is not transported or stored in a way that could cause it to be damaged.
Reclaimed Asphalt (RA)	Also referred to as Reclaimed Asphalt Pavement (RAP), refers to asphalt pavement that has been removed from its original installation and is intended for reuse, typically in new asphalt mixtures, classified in accordance with with BS EN 13108-8 [5].
Recycled aggregate	Aggregate produced in compliance with the *Quality Protocol for the Production of Aggregate from Inert Waste* [6].
Waste	Any substance or object which the holder discards or intends or is required to discard [7]. In the UK, the four environmental regulators generally take the view that all arisings from construction processes, including demolition and excavation, should be classed as waste [8].

Executive Summary

Through its Environmental Sustainability Strategy, National Highways has made optimising resource and energy use one of its nine priority areas, reinforcing its ambition to embed circularity principles operationally. Following the recent publication of CEDR and EAPA position papers and recognising similar challenges, the MPA and its members have demonstrated interest in joining forces to overcome current barriers and enable greater circularity in the sector.

In light of the above, AECOM was commissioned to perform a gap analysis on the concept of circularity for asphalt, reviewing literature, metrics, and hosting a workshop to identify challenges and opportunities for the sector to focus on.

Key outcomes include:

- The ISO 59004:2024 [3] definition has been amended to i) reflect stakeholder feedback, and ii) simplify the language so that it is more readily accessible for a non-technical audience. Although validation of its applicability is required, this provides a robust baseline and solid principles for defining circularity for asphalt.
- In terms of metrics, an initial literature review was conducted, analysing a total of 12 metrics. These were assessed for their applicability, effectiveness, and ability to monitor progress toward greater circularity over time. A shortlist, including metrics such as ESCi, MCI and others, was ultimately provided, as potentially applicable for asphalt.
- Based on findings from the literature and early engagement with key stakeholders, it was identified that Digital Product Passports (DPPs) present challenges but also opportunities to enable greater circularity for asphalt. However, significant gaps in data were identified. While deploying asphalt DPPs effectively may require considerable effort from the industry and clients, recent changes in EU regulations are likely to influence industry practice in the UK as well. Therefore, taking the lead and supporting these changes could effectively manage risk.
- Findings from the literature and outcomes from the industry workshop have supported the team to perform a gap analysis, outline key challenges and opportunities, and ultimately define priorities for National Highways and the supply chain to address going forward, to enable greater circularity for asphalt. In summary:

  Governance, standards, and definitions: Key opportunities for the asphalt sector exist in validating and refining the proposed definition of circularity through targeted case studies that advance National Highways and the MPA goals. In this regard, equipping the supply chain with clear guidance and training on circular economy and related terminology; and collaborating with standardisation bodies to enable better data collection and performance based requirements, could be beneficial.

  Data, metrics and knowledge: There are opportunities to modernise pavement related databases and build a trusted data-sharing model that balances the protection of IP with transparency. It is recommended piloting practical metrics (e.g., ESCi) to validate usability, close gaps, and establish robust circularity measures. In terms of DPPs, revisiting the 2014 RFID pilot with today's capabilities - e.g. advancements in BIM, pavement management systems, digital twins, blockchain, near field communication, and the internet of things - to prove how asset-held data can flow into existing systems and enhance accessibility could be beneficial.

  Operations and engagement: There is an opportunity to build on current industry best practice and develop an action plan to overcome practical barriers such as stockpiling, transport and site-level workflows. This is anticipated to involve both engagement with and taking learnings from: existing schemes, stakeholder engagement and recent trials performed on the SRN and local authority network.

  Commercials and strategy: The start of RIS3, and commencement of SDF2 and M&R2 frameworks - due to start in 2027 - present opportunities for National Highways to better embed circular economy principles into the asphalt sector. In this sense, prioritising the use of reclaimed asphalt and incentivising innovation through shared risk models can drive meaningful change in commercial frameworks.

This note provides a comprehensive overview of the current challenges and opportunities for enhancing circularity in asphalt, identifying key areas for future research. As the technical and regulatory landscape evolves rapidly, it is essential to recognise that these changes may shape the direction of circularity initiatives. Adopting a systems-thinking approach is crucial; therefore, timely reviews of technological advancements and regulatory developments, alongside insights from ongoing workstreams, should inform the implementation of recommendations. This work serves as a foundational starting point, demonstrating that by focusing on a select few priorities, the sector can better align its practices with circular economy definitions and principles. Ultimately, this alignment will facilitate greater circularity for asphalt and support National Highways and the MPA in achieving their ambitious sustainability goals.

1 Introduction

National Highways is committed to optimising resource and energy use as part of its Environmental Sustainability Strategy, and aims to embed circularity principles by reusing materials, treating waste as a resource, and integrating a whole life approach into design and maintenance standards by 2030 [9]. Similarly, the Mineral Products Association (MPA) and its members support circularity as a key lever in reducing greenhouse gas (GHG) emissions and supporting net zero goals. These efforts align with European initiatives by the Conference of European Directors of Roads (CEDR) [10] and the European Asphalt Pavement Association (EAPA) [11, 12].

In recent years, National Highways' approach has intentionally shifted in focus from new construction to maintenance [13]. This transition emphasises the importance of sustainable practices in pavement management, particularly in leveraging circular economy principles to conserve finite resources and avoid negative environmental impacts.

Considering that a high proportion of the pavements that constitute the Strategic Road Network (SRN) are made of asphalt, National Highways and the MPA have commissioned AECOM to research into the circularity of the material and explore ways in which greater adoption of circular economy principles could support them in achieving their objectives.

Encouragingly, the current state of the asphalt industry shows that it has effectively integrated the use of recycled asphalt into its standards and practice. This is facilitated by a relatively closed system, where asphalt is produced by a relatively limited number of manufacturers, transported to specific locations, and still eventually replaced at the maintenance stage by asphalt containing (or not) recycled material, both of which have demonstrated to enable manufacturers and contractors to achieve the level of performance required in standards [14].

Additionally, international experiences – such as the Low Emission2 Asphalt Pavement (LE2AP) project in Netherlands, the MURE (Multi-Utilisation/recyclage des Revêtements Enrobés - Multi-recycling of Asphalt Mixes) and “La route 100% recyclée” A10 in France – have demonstrated that high contents of reclaimed asphalt (RA) can be successfully incorporated into bituminous mixtures, over multiple lifecycles, beyond current UK standard practice [14, 15].

Although recent updates to MCHW CC 202 “Flexible pavement construction” [16] have tried to eliminate any direct limits on the amount of RA that can be used in construction, focussing on performance, there are still references made to BS EN 13108-8:2016 [5] and PD 6691:2022 [17] Table 1, which set stringent thresholds on RA content and laboratory test requirements, that can generate confusion and potentially represent a barrier for industry to embrace greater circularity.

Beyond the technological and standards related challenges, there is some agreement within industry that there are regulatory, commercial, data collection and transparency related challenges that currently affect the way circularity principles are applied within the sector and that require broader stakeholder engagement and consensus to be achieved.

In consideration of the above, this work aims to explore the existing challenges and opportunities, as well as potential strategies road authorities and supply chain shall embrace in order to enhance greater circularity for asphalt in roads.

1.1 Project aim

The overall aim of this research is to investigate the interpretation and application of circularity principles to asphalt. Although findings could be potentially applicable to a wider context, focus of the present study is on the asphalt used on the SRN, that exists within the pavement asset, and that could be regarded as a resource to be recovered during future maintenance or enhancements to roads.

This research encompasses a review of circularity principles and aims to identify a suitable definition and circularity metric for assessing circularity for asphalt. Its findings are intended to inform future research projects, such as to implement appropriate data capture points and metrics across the pavement lifecycle, enable change where greater opportunities for circularity exist and estimate its secondary benefits in terms of e.g. carbon reduction potential.

1.2 Scope

To achieve the objectives of the project, the list of tasks outlined in Table 3 was undertaken.

Table 3. Scope of works

Tasks
Task 1 Circularity Definition and Principles: Review of standards and the work from non-governmental organisations and road authorities in other countries covering circular economy definitions. The various definitions of circularity have been mapped against current standards, processes and product lifecycle of asphalt pavements, to develop a draft definition and list of principles relevant to the asphalt sector and to support gap analysis (Task 5).
Task 2 Metrics: Literature review to identify metrics that could be suitable for evaluating circularity for asphalt and track progress towards improved circularity over time. This has included reviewing data requirements, in terms of source, quality and repeatability in relation to the metrics considered.
Task 3 Industry Workshop: Representatives of road managers, industry, contractors and consultancy were invited to the workshop, to cover for the widest and yet relevant range of perspectives and discuss findings (see Appendix D).
Task 4 Digital Product Passports: Review current and emerging requirements that can impact the recyclability of asphalt, particularly for reuse in the surface course, and provide an evaluation of the benefits, drawbacks, opportunities and challenges of introducing digital product passports or similar solutions – particularly for polished stone value (PSV). This has included considerations on historic data, effect of polishing over time and other data collection related factors.
Task 5: Gap Analysis: Carry out a high-level gap analysis of the existing asphalt management practice of England to identify where the most significant opportunities may be for improving circularity and enhancing the collection of supporting data. This has highlighted areas where future research may be most beneficially focussed.
Task 6: Reporting: Collate the outputs of the previous tasks into this Technical Note outlining the proposed framework for asphalt circularity, results of the performed gap analysis and identified priorities for the sector.

2 Circular Economy Definition and Principles

2.1 Context

To define circularity for asphalt, it is essential to first assess the current state of circularity practices. This understanding helps identify how existing principles are applied and how a refined definition can advance the circularity agendas of both National Highways and the MPA.

In order to do this, the lifecycle stages of asphalt and its associated activities have been mapped against the circularity definitions and principles and discussed with workshop stakeholders - a further breakdown of this is provided in Appendix A. Themes that emerged from the assessment, that were considered when evaluating an appropriate definition, include:

- In the UK, the asphalt lifecycle operates as a relatively closed system. Unlike typical consumer products, asphalt is produced by a relatively limited number of manufacturers, it is often recycled locally, or goes to specific, regulated locations such as aggregate manufacturers or permitted recycling facilities, where it can be reprocessed. All steps are documented through mechanisms like waste transfer notes, enabling traceability and compliance with UK regulations. This structured approach, combined with the limited number of producers creates a controlled and largely ‘closed’ recycling loop, where materials are replaced almost like-for-like.
- The recycling of asphalt is commonplace across the industry and is typically undertaken once the functional performance in a given pavement layer - at the surface or deeper within the pavement - has expired, necessitating a replacement (subject to maximum RA content and performance requirements).
- Downcycling refers to those recycling activities that obtain recovered resources with a lower value[1] than initially given. This typically occurs due to traffic and environmental loads, making e.g. bitumen oxidise and partly lose its ability to adhere to the aggregates, and aggregates polish to compromise their frictional properties. There are also operational and commercial factors, such as the ability to store large quantities of materials off site, which can restrict the preservation of high-quality materials for long periods of time, resulting in downcycling.
- Previous experience, e.g. with coal tar, highlighted that unintended consequences must be considered. For example, the use of novel materials could potentially impact future recyclability, and the use of biogenic

[1]ISO 59004 defines value as being broader than monetary value. It is defined as follows: *gain(s) or benefit(s) from satisfying needs and expectations, in relation to the use and conservation of resources. Value is relative to, and determined by the perception of, those interested party(ies) able to capture it. Value can be financial or non-financial, e.g. social, environmental, other gains or benefits. Value is dynamic over time.*

materials could impact land use conversion, and so a systems thinking perspective is imperative when considering a definition.

2.2 Circular economy definition for asphalt

A summary of our approach to reviewing circularity definitions and their associated principles is provided in Appendix A. Of the circularity definitions and principles reviewed, ISO 59004:2024 [3] was selected as the most appropriate definition. The ISO 59004 is a globally recognised standard, and so its selection provides credibility. Other definitions were reviewed and agreed to either be too broad, missing sector nuances, and/or contained reference to activities that were not perceived to be as relevant to asphalt.

In addition, ISO 59004's recognition of 'the circular flow of resources will be kept as closed as possible' was also agreed with stakeholders to be pertinent to asphalt – given it's already relatively closed nature, as well as it's recognition of recovering, retaining or adding to asphalt's value - which are activities that would support the elevation of current approaches towards asphalt (e.g. by avoiding downcycling).

The ISO definition was subsequently amended to i) reflect stakeholder feedback, and ii) simplify the language so that it is more readily accessible for a non-technical audience. Figure 1 shows the proposed working definition for asphalt, with proposed removals in ~~strikethrough~~, and suggested additions in *italics*.

Figure 1. Proposed working definition of circularity for asphalt

"The circular economy is an economic system that uses a systemic approach to ~~maintain a circular flow of resources~~ *keep resources* in use for as long as possible*, by recovering, retaining or adding to their value, ~~while contributing to sustainable development~~ "**

- *Resources can be considered both stocks and flows of materials.
- **The inflow of virgin resources ~~is kept as low as possible~~ *should be optimised*, and the circular flow of resources will be kept as closed as possible to minimise waste, losses and releases from the economic system."

2.3 Circular economy principles for asphalt

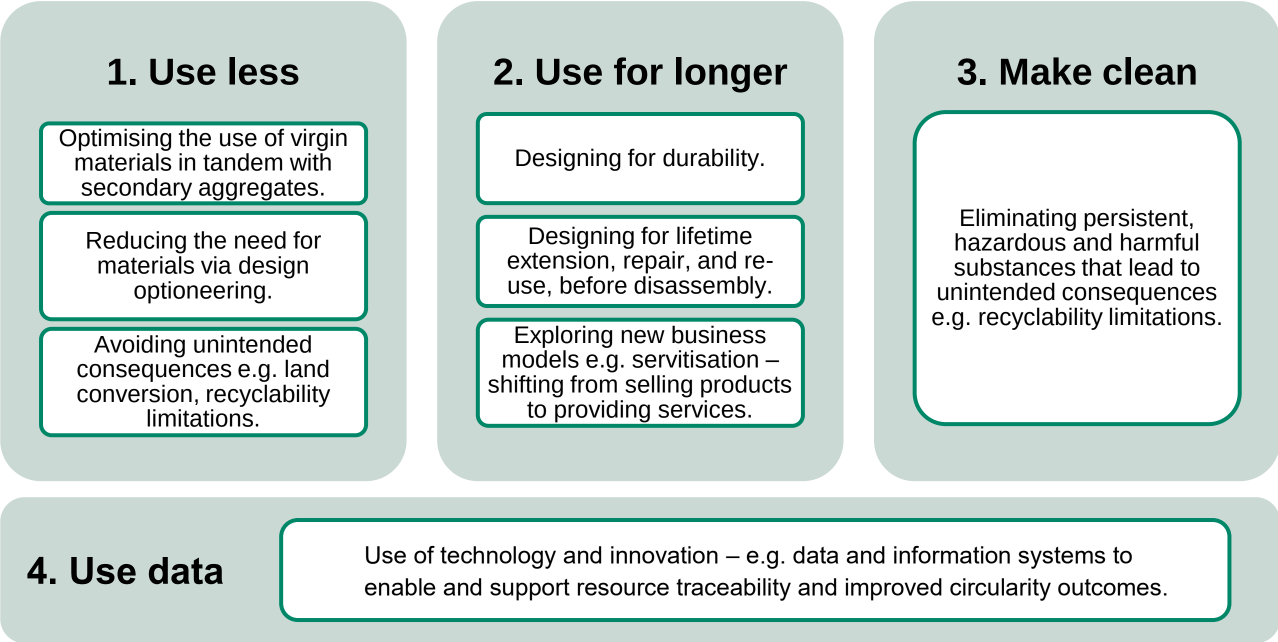
When considering the circular economy principles that apply to asphalt, the Delft University of Technology Circularity Deck [18] is used as a framing tool. The Circularity Deck builds upon established circular economy models, such as the globally recognised work of the Ellen MacArthur Foundation, whilst aiming to remove any ambiguity in terminology through five principles that avoid jargon.

Whilst much of the literature on circular economy lacks applicability [19], the Circularity Deck is specifically designed for business use, providing solution-oriented guidelines that serve as an effective framework without overwhelming those unfamiliar with the intricate nuances of circular economy concepts. Given how relatively new the asphalt industry is in relation to circular economy related terminology and application frameworks, associated data capture and overall implementation of circular economy principles, using straightforward language is essential for clarity and ease of understanding.

Figure 2 shows the working circular economy principles for asphalt, the key actions associated with these principles considered information from other circular economy definitions in combination with workshop engagement, for more details on how these were narrowed down from the full list of circular economy principles please see Appendix A.

It should be noted that one of the Circularity Deck's principles "use again" was not included, as it was felt that this was an already well-established activity and an expected 'minimum' across the sector.

Figure 2. Working circular economy principles for asphalt



The recommended working definition and principles are also supported by:

- National Highways existing ambitions to "have a whole life cycle understanding of the flow of materials through our activities" and its plans to integrate "material flows" into relevant design and maintenance standards [9].
- The MPA's position that "asphalt is 100% re-usable and recyclable back into asphalt and other road construction applications and understanding the UK industry needs to drive towards the production and use of more sustainable and environmentally friendly asphalts, through increased use of recycled materials and targeting reductions in energy use to contribute towards the national net-zero targets".
- Industry position papers and guidance encouraging the use of RA, design for reuse, and adoption of higher recycling rates in the construction, maintenance and renewal of road pavements [11, 12].
- The UK Government's Net Zero Strategy ("Build Back Greener") which calls for decarbonising construction materials and accelerating a circular resource-efficient economy "Net zero will mean maximising the value of resources within a more efficient circular economy", providing policy-level support to "use less", "use for longer" and "make clean" principles [20].

3 Circularity Metrics

3.1 Introduction

To evaluate and track the progress of circularity for asphalt, an initial literature review was conducted, analysing 12 metrics. These metrics were assessed for their applicability, effectiveness, and ability to monitor progress toward enhanced circularity over time. Key considerations included data requirements, such as sources, quality, and repeatability (i.e., ensuring the methodology can be consistently applied by different users).

A full assessment is provided in Appendix B.

While several metrics show potential for adaptation to asphalt and some capture broader environmental factors, the review revealed a significant gap in their application to real-world, asphalt-specific contexts. As a result, no single metric emerged as a definitive choice for the MPA and National Highways at this stage. It is recommended that the shortlisted metrics be tested on real-life projects to evaluate their practicality and inform subsequent baselining efforts.

3.2 Summary of shortlisted metrics

Table 4 provides an overview of the shortlisted metrics, highlighting their respective strengths and weaknesses.

Table 4. Shortlisted metrics and their respective strengths and weaknesses (summarised from Appendix B)

Metric	Strengths	Weaknesses
Environmental Sustainability and Circularity indicator (ESCi) [21]	• Combines circularity principles and Life Cycle Assessment (LCA) for a unified evaluation of circularity and environmental impacts. • Peer reviewed, ensuring scientific rigor. • Specifically designed for asphalt, addressing closed-loop systems and performance metrics (e.g., resistance to fatigue). • Comprehensive: evaluates virgin and recycled material use, waste management outcomes, and performance under stress.	• Lacks a practical tool for implementation, requiring further development for consistent application. • Utility factors obtained via testing. • No real-world applications to date. • Cradle-to-gate assessment only: Further research is required to explore potential expansions if deemed beneficial.
Material Circularity Indicator (MCI) [21, 22]	• Peer-recognised and ISO-aligned, ensuring credibility. • Transparent, publicly available methodology with open-access calculations. • Quantifies material flows, recycled content, product lifespan and end-of-life recovery. Interim metrics pinpoint hotspots and improvement opportunities along the value chain. • Factors in durability, repair, reuse, redistribution, and frequency of use - key for infrastructure assets such as asphalt pavements with multiple maintenance cycles. • Incorporates material loss factors to reflect real-world inefficiencies and leakage. • Calculations can be automated in common tools like Excel. • Applicable to complex, multi-material products like asphalt mixes • Includes complementary risk and impact metrics for robust decision-making.	• Generic, not tailored to asphalt. • Assumes recycled materials are of equivalent quality to virgin materials. • Primary methodology overlooks supply chain material losses (though an expanded version address this).
Circular Transition Indicators (CTI) [23]	• Created, tested, and reviewed through a collaborative process involving industry, non-governmental organisations and academia, ensuring broad acceptance, relevance, and comparability. • ISO and reporting standards alignment: Designed to comply with ISO 59020 and other corporate reporting frameworks, including the GHG Protocol, enhancing its credibility and applicability. • Modular approach: includes 'Close the loop' and 'Optimise the loop' modules applicable at both organisational and product levels, allowing for tailored assessments. • Focus on material flows explicitly tracks material inflows and outflows, and value-retention pathways, giving clear visibility of where materials circulate or leak. • Integrated environmental metrics incorporates modules to estimate emissions and broader environmental impacts, enhancing the understanding of circularity beyond material flows alone.	• Generic, not asphalt-specific. • Paid online tool limits accessibility. • Primarily designed for organisational-level assessments, though adaptable for products. • Self-assessed methodology would benefit from independent verification.

3.3 Detailed analysis of metrics

3.3.1 Sector specific vs. generic metrics

Several metrics reviewed were originally designed for application in the building sector, such as the Building Circularity Indicator (BCI) [24], Circular Construction Evaluation Framework [25], and the Madaster Circularity Indicator [26]. Due to their tailored nature, it is apparent that some aspects of these metrics are not wholly relevant to asphalt circularity. For instance, all three assess the functional lifecycle of various building layers (e.g., site, structure, skin, services, space plan, and furnishings), which do not translate to asphalt applications. While these metrics may have the potential for adaptation to the asphalt context, their application would require effort to unpick and modify.

In contrast, sector-agnostic metrics like the MCI may offer a more straightforward approach. For example, both the BCI and Madaster metrics are based on the MCI indicator but have been expanded to address the specific needs of the buildings sector. A similar adaptation has already been applied to pavements, where the MCI indicator has been tailored for this context [27]. As a result, these building related circular economy metrics were not considered suitable for further development in the context of asphalt circularity.

3.3.2 Review of pavement-specific tools

The review also considered sustainability tools developed for pavements to assess their relevance to circular economy principles and metrics. This included the CERCOM Risk Based Assessment Framework (RBAF) tool [10], asPECT [28], PavementLCM [29] and CIROAD [30]. However, some of these tools were not originally designed with either circularity or material (asphalt) level assessment as a primary focus, leading to their exclusion from further consideration due to their limited ability to effectively track circularity improvements. For instance:

- The asPECT tool calculates the carbon footprint of asphalt mixtures used on the SRN and seems intended for use by designers and probably asphalt producers. However, it does not currently account for waste generated during manufacturing and construction, excludes impacts during the use phase (such as maintenance), and relies on generalised assumptions regarding the end-of-life of asphalt materials.
- The CIROAD evaluation model [30] was designed to assess the environmental, social, and economic circularity for road projects, including the evaluation of enabling technologies. While this broader systems-level approach is valuable, its application to asphalt products presents challenges. The methodology is notably complex, employing an Analytic Hierarchy Process that lacks transparency, based on the initial review. Additionally, the model is tailored to the Chilean-specific context, which restricts its applicability in other regions (see Appendix B).

3.3.3 Metrics with relevance to pavements or infrastructure

Two metrics were found to be most relevant to a pavements or infrastructure context:

- Circular Economy Index (CEI) [31]: measures the ratio of the material value generated by the recycler (market value) to the intrinsic material value of materials entering the recycling facility. It was recognised as relatively straightforward for the industry to adopt, given the limited number of data points required for its calculation [21]. Additionally, the CEI showed potential in addressing the challenge of downcycling. However, the index was ultimately deemed unsuitable for broader application. Key concerns included the variability in market values and the influence of supply and demand on pricing, which could undermine its reliability. Furthermore, the CEI fails to adequately capture the benefits associated with using higher percentages of RA and implementing low-emission technologies, both of which are critical for advancing sustainable practices in the industry.
- CB’23 [32] was developed collaboratively by Dutch public agencies and industry partners as a metric intended for use across all construction sectors. It produces a suite of individual indicators rather than a single composite metric. While the framework has notable strengths—such as its clear reference to LCA module stages, provision of environmental protection indicators, and the availability of supporting guidance and calculation tools—it was acknowledged that its application to asphalt may be premature. Much of the documentation and toolkit remain available only in Dutch, guidance on interpreting results is limited, and initial testing has revealed unresolved methodological challenges and complexities. Accordingly, it was concluded that this metric should not be taken forward at this time.

3.4 Broader considerations and challenges

Some circularity metrics adopt a multi-level approach, addressing material, product, and system-level circularity. While this perspective could be relevant for future asphalt-specific metrics, further discussions are needed to align with broader stakeholder objectives and clarify the scope of development.

Furthermore, from the early stakeholder engagement performed as part of this task, more challenges have emerged, e.g. data availability and the need for capacity development, which highlight potential barriers to implementation. Addressing these issues will require:

- Establishing clear definitions and guiding principles for asphalt circularity.
- Ensuring data quality and accessibility, as data is a fundamental enabler of circularity progress.

In order to address these issues, Chapter 5 outlines a series of recommended next steps aimed at bridging these gaps and facilitating the successful adoption of the proposed metrics. The challenges surrounding data availability emphasise the critical importance of establishing a clear definition and guiding principles for asphalt circularity – as data serves as a fundamental enabler in driving progress towards circularity goals.

4 Digital Product Passports

A Digital Product Passport (DPP) is a digital record storing comprehensive, verifiable data about a product's entire lifecycle [2]. This is a structured, standardised dataset that travels with a product and captures its key attributes throughout its lifecycle.

Primarily driven by the EU's Ecodesign for Sustainable Products Regulation (ESPR) [33], DPPs have been proposed to boost transparency, sustainability, and circularity of products. These include and build upon Environmental Product Declarations (EPDs), using them as a core data source for a broader, dynamic digital record. Linked via a unique ID, they include details on origin, supply chain information, materials, environmental impact, and any repair or recycling instructions for end of life, enabling more informed choices.

Despite growing adoption in the building sector, the application of DPPs in road infrastructure remains limited [34]. A review of current literature revealed limited practical examples of DPPs in asphalt applications, with Senarathne *et al*. [34] that recently proposed a roads specific passport framework (see Appendix C).

The proposed framework provides a comprehensive blueprint for capturing critical pavements-related data, including general, condition, mechanical attributes, and environmental information. It is structured into three hierarchical layers, which effectively differentiate between pavement components:

- Product Level – Focuses on scheme or road sections level.
- Layer Level – Considers the surface, binder, base, sub-base and subgrade layers of a pavement.
- Material Level – Covers materials such as binders, aggregates, fillers, RA, lime, cement, fly ash, crushed rock, steel reinforcement and additives.

The proposed DPP framework outlines 130 attributes. While some of these data points should be readily available from existing information sources, such as National Highways' Pavement Asset Management System (P-AMS), there is work to do to better define whether stakeholders can efficiently adopt the framework without significant additional resource demands, to enable a streamlined approach to capturing detailed data to input in DPPs.

4.1 The role of data and information management systems to enable PSV DPPs

The effective implementation of DPPs relies on the availability of complete and most importantly reliable information. This is essential for ensuring policymakers, the supply chain and wider stakeholders can trust the information received and make decisions from it. On its own, a DPP has limited value: if the data are inaccessible, poorly governed, or inconsistently stored, the goals of transparency, regulatory compliance, end-of-life recovery, and CE reporting, cannot be achieved. In fact, in order to deliver their intended value, DPPs must be supported by a coherent, secure, and interoperable data sharing platforms that store, maintain, and integrate data across the full product lifecycle. In this sense the role of robust and secure Information Management Systems (IMS) is key.

IMS are defined as a structured and systematic approach to managing the entire lifecycle of data—from its initial collection and storage to its organisation, retrieval, and final destruction. In this context, P-AMS constitutes a centralised cloud-based solution to manage information related to pavements on the SRN. This enables National Highways and its supply chain to collect, analyse and manage data about pavements, provide support for operational decision making and support strategic planning and forecasting, ensuring pavement data is integrated into whole lifecycle asset considerations under a unified data model. The research conducted by Senarathne *et al*. [34] emphasises that the framework necessary for enabling road DPPs must encompass a broader scope than what the current P-AMS offers. This is particularly important given that P-AMS was not originally designed to facilitate decisions aligned with circular economy principles. Nevertheless, P-AMS has the potential to serve as a valuable source of information for the future implementation of DPPs within the asphalt sector.

However, it is important to acknowledge that current P-AMS may have limitations, particularly concerning their level of detail and flexibility for modification, which could hinder the potential to leverage P-AMS for DPPs in the near term. Further to that, limitations include the inability to obtain data that is typically held exclusively by manufacturers, due to commercial and intellectual property. To address these challenges, it is essential for stakeholders to reach a consensus on establishing new minimum data-sharing requirements, to enhance transparency, support the adoption of DPPs and ultimately enable greater circularity for asphalt.

4.2 Technology as a potential enabler for DPPs

Based on the discussions had during the industry workshop (see Appendix D), a significant challenge for the sector is currently related to retrieving data on pavement properties in situ.

While practical examples of infrastructure-based DPPs remain limited, an early study by Cook and Crabb [35] demonstrated the feasibility of embedding Radio Frequency Identification (RFID) tags in asphalt mixes. This is wireless technology that uses radio waves to imprint information into objects, vehicles, structures, documentation or even living beings, through a tag, allowing data to be read remotely without physical contact or line of sight, which have found extensive applications in sectors like retail, healthcare, and logistics [36]. The study by Cook and Crabb [35] showed that RFID tags could be integrated into pavements in production, and that the information remained readable after mixing, transport, and compaction phases.

Although early findings seem to highlight RFID as a practical tool for capturing and storing material-related information directly on-site, offering insights into survivability and workflow integration, there are several critical questions that currently remain unanswered concerning the long-term readability of RFID tags, readability at depth, recoverability of embedded tags, secure addition or modification of information on the tags, and impact of the RFID tags on recyclability. In addition, the associated costs in tag implementation remain unclear. These uncertainties reduce the immediate appeal of adopting RFID or similar technologies in pavement applications and indicate the need for further research/trials.

Subsequent developments in Building Information Modelling (BIM), pavement management systems, and the advent of new technologies such as digital twin, blockchain, and the internet of things (IoT), present opportunities to overcome the technical obstacles encountered by RFID, and provide more rigorous ways to store and access data.

Overarchingly, a higher priority for the sector at present should be to improve the completeness and accuracy of underlying data, such as that contained in pavement management systems as the foundational source of information for any technology the sector may end up adopting to support the deployment of DPPs for asphalt. Focussing on National Highways, although the primary purpose of P-AMS has never been to capture circularity or carbon-related data, the growing importance of sustainability in pavement asset management suggests that it could be worthwhile to explore how such information could be integrated into future systems, which could potentially support a smoother transition towards greater circularity for asphalt.

4.3 Performance requirements and safety considerations

DMRB CD 236 [37] and MCHW CC 202 [16] set the performance standards for the use of materials in the construction of flexible pavements, including RA. From a safety perspective, one key requirement for surface course asphalt products is around the ability of the aggregate to retain its Polished Stone Value (PSV), or in other words its microtexture, after abrasion due to trafficking in operation. From a circularity perspective, it is key that data about the way PSV evolves and how that affects the future reuse or recycling of asphalt is available. In fact, if asphalt DPPs were to be established, it could be key that this information is included, to possibly ease any requirements on further testing.

It is understood that the portion of aggregates that are in direct contact with traffic are subject to polishing and can lose their characteristic microtexture or contribution to skid resistance at low speeds. In this regard, there are still unanswered questions that impede asphalt always being recycled and extensive laboratory tests are required before the material can be reused, i.e.:

- **a. Location.** Where has high PSV aggregate been used and where is it required on the SRN?
- **b. Durability.** Is the original PSV maintained throughout a surface's life and to what degree does it change, i.e., after polishing?
- **c. Thresholds.** Can satisfactory microtexture be achieved only up to a certain RA content threshold?
- **d. Performance.** Practically, what needs to be implemented in terms of quality protocols to enable better understanding of performance in terms of PSV and ultimately greater circularity?

In regard to these questions, a search through existing literature has highlighted that:

a) Location. Analysis of P-AMS data by Wright *et al*. [14] has showed that the network has a high volume of high-quality PSV aggregate. However, the study has made clear that P-AMS has significant gaps, with no data on PSV or nominal aggregate size for 43% and 49% of lane kilometres respectively, meaning that data cannot always be relied upon to characterise RA and support its reuse in future roadworks. This gap in existing PSV data has been recognised as a barrier to increasing RA levels in surface course materials, requiring additional resources and testing [38].

b) Durability. Research has shown that skid resistance generally falls from the high "as-laid" level toward a lower equilibrium as traffic abrades the microtexture; the rate depends on traffic volume, climate and aggregate type [39]. In fact, typical UK surface course materials exhibit an initial increase in skid resistance for the first 6–12 months, followed by a gradual decline towards their limit [39]. Specifically to PSV, Roe and Hartshorne [40] found that newly laid materials (no RA content) exhibit 5 to 10 unit drops in PSV for heavily trafficked roads within five years, which then tends to stabilise. Although, different mixture types and aggregate particle sizes were tested, it is currently unclear to what degree the results from this research are relevant to modern materials and construction techniques.

c, d) Thresholds and Performance. Looking into the inclusion of RA into new mixes, Dunford [41] evaluated surface course mixes containing RA from existing high-PSV surface layers. The results from tests performed over a single cycle of recycling showed that mixtures with 30% RA by mass of aggregate showed no statistically significant reduction in the resulting skidding resistance when compared with control mixes containing solely virgin aggregate. However, what the implications of inclusion of previously polished aggregate in new asphalt mixes, and the effects of that to the resulting skidding resistance, over multiple cycles, are unclear. Therefore, historically, limits of 10% to 20% have been imposed, requiring rigorous testing, which currently remain standard practice [5, 17].

With the aim to push more sustainable practice in road construction, the recent ADEPT guidance [8] recommends project-specific risk assessment and appropriate experts being consulted as necessary, with ≥40% RA contents that have been considered acceptable on low-to-medium-speed roads where skidding resistance requirements (or investigatory levels) are lower, but no specification or quality assurance protocol has been established yet.

Furthermore, looking at the results from trials conducted by National Highways themselves, it is apparent that RA contents up to 50%, are technically feasible, with materials that meet both the due safety and mechanical performance requirements [14, 42]. This seems to imply that the current RA content thresholds imposed are limiting and that more performance based requirements – possibly dependent on the quality of the material recycled and the number of cycles this has been subject to – could be established, to enable greater circularity.

From a practical perspective, four key gaps/opportunities emerge:

1) Knowing the source and the original specification requirements of any RA is key to enable its recyclability, especially when reuse is intended for the surface course [41]. In this regard, being able to access this information directly from site could enable more in-situ recycling than currently is practicable.
2) When the properties of the RA are not known, two options arise: i) stick to the current 10%-20% limits, and related testing, recommended in BS EN 13108-8:2016 or ii) perform the necessary in-depth investigations to identify the appropriate virgin aggregate to RA blend that allows to meet the specification [41].
3) In terms of durability, there is currently little to no data or understanding to what the effect of multiple recycling cycles of the same RA is on PSV and resulting skidding resistance. In this regard, use of the Wehner-Schulze machine has demonstrated potential to provide this information [43].
4) Although research and testing are required to fill some gaps in knowledge, i.e. on durability and recyclability, and historical data [14], there is an opportunity to expand on the scope of pavement management systems to become the sole industry point of reference for collecting data on e.g. material properties, number of recycling cycles the RA was already subject to and shareability of resources in between sites, that could enable better transparency and greater circularity.

4.4 Next steps for implementation

From a regulatory perspective, the ESPR [33] is now in effect, with forthcoming delegated acts expected to clarify the scope of DPPs. In alignment with the broader environmental goals of the ESPR, the revised Construction Products Regulation (CPR) of 2024, which came into effect in 2025 and first applied starting from January 8, 2026, mandates environmental data reporting through the use of DPPs for construction products. Moreover, the UK Government published its Construction Product Reform White Paper on 25 February 2026 (currently open for consultation) [44], proposing broad alignment with the EU's environmental and sustainability standards. These developments are likely to accelerate the integration of DPPs in construction and pavement applications. From this perspective, National Highways and the supply chain face two strategic options:

1) Reactive alignment: Both choose to monitor the current transition and align their requirements to European standards adopting (or adapting) industry best practices from other countries.
    a. Advantages: This approach minimises immediate effort and resource allocation.
    b. Challenges: It could delay progress towards strategic sustainability goals, hinder innovation, and result in both falling behind as global sector leaders.
2) Proactive engagement: Both actively collaborate with European counterparts and standardisation bodies, leveraging local expertise to facilitate knowledge transfer and drive change.

a. Advantages: This approach enables National Highways and the supply chain to set new benchmarks, accelerate progress toward sustainability goals and enhance their leadership reputation.

b. Challenges: It requires greater investment in resources and expertise.

Regardless of the approach taken, input from key stakeholders such as members of the MPA, will be crucial in defining a clear roadmap and successfully implementing DPPs within the UK, particularly for the asphalt industry.

5 Gap Analysis

Following analysis of existing practices for asphalt management in England (including stakeholder feedback and research), Table 6 presents a high-level gap analysis, highlighting where the most significant opportunities may be for improving circularity and enhancing the collection of supporting data for asphalt.

In order to support subsequent prioritisation of these opportunities, significance has been defined at a high level in terms of impact and effort (see Table 5). Recommendations as to where future research may be most beneficial are described in Section 5.1.

Table 5. Prioritisation scoring

Impact	Effort
Low - Minimal or localised benefit, limited alignment with strategic goals.	Minimal cost time, or change, straightforward implementation.
Noticeable benefit to multiple stakeholders; supports strategic goals.	Moderate resources, co-ordination or change required.
Significant industry wide benefit, strongly advances strategic goals.	High cost, multistakeholder co-ordination, or major process/ tech changes.

Table 6. Gap analysis

Challenge	Identified Gap	Opportunity	Impact	Effort
Governance, Standards, and Definitions	• Lack of standardised definition and principles	• Demonstrate the applicability of the working circularity definition and principles for Asphalt. In this regard development of a case study could help gather the necessary evidence to validate the suitability of the proposed definition, or inform suitable changes, that can drive both National Highways and the MPA's goals.	🟨	🟩
	• Lack of industry specific guidance	• Develop Guidance Document and Training Materials which sets out circular economy and waste terminology for key industry stakeholders (e.g. the supply chain), to provide clarity, consistency and avoid ambiguity.	🟩	🟨
	• Current regulations increase the risk of downcycling for asphalt	• Engage with regulators to understand the current constraints which classify waste, requiring extensive testing and operational adjustments to avoid downcycling (investigation into records of coal tar on the SRN is underway).	🟩	🟥
	• Lack of performance based requirements for RA	• Continue to engage with standardisation bodies and technical committees, in relation to as BS EN 13108-8, utilising existing evidence base to update the performance as well as data requirements for mixture containing high proportions of RA.	🟩	🟥
Data, metrics and knowledge	• Incomplete or inaccurate historical data	• A review of existing data systems across the lifecycle of pavements e.g. P-AMS, resource planning systems, emerging circularity platforms and associated governance should be performed. This would help to understand availability, completeness and accessibility of material and asset data, and improve transparency.	🟩	🟨
	• Little circularity-specific data available	• Research / engagement with other sectors and industry leaders (e.g. Netherlands) to identify best practices in circularity-related data collection and sharing.	🟩	🟨
	• Concerns on product IP and consequent low transparency	• Undertake concerted stakeholder engagement with asphalt producers/ commercial stakeholders to effectively balance protection of proprietary knowledge with the sector's need for sufficient transparency to enable decision making.	🟩	🟩
	• Lack of metrics and industry goals	• Using a pilot or an upcoming project to apply the identified suitable metrics, such as ESCi. This would test the practical application of the metric, identify potential gaps, and inform the subsequent establishment of a practical circularity metric.	🟨	🟨
	• Europe DPP route map and requirements • Lack of standardised data reporting • Inconclusive previous research	• Expand on the early 2014 pilot study on RFID technology, incorporating subsequent advancements in technology (e.g. internet of things devices) and digital solutions (e.g. advancements in BIM, pavement management systems and digital twin). This could help National Highways and the MPA better understand how DPP information could be stored within or accessed while standing by the physical asset to enable greater circularity for asphalt.	🟩	🟨
	• Unclear definition of service-life	• Extending service life reduces replacement cycles, materials demand, and disruption. Apply advances in road condition monitoring and data analytics to a pilot study, to identify the circularity, GHG, and cost impacts.	🟨	🟥
	• Unclear understanding of the impact of foreign matter on future recyclability	• Undertake further research into the application of novel materials into roads and the potential for unintended consequences.	🟨	🟩
Operational	• Low understanding of operational requirements	• Build on current industry best practice and develop an action plan to overcome practical barriers such as stockpiling, transport and site-level workflows. This is anticipated to involve both engagement with and taking learnings from: existing schemes, stakeholder engagement and National Highways trials will be key to identify and illustrate case studies to demonstrate both challenges and successes within industry.	🟩	🟨
Commercials	• Lack of circular economy metrics in contracts	• Commercial frameworks often determine whether circular solutions are even considered. Update contracting and procurement practices to: – Make RA the primary choice in new contracts. – Enable circular options ensuring that there is continuity with other sustainability priorities, to enhance value. – Incentivise circular innovation through shared risk models.	🟩	🟨

5.1 Gap analysis recommendations

The gap analysis has identified the following research areas as being the most beneficial in improving circularity and enhancing the collection of data in an asphalt context. It should be noted that some of these recommendations are focused on both research and practical action orientated exercises to enable both National Highways and the MPA to strategically support change more rapidly.

5.1.1 Case study to validate circularity for asphalt

★**Recommendation:** create a detailed case study showcasing the practical application of the working circularity definition and principles specifically for asphalt.

Using the outputs of this Technical Note, a case study should be developed to illustrate how the definition aligns with and supports the achievement of both National Highways and the MPA's strategic goals. By providing real-world evidence, it will strengthen the credibility and relevance of the circularity framework while identifying potential opportunities for refinement.

5.1.2 Enhancing data collection to improve circularity

Effective data management and collation are crucial for understanding an asset's materials and components, as well as for maintaining accurate data throughout its lifecycle. Digitisation in turn, also offers significant potential to accelerate the adoption of circular economy principles, via smarter, more efficient practices.

However, the value of data collection and opportunities for digitisation are diminished if data cannot be properly stored, accessed, and utilised. Robust systems for data storage and accessibility are essential to ensure that collected information can support informed decision-making and enhance overall asset management.

The following recommendations take a holistic approach to improving circularity—not only through enhanced data collection but also by addressing the underpinning systems and opportunities for digitisation. This integrated approach ensures that both National Highways and the supply chain have the tools and infrastructure needed to drive meaningful improvements in circularity across the asphalt lifecycle.

5.1.2.1 Data mapping and gap analysis

★**Recommendation:** undertake a targeted research project to map existing data across the asphalt lifecycle and identify gaps that hinder the practical deployment of circularity indicators and DPPs for pavements.

The research should align with ongoing sustainability efforts, particularly GHG initiatives, to leverage existing methods, datasets, and governance structures and avoid duplication. The recommended scope should review data systems and practices across the full asphalt lifecycle and is shown in Table 7. Through structured interviews with internal National Highways teams and the supply chain, plus cross-sector benchmarking of best practices for data collection and sharing, the study will produce actionable, time-bound recommendations with clear ownership to accelerate circularity adoption.

Table 7. Recommended scope for data mapping and gap analysis

Lifecycle stage	Data mapping
• Planning and design • Procurement • Construction • Operation and maintenance (with emphasis on condition and maintenance data) • End of life	For each stage, the following should be mapped: • Key stakeholders e.g. roles, responsibilities, decision points* • Data requirements - aligned to the shortlisted indicators and DPP inputs*, specifically – the 130 attributes of the pavements DPP framework described in Chapter 4 • Data currently collected e.g. granularity, frequency, formats, purpose, sources* • Data quality e.g. completeness, accuracy, consistency* • Systems of record and interfaces e.g., P-AMS, BIM, enterprise resource planning systems, asset management platforms, emerging circularity solutions • Governance e.g. mandatory fields, QA/QC, ownership, access rights, change control

* Using earlier research outputs from T0049 Collaborative research with industry partners (Work Package 1 – Environmental Sustainability Indicators, Work Package 2 – Next Generation Sustainability Measurement) developed by AECOM [45].

Good data management and collation is essential for understanding an asset's materials and components, updating data throughout its lifecycle, and supports effective management and informed decision-making. This recommended exercise would support National Highways and the MPA in better understanding the barriers and opportunities of existing system architecture. By pinpointing where data is already collected in current systems and at which lifecycle stages, the outputs should provide the foundation for consistent, reliable use of circularity metrics and DPPs. In addition, by identifying where critical inputs are missing and levels of interoperability and traceability, it should establish the supply chain's role in closing gaps, such as which procurement mechanisms can best drive compliance and data quality to accelerate the National Highways and the MPA's broader sustainability agenda.

5.1.2.2 Pilot for recommended circularity metrics

★ **Recommendation:** build on the foundational work outlined in Recommendation 5.1.2.1, it is recommended to pilot the shortlisted circularity metrics on a live or imminent asphalt project. This pilot will serve to validate the end-to-end feasibility of these metrics, including critical aspects such as data capture, workflow integration, supplier readiness, and alignment with related frameworks (e.g., DPPs and relevant sustainability reporting).

Chapter 3 identifies the shortlisted metrics, piloting these metrics is essential to assess and compare their practicality, data availability, and accuracy in an operational setting. This study should also address the following key areas:

i. **Alignment with existing asphalt LCAs:** Evaluate how the metrics integrate with established LCA frameworks, including system boundaries, data sources, and processes. Assess the extent to which circular economy principles can be embedded into LCA calculations.

ii. **Benchmarking against other metrics:** Compare the outcomes - which includes product-specific modules created by industry for industry and explicitly accounts for broader environmental impacts.

iii. **Lifecycle coverage:** Ascertain the possible lifecycle coverage of each metric, for example, whilst ESCi only assesses circularity up to the factory gate, the MCI (which ESCi has adapted to an asphalt context) provides supplementary calculations that capture material losses across the supply chain.

It is anticipated that the pilot will raise practical issues, such as gaps in required inputs, definitions, governance, and system interoperability, and testing of how well the metrics inform real design, procurement, and asset management decisions. The pilot should establish clear success criteria (e.g., data completeness and quality, reproducibility, decision-usefulness, reporting readiness, and stakeholder effort), and a structured post-pilot evaluation.

Findings should feed into Recommendation 5.1.2.1 and directly inform refinement in the establishment of a practical circularity metric, including recommended data standards, procurement levers, and capacity development to inform scale-up.

5.1.2.3 Intellectual property

★ **Recommendation:** conduct independent research to identify and address intellectual property barriers that hinder the sharing of circularity data (with consideration of other sustainability factors as relevant to the asphalt supply chain).

Building on the previous data mapping and gap analysis (see Recommendation 5.1.2.1), structured and anonymised interviews should be held with asphalt producers and key stakeholders, such as procurement leads, asset owners and members of the supply chain, to uncover the major obstacles to data sharing. An independent facilitator should conduct these interviews under pre-agreed confidentiality protocols to encourage open and honest dialogue.

This research should map barriers related to intellectual property, define a data sharing decision matrix, explore model agreements, and define a governance framework that outlines roles and responsibilities. The outcome of this research will be a practical framework that balances the protection of proprietary knowledge with the transparency needed to improve circularity and enhance data collection. This initiative aims to improve data completeness and quality, reduce legal and commercial friction, and ultimately support the broader sustainability objectives of the asphalt industry.

5.1.2.4 DPP practical applicability review and technology-enabled trial

★ **Recommendation:** expand on the early RFID pilots to assess DPP applicability in light of advancements in technology and digital solutions such as BIM, digital twins and the internet of things.

An evaluation of the technical options for storing and retrieving DPP identifiers and payloads near or remote to asphalt assets (e.g., embedded tags, surface markers, sensor gateways) should be undertaken, as well as the identification of potential technology suppliers. The evaluation outputs should be mapped to understand how this information transfers into National Highways existing systems, and the review should consider durability, read reliability in real-world conditions, cybersecurity, data integrity, lifecycle maintainability, indicative costs, alongside research gaps, and implications for supplier workflows and data governance. The review would include recommendations to inform the development of a technology-enabled trial.

It is recommended that this work be undertaken either in conjunction with or following Recommendation 5.1.2.1. The outcomes will provide National Highways and the MPA with a decision-ready framework for a practical DPP architecture—what to store physically versus in back-end systems—plus integration pathways, governance requirements, and procurement levers for scalable adoption which can improve traceability, circularity, and enhanced data collection.

5.1.3 Overcoming logistical and operational barriers to circularity

★ **Recommendation**: undertake targeted research to address logistical and operational challenges identified by stakeholders in adopting circular practices, such as stockpiling constraints, transport inefficiencies, and site-level workflows.

Overcoming logistical and operational barriers research: this research should synthesise learnings from existing schemes, stakeholder engagement, and National Highways' recent Material Exchange Platform trials. Structured engagement with contractors, suppliers, and asset owners will help diagnose bottlenecks, including resource availability, coordination of logistics, and knowledge gaps. Based on workshop feedback, it is recommended that this engagement also include an element of capacity development – using existing case studies to demonstrate how recycled materials can be successfully applied to new schemes while ensuring consistent performance with virgin materials, which should in turn also support the identification of further barriers and solutions.

Practical action plan: Building on these insights, a concise, practical time-bound action plan should be developed to overcome these barriers. This could explore improvements to standard operating procedures for stockpile management, transport coordination, site-level workflow templates, quality assurance protocols for recycled materials, and digital improvements. It is anticipated that the findings from the data management and improvement research will help address several operational barriers that the supply chain is likely to encounter. Therefore, it is recommended that any insights gained are integrated into future workstreams to facilitate the identification and implementation of effective solutions.

By addressing these operational and logistical challenges, this initiative will provide actionable steps to scale circular practices across programmes while simultaneously enhancing the quality, consistency, and availability of data needed to support circularity and decision-making.

5.1.4 Circular economy and waste terminology guidance

★ **Recommendation**: develop a practical Guidance Document to standardise circular economy and waste terminology for the supply chain and other key stakeholders.

- The guidance should set expectations with suppliers ahead of procurement exercises, providing clarity and consistency to eliminate ambiguity and enable alignment on definitions and concepts critical to advancing circularity goals. To support adoption, we recommend complementing the guidance with targeted training materials (e.g., a webinar).
- The materials should be tailored to the needs of diverse stakeholders, combining plain-language definitions with a glossary, and practical examples. By establishing a shared vocabulary and consistent expectations, the initiative will enhance collaboration across the industry and accelerate the effective implementation of circular economy principles.

6 Conclusions

This research demonstrates that by amending ISO 59004:2024 [3] and engaging stakeholders, a workable definition of circularity for asphalt can be established, enabling stakeholders to move beyond conventional practices. The exploration of circularity metrics revealed no single definitive metric, highlighting the need for further research to apply shortlisted metrics in real-world scenarios. Similarly, significant gaps in literature regarding DPPs suggest that practical pilots would be beneficial, especially as the supply chain and National Highways navigate an evolving legislative landscape.

The findings identify four key areas where the MPA and National Highways can exert the most influence:

- **Governance, standards, and definitions:** validating and refining the proposed definition of circularity through targeted case studies that advance National Highways and the MPA goals; equipping the supply chain with clear guidance and training on circular economy and related terminology.
- **Data, metrics and knowledge:** modernising pavement related databases and building a trusted data-sharing model that balances the protection of IP with transparency. This should support the adoption of robust sector specific circularity metrics (e.g., ESCi, MCI or others) and enable the implementation of DPPs.
- **Operations and engagement:** building on current industry best practice and developing an action plan to overcome practical barriers e.g. stockpiling, transport and site-level workflows. Including both engagement with and taking learnings from: key stakeholders, existing schemes and recent trials.
- **Commercials and strategy:** RIS3, Scheme Delivery Framework 2 (SDF2) and Maintenance & Response 2 (M&R2) framework present critical opportunities for National Highways to better embed circular economy and waste principles into the asphalt sector, prioritising the use of RA whenever possible and incentivising innovation through shared risk models.

While this research sets out the current challenges and opportunities to enable greater circularity in asphalt, the technical and regulatory context is evolving rapidly and may shape these recommendations. Key developments include:

- **Data and reporting**: ongoing refinement of EPDs and complementary product category rules (c-PCRs) for construction products, for example: FprCEN/TS 18301 “Road materials - Environmental product declarations - Product category rules complementary to EN 15804 for bituminous mixtures” (draft) [46].
- **Regulation:** implementation of the EU CPR and its implications for UK operations and legislation; with the publication of the UK Government’s Construction Products Reform White Paper.
- **Standards and committees:** active work within CEN/TC 227 (e.g., WG6 on c-PCRs and potential EN-level PCRs via WG1/TG6), BSI Committee B558/1, and CEN/TC 350/SC1—including WG1 on framework, principles and definitions, e.g. prEN 18177 “Circular economy in the construction sector – Framework, principles, and definitions” (draft) [47], and WG4 on circularity-related product, material and building passports/logbooks[2].

In conclusion, this note provides a foundational perspective and a clear direction of travel, emphasising how addressing a select few priorities can enable the MPA and National Highways to advance their ambitious sustainability goals. However, a systems-thinking approach is essential – to navigate the rapidly evolving regulatory landscape and integrate insights from ongoing workstreams, it is essential to review changes alongside these findings. By doing so, the sector can position itself more effectively to accelerate progress towards greater circularity and sustainability, enabling long-term value for the asphalt industry and its stakeholders.

[2] Other CEN TC 350 SC1 working groups that may be relevant include: WG5 Circularity Assessment, WG6 Reuse of construction, products, and materials, WG7 Design for circularity at all levels for construction, and WG8 Pre-deconstruction and pre-redevelopment audits and evaluation

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Appendix A Definitions and Principles, Further Considerations

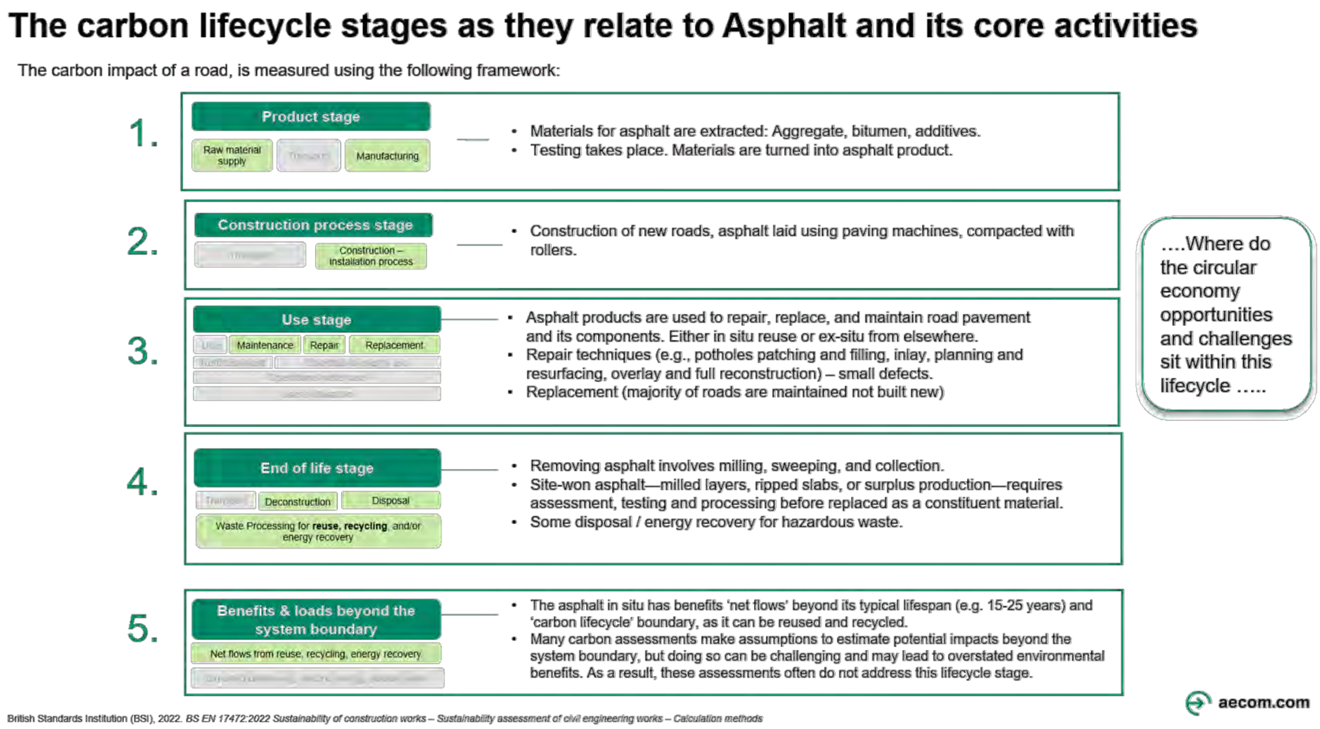


Figure A.1 Asphalt carbon lifecycle stages. Adapted from BS EN 17472:2022 [48].

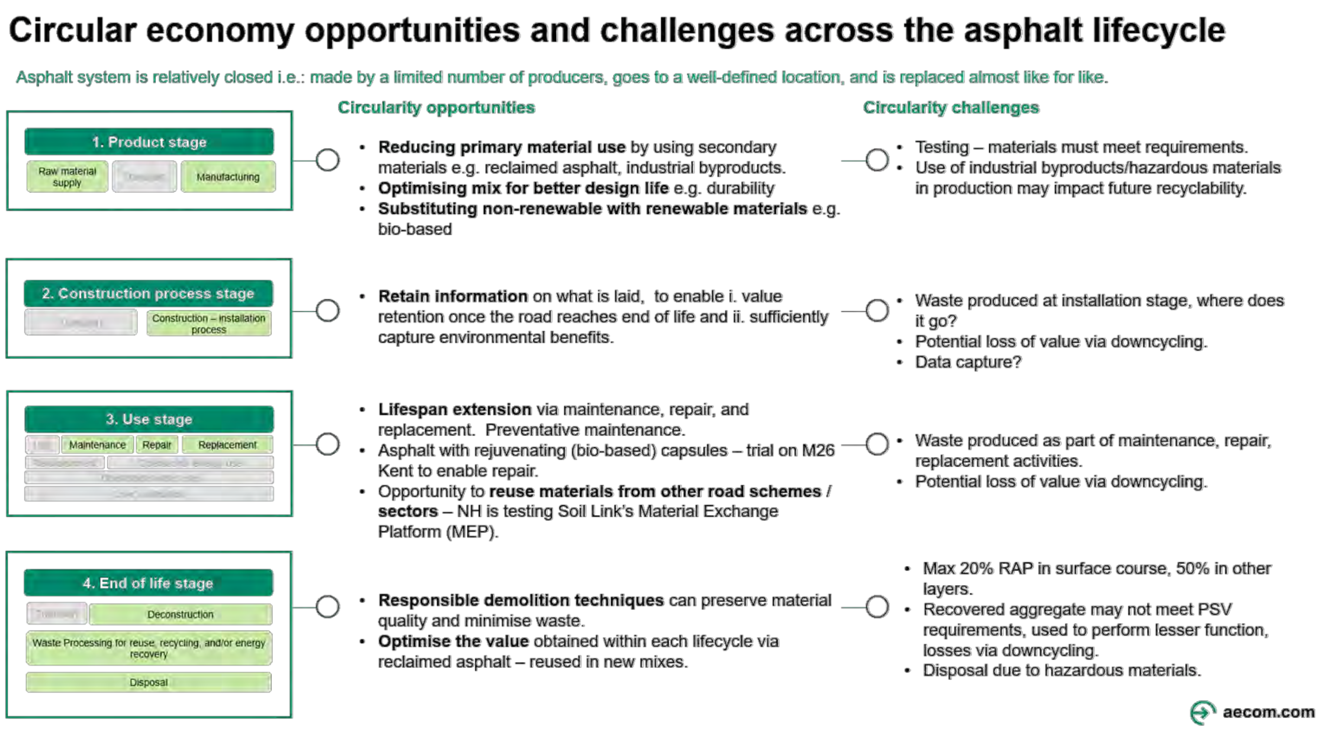


Figure A.2 Mapping of circular economy opportunities and challenges.

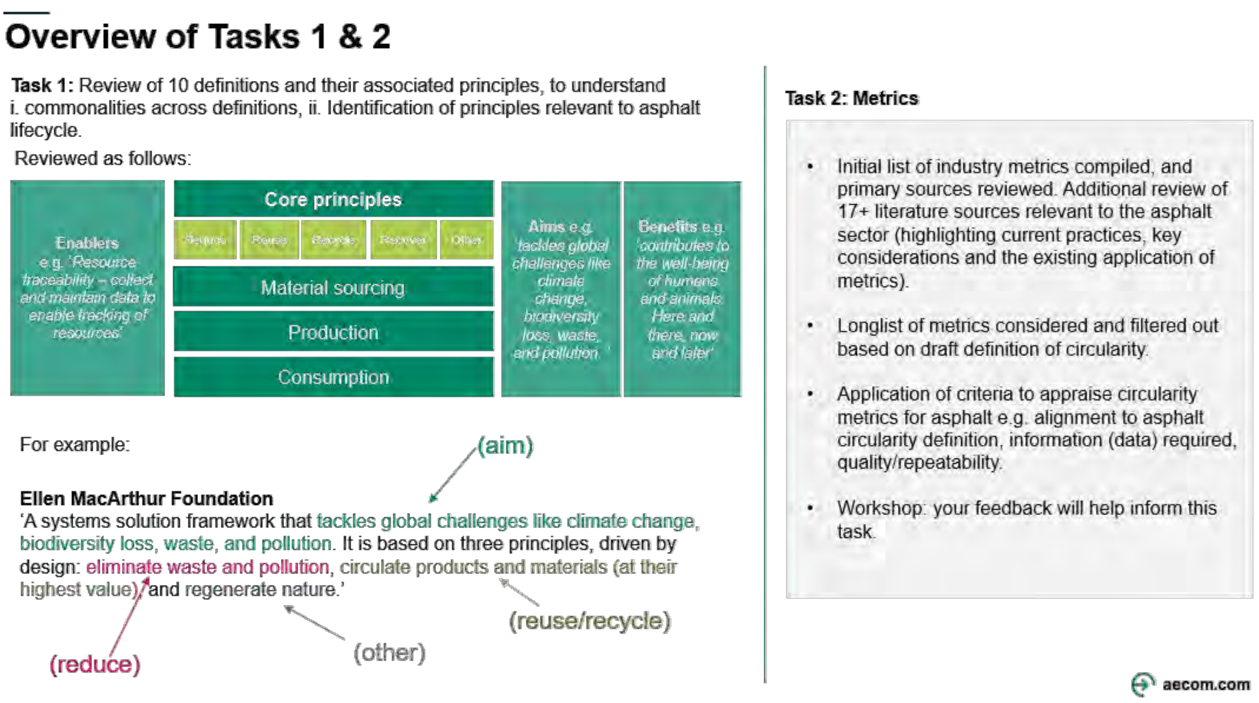
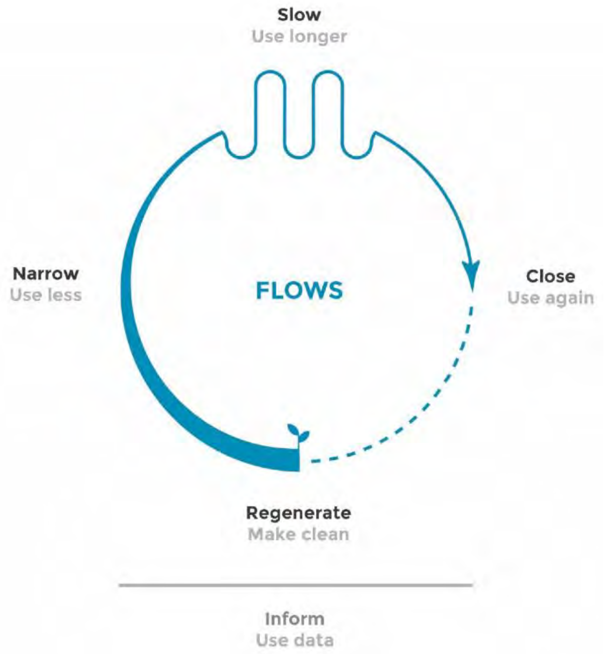


Figure A.3 Overview of the findings from Task 1 and 2. Definitions and metrics.

Table A.1 Circularity definitions and principles reviewed

Source	Definition
International Organization for Standardisation [3]	'Economic system that uses a systemic approach to maintain a circular flow of resources, by **recovering**, **retaining** or **adding** to their value, while contributing to sustainable development Note 1 to entry: Resources can be considered concerning both stocks and flows.' *Note 2 to entry: The inflow of virgin resources is kept as low as possible, and the circular flow of resources is kept as closed as possible to minimize waste, losses and releases from the economic system.* ISO's circular principles include: • **Systems thinking**: Organizations take a life cycle perspective and apply a long-term approach when considering their impacts on environmental, social and economic systems. • **Value creation:** Organizations **recover, retain or add value** by providing effective solutions that contribute to socio-economic and environmental value, and use resources in an efficient way. • **Value sharing**: Organizations collaborate with interested parties along the value chain or value network in an inclusive and equitable way, for the benefit and well-being of society, by sharing the value created with the provision of a solution. • **Resource stewardship**: Organizations manage stocks and flows in a sustainable way including by **closing, slowing and narrowing resource flows** to contribute to resource accessibility and continued availability for present and future generations and to reduce risks associated with dependence on virgin resources. • **Resource traceability:** Organizations collect and maintain data to enable tracking of resources through their value chains and are accountable for sharing relevant information with interested parties. • **Ecosystem resilience**: Organizations **develop and implement practices and strategies** that protect and contribute to the resilience and regeneration of ecosystems and their biodiversity, including preventing harmful losses and releases and taking into account planetary boundaries.
Ellen MacArthur Foundation (n.d) [49]	'A systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature.' The circular economy is based on three principles, driven by design: – Eliminate waste and pollution – Circulate products and materials (at their highest value) – Regenerate nature
World Business Council for	'The circular economy is an economic model that is regenerative by design. The goal is to retain the value of the circulating resources, products, parts and materials by creating a system with innovative business models that allow for renewability, long life, optimal (re)use, refurbishment, remanufacturing, recycling and

Source	Definition
Sustainable Development [23]	biodegradation. By applying these principles, organizations can collaborate to design out waste, increase resource productivity and maintain resource use within planetary boundaries.' Note: CTI (WBCfSD) is in alignment with the Ellen MacArthur Foundation circular economy principles: – Design out waste and pollution – Keep products and materials in use – Regenerate natural systems
TU Delft [18]	• Narrowing refers to using fewer products, components, materials and energy during design and production, and during delivery, use and recovery. A *product principle* for narrowing is 'design with low-impact inputs. • Slowing refers to using products, components and materials longer. A *product principle* for slowing is 'design for physical durability'. A product is physically more durable if its performance over time degrades more slowly than comparable products on the market. A *business model principle* for slowing is 'offer the product as a service'. • Closing refers to a business activity that brings post-consumer waste back into the economic cycle. A *product principle* for closing is 'design with materials suitable for primary recycling'. An example of a *business model principle* for closing is 'enable and incentivize product and component returns. • Regenerating refers to a business activity that manages and sustains natural ecosystem services, uses renewable and nontoxic materials, and is powered by renewable energy. This strategy mostly relates to the 'biological cycle' of the circular economy but also contains elements that are relevant for the 'technical cycle', especially with regards to the use of renewable energy. A *business model principle* for regenerating is 'produce with renewable energy'. • Informing refers to using information technology as a support strategy for the circular economy. A product principle to inform flows is, for example, 'design connected products'. Connected products can slow flows by informing maintenance and repair needs. A *business model principle* for informing is 'track the resource intensity of the product-in-use'. 
Government of the Netherlands [50]	Circularity is a broad concept and relates to all raw materials (biotic and abiotic, including water). In this NPCE we have opted for a focus on a number of specific raw materials and product groups. This definitely does not exclude the importance of, or attention paid to, other circularity topics. We expect to add other product groups when the next review takes place. The Dutch government refer to 'four knobs' it can apply to make its raw materials more circular. Derived from the advice provided by PBL, and is a simplified version of the R-Ladder: 1. Reducing raw material usage: using fewer (primary) raw materials by abstaining from the production or purchase of products, sharing products or making them more efficient ('narrow the loop'); 2. Substituting raw materials: replacing primary with secondary raw materials and sustainable bio-based raw materials (in high-value applications), or with other, more generally available raw materials with a lower environmental burden; 3. Extending product lifetime: making longer and more intensive use of products and components through reuse and repair will slow demand for new raw materials ('slow the loop'). 4. High-grade processing: closing the loop by recycling materials and raw materials.

Source	Definition
	This will not only reduce the amount of waste being incinerated or dumped, but ensure a more high-grade supply of secondary raw materials as well ('close the loop')
Ministry of Infrastructure and Water Management of the Netherlands [51]	Circular construction is defined as the development, use and reuse of buildings, areas and infrastructure without unnecessarily exhausting natural resources, polluting the living environment, and affecting ecosystems. Construction in a way that is economically sound and contributes to the well-being of humans and animals. Here and there, now and later. The following three pillars are key in our strategy: • Optimal use of materials for all phases in the construction cycle. • Using as many 'infinite' sources as possible. More and higher-grade reuse in the construction industry and at the end of the use phase. • Making use of finite sources as efficiently as possible. These three pillars lead to various design strategies [explained via an example].
Conference of European Directors of Roads (CEDR) [52]	In order to develop a roadmap for NRA implementation of circularity, CERCOM in the first instance required a definition of RE and CE. Based on previous research, it was found that attempts to address a scope that is too broad are unlikely to be successful since the data to support measurement of performance or assessment of the circularity of different maintenance options is unlikely to be available. Furthermore, National Road Administrations will differ in the extent to which they have already implemented circularity principles and in their rate of development. For these reasons, the following definition was used in CERCOM Circular Economy and Resource Efficiency for Road Maintenance means, by design: • Minimising consumption of natural resources • Designing out waste and keeping resources in use at their highest level of utility • Optimising the value obtained within each lifecycle • Improving environmental performance and contributing to societal development
prEN 18177 Circular economy in the construction sector - Framework, principles, and definitions (Draft) [47]	*Circular Economy: Definition: 'economic system* that uses a systemic approach to maintain a circular flow of resources, by regenerating, retaining or adding to their value, while contributing to sustainable development' Note to entry: In an ideal circular economy materials, components and products are kept in closed loops and Never reach end of life.' Circular Construction: 'creation, use, reuse and repurposing of construction works, construction products, materials and the built environment whilst minimising the depletion of natural resources and environmental pollution and negative impacts on ecosystems' Note to entry: Specifically, regarding construction works, a circular structure maximises resource utilisation and minimises waste across its lifespan. [SOURCE: Circular construction and materials for a sustainable building sector, BUILD UP (europa.eu), modified to be compliant with terms and definition used here.] Principle 1: Prevent the depletion of primary raw materials by construction products and their use in construction by design. **Objectives:** Limit the depletion of stocks of non-renewable resources, maximising the availability of those resources for future generations by progressively increasing the use of renewable and/or recycled materials, and the re-use of construction products, where safe to do so. **Principle 2: Reduce or prevent emissions and waste** caused by construction products and their use in construction through design for circularity. Objectives: - Limit the environmental impacts resulting from the primary raw materials throughout all of the use cycles. - Eliminate emissions to air, soil and water. Principle 3: Protect and regenerate natural systems. Objectives: - Limit land use for primary raw materials extraction (both non-renewable and renewable) and for landfill. - Regenerate ecosystems that have been degraded as a result of resource extraction. - Enable construction works that have minimum impact on natural ecosystems and where possible regenerate ecosystems. **Principle 4: Extend service life** of construction works, construction products and parts to allow multiple use cycles for as long as functional requirements are fulfilled. Objectives: - Reduce depletion of primary stocks. - Retain functional, technical and economic value. **Principle 5: Retain value** Decouple economic activity from the consumption of finite resources by retaining functional, material and economic value from previous cycles. Objectives:

Source	Definition
	- Retain functional, technical, environmental and economic value over multiple use cycles. - Eliminate the use of persistent, toxic and bio-accumulative substances hindering recycling options in future use cycles. Under this condition the use of industrial by-products and residues can be used as a resource in circular manner.
Transport Infrastructure Ireland [53]	TII aims to adopt a circular economy approach to standards, operations, and TII delivered and funded projects and programmes. The circular economy seeks to keep materials, components, and products in use for as long as possible. The TII approach to circular economy aims to: • Reduce resource consumption; • Keep assets, components, and materials at their highest value; • Maintain safety and technical function of services, assets, and components; • Promote restorative and regenerative design; and • Reduce emissions. [TII Guidance] Applies the 9R's specific to roads (adapted from the European Commission Categorisation System for the Circular Economy [54]) • R1 - Refuse: Ensure a clear need is demonstrated for National Road assets. Consider alternatives in detail and maximise use of existing infrastructure. • R2 – Rethink: Intensify the use of existing assets, e.g., by delivering infrastructure for multiple transport user groups including those in shared vehicles, and in particular buses. • R3 - Reduce and Design for Deconstruction: Ensure design for disassembly and maintenance is central to development. Employ lean design during national road development. • R4 - Re-use: Re-use assets, components, and materials within road development (e.g., re-use pavement materials such as asphalt). • R5 – Repair: Continue to repair and maintain National Road assets and components as appropriate to prevent asset deterioration or degradation. • R6- Refurbish: Recover used road network assets and components as appropriate to current standards to extend their useful life. • R7 – Remanufacture: Incorporate remanufactured materials and components (re-used and repaired with new parts) into National Roads development. • R8 – Repurpose: Incorporate repurposed materials and components into National Roads development. • R9 – Recycling Incorporate recycled materials into National Roads development.

Appendix B Circularity Metrics, Further Considerations

Table B.1 Circularity metrics reviewed

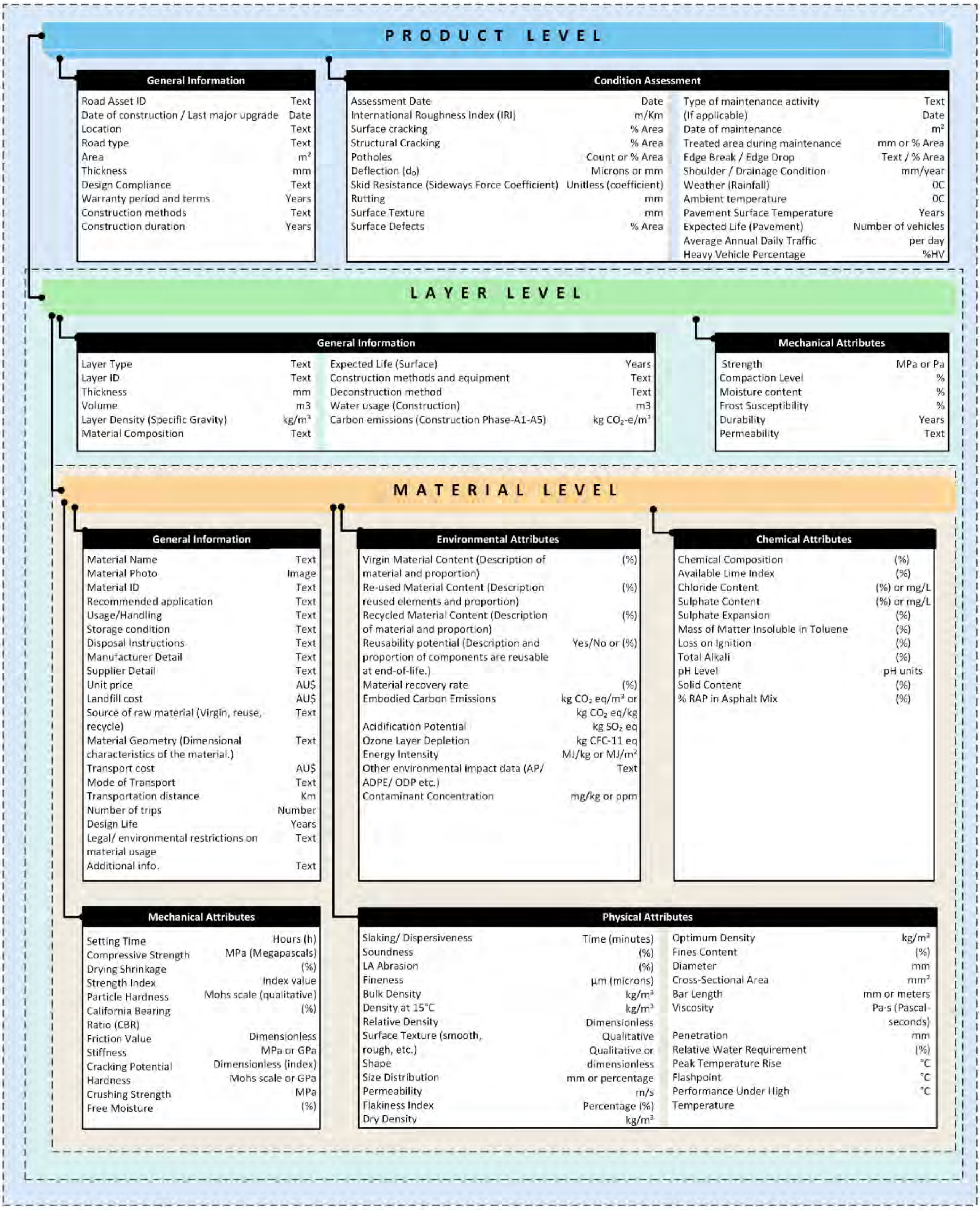
Metric	Brief Description	Alignment to Circularity Definition	Data sources	Appropriateness	Strengths	Weaknesses	Quality	Repeatability (Comparability)
Material Circularity Indicator (MCI) [21, 22]	Developed by the Ellen MacArthur Foundation [49, 55]. Designed to assess the circularity of products and materials. Quantifies restorative material flows, measures recycled/renewable content, lifespan, and reuse and recovery at end-of-life	Considers intensive use, use of biological materials from sustainable sources, durability, reuse, redistribution, and feedstock from reused or recycled sources.	Material mass, composition, end-of-life breakdown, process efficiency, utility/lifespan.	Developed for product-level comparison. Applicable to asphalt, as illustrated by academic studies [21].	• Peer-recognised and ISO-aligned, ensuring credibility. • Transparent, publicly available methodology with open-access calculations. • Quantifies material flows, recycled content, product lifespan and end-of-life recovery. Interim metrics pinpoint hotspots and improvement opportunities along the value chain. • Factors in durability, repair, reuse, redistribution, and frequency of use - key for infrastructure assets such as asphalt pavements with multiple maintenance cycles. • Incorporates material loss factors to reflect real-world inefficiencies and leakage. • Calculations can be automated in common tools like Excel. • Applicable to complex, multi-material products like asphalt mixes • Includes complementary risk and impact metrics for robust decision-making.	• Generic, not tailored to asphalt. • Assumes recycled materials are of equivalent quality to virgin materials. • Primary methodology overlooks supply chain material losses (though an expanded version address this).	Robust and scientifically validated, aligned with ISO standards.	• A full and transparent methodology is available and publicly accessible. • Calculations could easily be set up in an Excel tool.
Madaster Circularity Indicator (Madaster CI-Score) [26]	Developed by Madaster, this metric quantifies the circularity of buildings by evaluating material usage, durability, and potential for reuse. It is based on MCI but adapted for a buildings focused context.	As for MCI.	As for MCI. However, the Madaster Platform enables Metrics to be linked to material passports (so data can be obtained from these).	Greater resolution compared to MCI with respect to product disassembly at the end-of-life phase. Systems focus - primarily buildings.	• As for MCI. • Includes health/adaptability factors (for buildings) – supports sustainable asset management.	• Better suited to buildings or complex assets, less applicable to non-building products, methodology less standardised across industries. • Paid for tool to generate outputs.	As for MCI.	• As for MCI. • Largely applies MCI principles and methodology. • Would require users to adopt paid for tool.
Circular Construction Evaluation Framework (CCEF) [25]	A free-to-use assessment tool designed to quantify the circularity of construction, and credentials of components / elements.	Assesses the durability of products as part of the construction assembly (in terms of both past and future life). Includes material inventory (including inventory, warranties and processing), finishes / treatments and end-of-life scenarios. Considers design for longevity, design for adaptability and disassembly, construction and end of life circularity.	• At a buildings level, requires data on the following: recorded information, adaptability in design, simplicity, and health & safety. • Element/component level: durability, material inventory (including LCA data), finishes/treatments, reversibility, reusability, recyclability.	Tailored for construction and makes specific references to buildings. Could be appropriate but depends on the preferred framing / boundaries e.g. product or asset level.	• Takes into account LCA/EPD outputs, caveats limitations in relation to challenges surrounding temporal boundaries. • Looks at whole building (asset level) and element/component level. Could be adapted for pavements context. • Requires evaluation and documentation of history, current status, and potential future of element. Rewards reuse. • The metric gets into the detail of circular economy principles, whilst having achievable data requirements (primarily score based).	• CE factors (design for disassembly, adaptability, design life expectancy) have been tailored to buildings context, largely irrelevant to asphalt. • Would require rework to tailor to asphalt context.	• Uses BS ISO 20887:2020 guidance to ascertain degree of disassembly and adaptability. • Peer reviewed.	• Input data is based on users knowledge of asset and materials. • Scoring criteria enables repeatability, however, authors recognise that bias may play a part - suggesting a secondary evaluator role to compensate.
Verberne Building Circularity Indicator (VBCI) [24]	A multi-layered assessment methodology developed from and expanded upon the Ellen MacArthur Foundation & Granta (2015) Circularity Indicators. It combines four levels: Material (MCI), Product (PCI), System (SCI), and Building (BCI) circularity.	As for MCI but incorporates disassembly determining factors.	As for MCI, as well as product information (as it relates to disassembly) and building information.	Comprehensive, multi-level, buildings focus, but material and product level methodology is somewhat appropriate.	• Integrates MCI with broader context. Useful for whole-system analysis (e.g. material - product - system - building). • References a number of drivers that can complement the assessment (e.g. material health, energy use, material value potential).	• Specifically adapted for buildings context (e.g. reference to Brand's (1994) Shearing Layers. • Complex/overengineered for single products.	Peer reviewed, model validated by author.	Methodology available, would require further development to enable comparability.

Metric	Brief Description	Alignment to Circularity Definition	Data sources	Appropriateness	Strengths	Weaknesses	Quality	Repeatability (Comparability)
CB'23 [32]	Developed as a collaborative initiative between Dutch public agencies and industry partners, Platform CB'23 aims to accelerate the transition to circular construction. Its methodology enables the measurement of circularity across all construction sectors (including buildings and infrastructure), at various scales (from material to area), and throughout all project phases.	• Indicators 1 to 3 consider the protection of stocks of materials. • Indicator 2 considers the quantity of materials available for the next cycle. • Does not consider duration of useful life.	• Quantity of primary materials and secondary materials (including proportions from reuse and recycling). • Environmental: climate change potential, toxicity, eutrophication, depletion of abiotic raw materials. • Functional information: relating to the quality, degradation and potential for reuse at the end of the life cycle.	The method seeks to address circularity in the construction industry, to enable the circularity of an object, such as a house or a road to be measured, so is highly appropriate.	• Provides indicators for environmental protection and value retention which is not covered by all circularity indicators. • The methodology makes clear reference to the LCA Module stages. • Users of the calculation method can freely select specific data or generic data. • Range of guides and tools to support calculation.	• Elements of the 'Measuring Circularity Guide' and other elements of the wider guide and tool kit are available only in Dutch. • Generates a range of individual results as opposed to a single consolidated metric- whilst these are expressed as percentages, there is little guidance provided with respect to performance and interpretation of these. • There are no available tools to support the calculation using this method, which is likely to require interpretation during the process of calculation. • The method has been tested on pilot projects however this highlighted challenges relating to the process and complexities. • The inputs to the environmental protection indicator appear to be scientifically complex and requires a separate method 'Determination Method' to be applied (this has not been reviewed as part of this exercise where it does not relate directly to circularity).	Where the use of factors or categorisation is necessary to determine inputs, these are defined in the appendix.	• The methodology remains under development which may pose ongoing challenge to consistent calculation for comparison. • Use of generic data may negate comparability. • Guidance and factors are missing in some areas.
asPECT [28]	The asPECT tool was designed to be used by asphalt producers to calculate the carbon footprint of the asphalt mixtures used on the Strategic Road Network. It provides three separate methods to calculate the carbon emissions (two of which are not compliant with BS EN 15804).	Includes reclaimed asphalt.	Total tonnage of mixture and % breakdown of materials. Annual sales data and annual fuel usage or measured /assumed energy consumption, transport data.	The method primarily calculates lifecycle carbon emissions; applying it to circular economy assessment is disproportionate and fails to reflect the specific circularity opportunities and constraints of asphalt.	• Requires users to input material data (including reclaimed asphalt quantity) at the production phase.	• Current model is cumbersome and primarily focused on carbon emissions. • It does not account for waste generated during manufacturing and construction. • It excludes use-phase impacts such as maintenance, repair, replacement, refurbishment. • It assumes all asphalt is reused or recycled, overlooking limitations introduced by novel materials that may reduce carbon emissions but restrict recyclability • It assumes no asphalt is disposed of at end of life. • It requires limited product-specific inputs, reducing accuracy.	• Limited in-built quality control mechanisms. • Use of default values and generic assumptions for end of life and beyond system boundary impacts.	• Users can select either use of specific data or generic data for the production and construction phases • Differing calculation methodologies proposed and exclusion of the use phase do not facilitate comparability.
Environmental Sustainability and Circularity indicator (ESCi) [21]	Takes an integrated approach - combining LCA with Material Circularity Index (MCI) produce an overall Environmental Sustainability & Circularity Indicator, tailored to the asphalt context.	• Includes "mass virgin feedstock" • Uses a utility factor looking at i. the resistance to fatigue and ii. the resistance to permanent deformation. • Includes "fraction of feedstock derived from recycled sources" "Amount of waste going to landfill or energy recovery".	Same inputs as MCI, as well as: • LCA data, and • Utility factors.	Very appropriate - specific to asphalt, combines LCA with MCI, giving a holistic perspective.	• Combines circularity principles and LCA for a unified evaluation of circularity and environmental impacts. • Peer reviewed, ensuring scientific rigor. • Specifically designed for asphalt, addressing closed-loop systems and performance metrics (e.g., resistance to fatigue). • Comprehensive: evaluates virgin and recycled material use, waste management outcomes, and performance under stress.	• Lacks a practical tool for implementation, requiring further development for consistent application. • Utility factors obtained via testing. • No real-world applications to date. • Cradle-to-gate assessment only: Further research is required to explore potential expansions if deemed beneficial.	Peer reviewed.	Academic paper, without further guidance, would pose challenges in consistent calculation for comparison.
Circular Transition Indicators (CTI) [23]	The Circular Transition Indicators (CTI) developed by the World Business Council for Sustainable Development offers a universal and quantitative framework for evaluating how circular a company is.	Considered as part of the 'Close the loop', 'Optimise the loop' modules, as well as outflows.	Inflows of materials (mass), % renewable (sustainably grown bio-based sources) / non-virgin content. % of circular outflows (mass), % recovery potential versus % actual recovery.	This method, whilst focused on determining organisational CE, includes a 'Close the loop' module which can be applied at a product (group) level.	• Created, tested, and reviewed through a collaborative process involving industry, non-governmental organisations and academia, ensuring broad acceptance, relevance, and comparability. • ISO and reporting standards alignment: Designed to comply with ISO 59020 and other corporate reporting frameworks, including the GHG Protocol, enhancing its credibility and applicability. • Modular approach: includes 'Close the loop' and 'Optimise the loop' modules applicable at both organisational and product levels, allowing for tailored assessments. • Focus on material flows explicitly tracks material inflows and outflows, and value-retention pathways, giving clear visibility of where materials circulate or leak. • Integrated environmental metrics incorporates modules to estimate emissions and broader environmental impacts, enhancing the understanding of circularity beyond material flows alone.	• Generic, not asphalt-specific. • Paid online tool limits accessibility. • Primarily designed for organisational-level assessments, though adaptable for products. • Self-assessed methodology would benefit from independent verification.	Industry developed, tested, and reviewed via multi-stakeholder process. Designed to align with ISO 59020 as well as other corporate reporting standards (e.g. GHG Protocol).	Methodology is publicly documented and repeatable, but self-assessed, would benefit from independent verification.

Metric	Brief Description	Alignment to Circularity Definition	Data sources	Appropriateness	Strengths	Weaknesses	Quality	Repeatability (Comparability)
PavementLCM [52]	PavementLCM was developed for European National Road Authorities to support the adoption of standardised sustainability assessment processes for transport infrastructure.	N/A	N/A	Primarily an LCM mechanism, does not include any specific circular economy outputs. Comprised of information packages, tools and resources which are currently inaccessible via PavementLCM website.	• N/A	• N/A	N/A	N/A
CERCOM Risk Based Assessment Framework (RBAF) [10]	The RBAF tool is a risk assessment tool, which can be used to facilitate the procurement of circular solutions for road construction and maintenance.	N/A	General scheme information (e.g. budget, length), KPIs, Values for performance and risk.	Designed to be used at the optioneering/procurement stage, focused on risk and the use of KPIs, with no set metrics for CE. The appropriateness of this tool is therefore limited.	• KPIs cover performance, cost, resource efficiency and circular economy, environmental, and social.	• Complicated to interpret. • KPIs to evaluate risk, are determined by the user. • No set metrics/KPIs suggested beyond recycled content, no consistent measurement approach to CE.	Quality control measures are unclear.	Self-determined KPIs do not enable comparability.
CEI [31]	Value-based indicator that assesses material quantities and market prices to evaluate pavement infrastructure circularity.	N/A	• The number of physical units in monetary terms (price x physical value) • Material value recycled from end-of-life product • Material value needed for reproducing end-of life revenues • Expenditure associated with energy and input materials to produce the secondary materials.	Relates to pavements [21]. Compares the value of the product made from recycled material to the value of the waste material that entered the recycling facility at end of life. Assumes that other environmental factors, are incorporated within market value.	• Prioritises value retention through recycling and material preservation - may be a more suitable indicator given the asphalt context and ability to obtain data. • Indirectly accounts for the environmental, economic, and social impacts of a product as the market prices often (but not always) encompass the environmental and social taxes as well as account for the costs and benefits.	• Driven by the market prices of materials and activities. Fails to accurately reflect the benefits derived from using a higher percentage of RAP and low-emission technologies, such as WMA. • Rely on the premise that the quality of recycled materials is equivalent to that of virgin materials. • Careful interpretation is essential when utilising the CEI, due to the influence of market supply and demand on cost. • The indicator is based on the value of recycled materials after their EoL, thereby more suited for pavement maintenance when recycling activities are involved. • The indicator does not account for utility, i.e. the value added by the increased lifespan of a pavement after preservation activities – it is essential to modify the CEI in its current form to cover a broader range of pavement maintenance alternatives such as preservation.		Could vary due to regional nuances. May act as a good accompanying metric.
CIROAD [30]	Designed for urban road infrastructure projects, this approach integrates circular economy principles with Industry 4.0 technologies (e.g., BIM, digital twins and the internet of things) and applies the AHP multicriteria method to score projects. It has been designed to enable governments, designers, and contractors to assess the environmental, social, and economic "circularity" of road projects and pinpoint areas for improvement.	Considers waste reduction, circular construction, operation, and deconstruction and resource recovery. As well as industry 4.0 technologies (recognised as an important enabler).	25 data inputs, covering: • Circular materials • Circular design, construction, & operation approaches • Deconstruction & resource recovery • Social value creation • Economic performance.	Designed for road-level project assessments.	• Single weighted % score representing total circularity performance (based on respective 7 sub-criteria %s). • Includes question on EPD • Includes evaluation of industry 4.0 technologies	• Not a single metric - produces a weighted composite circularity index calculated using Analytic Hierarchy Process (AHP) from over 25 sub-indicators, synthesized into 7 intermediate criterion scores, aggregated into one weighted % score, and assigned a letter rating. • Methodology is very complicated, making it overly complex and difficult to adapt or simplify for application at a product level. • Sustainable development inputs not entirely linked with working circular economy definition for asphalt. • Rationale on weighting of different elements and dependency limitations when using AHP. • Chilean specific references (e.g. legislation).		Many qualitative elements, could be open to interpretation/bias, although states "each qualitative indicator has requirements and objective means of verification for each level (which must be verifiable through the technical background of the project under evaluation)".

Appendix C DPP Framework for Pavements

Figure C.1 Material DPP framework proposed by Senarathne *et al.* [34] for roads



Appendix D Industry Workshop

On 27 November 2025, AECOM hosted an Industry Workshop to present findings of its research and discuss current best practice and the challenges faced the sector when exploring circularity adoption. Participants involved representatives from AECOM, National Highways, the MPA, the Institute of Asphalt Technology (IAT), EAPA, Tarmac, Holcim, Eurovia, FM Conway, Breedon Group and Heidelberg Materials. In the following paragraphs, key considerations made during the event and relevant to the concept of circularity for asphalt are summarised in terms of 1) relevant standard and practice, 2) challenges and 3) opportunities.

D.1 Relevant standards and practice

The Manual Contract for Highways Works (MCHW) Clause 202 sets the standard for ""Flexible pavement construction" [16]. In particular, in terms of reclaimed asphalt, the standard refers to BS EN 13108-8:2016 "Bituminous mixtures – Material specifications Part 8: Reclaimed asphalt" [5] and PD 6691:2022 "Guidance on the use of BS EN 13108, Bituminous mixtures" [17] for compliance of the material used. These documents set the necessary materials and product type testing requirements to adopt reclaimed asphalt (RA) in-situ and ex-situ, checking for general and geometrical aggregate properties (e.g. shape and PSV), bitumen and bituminous binder characteristics, particle size distribution and presence of foreign matter and contamination (e.g. from coal tar) in the mix. In addition, BS 9228:2021 sets the specifics for the "Recycling of roads and other paved areas using bitumen emulsion, foamed bitumen or hydraulic material" [56], applicable for both in-situ and ex-situ cold recycling, including requirements on materials, production and installation.

In terms of data, BS EN 13108-8:2016 [5] requires all parties involved to keep track of the following information for the material that is reclaimed:

1) Presence, type and content of any "materials other than natural aggregate, not derived from asphalt".
2) Aggregate grading and particle size of reclaimed asphalt.
3) Content, type and properties of binder.

On the other hand, BS 9228:2021 [56] sets additional and more specific data requirements to be "supplied by the customer", usually a road authority or road manager, such as:

1) road classification and traffic flow,
2) aggregate polished stone value (PSV) requirement for the final surface,
3) environmental sensitivities (e.g. trees, noise, fumes),
4) existing drainage and utilities.

Furthermore, from an operations and maintenance perspective, it is important that any reclaimed material used as part of the surface course can provide surface characteristics in line with Design Manual for Road and Bridges (DMRB) CS 228 "Skidding resistance" [57] and CS 230 "Pavement maintenance assessment procedure" [58], in which, requirements in terms of skid resistance and textural properties of the finished surface of the pavement are established.

Given that existing asphalt roads in the UK were constructed several decades ago, adhering to various specifications, standards, regulations, and industry practices of their time, it is not unusual to encounter roads that now require maintenance. Many of these roads may contain materials that current standards classify as contaminants, necessitating special treatment prior to recycling.

From a legal perspective, there are key regulations – such as the Waste (England & Wales) Regulations 2011 [59], Waste Classification WM3 Guidance [60] and Regulatory Position Statements (RPS), like the Environment Agency RPS 157 [61] – that apply. For instance, based on current England and Wales regulations a material becomes waste when the holder discards it, intends to discard it or is required to discard it. Typically, asphalt that is removed from a pavement usually meets this definition the moment it is lifted from its original place, unless it can immediately be re-used under a valid by-product route [4, 8]. Similarly, based on WM3 Guidance [60], asphalt that is reclaimed from site and not used directly as is must be assigned an European Waste Catalogue (EWC) code, i.e. 170301 for hazardous waste and 170302 for non-hazardous waste [62]. The presence of e.g. coal tar triggers the hazardous code and removes recycling options without specialist treatment. Challenges surrounding a lack of historical data and mapping where hazardous substances might be, adds an extra layer of risk and complexity to works that intend re-using or recycling asphalt, or store it for future use.

All parties involved in the workshop demonstrated awareness of all the applicable regulations and related operational requirements.

D.2 Challenges

Workshop engagement highlighted the following challenges:

i. In today's industry adopting other sectors by-products in new materials is becoming the standard. This makes definitions of terms such as "virgin materials", "reclaimed asphalt", "feedstock", "byproduct" and "waste" less clear, and introduce additional testing requirements to e.g. evaluate the content of foreign matter, the properties of any recovered bitumen or recycled aggregate, or evaluating the particles size distribution in the new mix.

ii. Circularity principles generally include reduce, reuse, recycle, recover and regenerate. Although industry has historically focussed predominantly on recycling, discussions from the workshop have highlighted how there are other principles that road authorities and the supply chain can influence to enable greater circularity for asphalt.

iii. Often little to no information is available to designers and contractors when they deal with the recycling of asphalt pavements, often requiring additional testing. In this regard, historical data could be incomplete or less accurate. On the other hand, lots of information may be available but not openly shared due to intellectual property and the need for manufacturers to protect their know-how in a competitive world.

iv. Although current MCHW CC 202 [16] provides a fully performance driven view for the use of materials in road construction, PD 6691 [17] have not been updated yet accordingly, posing hard limits, such as 10%-20% of RA for the surface course and 50% in deeper layers relevant, for the industry to meet (even when trials have proven higher RA contents are technically achievable).

v. Limits on the amount of RA usable in construction generates downcycling. In this regard, based on current regulations, any material that is not directly re-used on site is classifiable as waste. To avoid that, extensive testing is needed to evaluate its re-usability and eventually space is required to stock the material, introducing additional operational requirements and costs to projects.

vi. Although National Highways is currently testing the adoption of a common Material Exchange Platform on a few schemes, providing details to what resource is available and where, no defined resource exchange mechanism is currently in place. This could limit the application of circular economy principles to a wider extent than currently possible.

vii. One of circularity principles is "use for longer". In this sense, the recent attempts made to update road surface deterioration models, to make forecasts specific of local conditions rather than network averages, and trials of new solutions have put National Highways on the right track to push more in this direction. This could possibly prevent the need for larger types of interventions to start with, but applications are limited.

viii. From a commercial point of view, some contracts still point to old standards and specifications, which forces designers and contractors to adapt and avoid circular economy principles and strategies. Similarly, at procurement level, sometimes circular economy options are discarded due to scope – requiring certain types of work to take place – or for pure economic reasons (for the proposal to be competitive).

ix. While regulations are crucial for ensuring that materials consistently meet performance standards and that health, safety, and environmental risks are effectively managed, they have also added extra operational requirements to the supply chain. As more demands, such as additional testing, are currently placed on circularity-driven options, there is a risk that these loose competitiveness in comparison to more traditional construction methods, both in terms of delivery timelines and cost.

x. Gaps in historical construction records and limited amount of reliably digitised data currently required limit the ability to propose circular economy focussed solutions, and that can impact pavement whole life cycle cost and resulting GHG emissions. In this regard, some of this information is currently stored in P-AMS, but updates to the system could be required, e.g. to the data model, if further information is required to be accessed through the system.

xi. The need for additional testing on reclaimed asphalt before it is re-used or recycled, makes ex-situ recycling more common than in-situ applications. In this sense, research dedicated to understanding how more in-situ recycling can happen, avoiding the need for stockpiling off-site and the risk for this material to be labelled as waste, could take place.

xii. No information about how use of recycled materials impacts the deterioration of textural and skid resistance properties of asphalt pavements, especially after multiple cycles of milling, relay and trafficking, is currently available, leaving open questions about the performance and durability of recycled materials in the real world.

xiii. Introduction of other industries by-products and wastes may generate unintended consequences, as was the case for e.g. coal tar, once widely adopted in asphalt mixtures and today to considered hazardous waste. In this sense challenges in terms of transparency - what substance has been placed where – and understanding of the impact these foreign matter has on future recyclability (also relevant to point xi) exist.

xiv. Task 2 (see Chapter 3) has evidenced how metrics that could help National Highways and its supply chain to track and evaluate the application of circularity principles for asphalt exist. However, it is unclear to date whether P-AMS or other National Highways system allows to store all the information needed to use these metrics as they are, to e.g. compare options, what impact collecting that information would have on site operations.

There is some broad consensus that the above list constitutes a good summary of the key challenges for the asphalt sector to further apply circularity principles has been reached. Beyond organisational and technological challenges, that industry is aware of and is working to resolve, there are commercial (at compliance, contract and procurement level) and data (both at collection and transparency level) challenges that still persist and that may be harder to resolve, as they require broader stakeholder engagement and consensus to be addressed.

D.3 Opportunities

From discussions had with participants at the workshop, the following opportunities have been raised:

i. One of the key circularity principles is to “build less”. In this regard, the Department for Transport (DfT) has recently indicated that future focus will be on road maintenance and renewal rather than new constructions [63]. This represents an opportunity for National Highways and its supply chain to push for more re-use and recycling.

ii. In terms of maximising the re-use and recycle of asphalt as primary options over the adoption of virgin materials, there is an opportunity to make this the primary choice in new contracts and shifting the responsibility onto the designer to prove that adoption of virgin materials can be a more sustainable choice if required.

iii. As part of circularity definitions, one of key principles that apply is to “maintain and retain value”. In this sense adopting a system approach, with clear information shared transparently amongst all parties would be key to maximise the potential for re-use and recycling of any feedstock or use as by-products in other sectors.

iv. There is an opportunity to learn from industry leaders working in other countries, such as the Netherlands, to understand what data is collected and how this information is shared amongst designers and contractors to enable better circularity for asphalt. In regard to data, it is highlighted that enhancements to P-AMS, implementation of DPP-related technology, could enable operators to retrieve any data needed without the need for further testing, with potential to enable more recycling and greater circularity overall, directly in-situ.

v. There is an opportunity to combine the efforts and resources put into GHG reduction along with circularity principles to support greater sustainability. For this, a combination of whole life cycle costing and risk management approaches will enable to industry to achieve a balance between mechanical performance and sustainable development.

vi. In order to be able to guarantee greater circularity for asphalt, ensuring resources can be exchanged amongst parties as swiftly as possible is key, to ensure the reuse of materials is maximised. In this regard there is an opportunity to expand on the recent trials of National Highways’ Material Exchange Platform for adoption by a larger portion of industry.

vii. Being able to reliably identify and characterise the materials exchanged is crucial, to minimise repeated testing. Although construction records from P-AMS could provide a solid baseline in terms of data requirements, further work is needed to 1) enhance the completeness of existing information, and 2) identify additional requirements for asphalt product feedstock, with particular focus on consistency and transparency to enable traceability.

viii. Results from strategic level modelling often diverges from actual operational needs. In this regard, advances in road condition monitoring and data analytics enable the development of material and location specific deterioration models. These could help engineers better understand material performance to identify longer-lasting materials, to maximise re-use and recycling and minimise costs and GHG impacts.

ix. With RIS3 and National Highways' SDF2 and M&R2 frameworks - due to commence work in 2027 – there are opportunities for National Highways to draw key learnings from recent trials on materials, data collection, materials exchange platforms used and general best practice and implement some of these as contract requirements.

x. With several successful trials on the use of high RA both in England and internationally [6], there is an opportunity to collect key lessons learnt and best practice and provide the necessary supporting evidence to facilitate updates to BS EN 130108-8 [5], PD 6691 [17], data requirements and material exchange platforms, to enable greater circularity.

xi. There is an opportunity for National Highways and the supply chain to optimise the re-use of all the available resources, within and across projects, making sure the materials are used at the right place and right time.

Based on the discussions had at the workshop, there is some general consensus that the above list constitutes a good summary of the key opportunities the asphalt sector has to further adopt circularity principles within the sector. Embracing these through dedicated research, not only will enable the sector to grow technically, but ultimately deliver better value for National Highways, the supply chain and ultimately its customers.

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