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6.1 LCM and Circular Economy: New challenges and Approaches, and

6.2 European NRAs and Circular Economy

Deliverables Nr 6.1 and 6.2

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6.1 LCM and Circular Economy: New challenges and Approaches,

6.2 European NRAs and Circular Economy

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Author of this deliverable:

Konstantinos Mantalovas, University of Palermo, Italy

Davide Lo Presti, University of Nottingham, University of Palermo

Elisabeth Keijzer, TNO, The Netherlands

Gaetano Di Mino*,* University of Palermo

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Executive Summary

The pavement engineering industry, having realised the significance of the impacts that imposes to the environment through the production, construction and management of their products and assets, has been driven towards transitioning to a more sustainable and circular way of operating. In other words, mostly sustainability and less frequently circularity indicators are being incorporating into the lifecycle management tools of different National Road Authorities (NRAs). However, not all of them seem to be adequately familiar with the aforementioned concepts. This is why the specific deliverable is trying to fortify the transition of the NRAs to a more circular way of doing business.

In ***Chapter 1***, the necessity of shifting towards circular economic models in the road engineering sector is being stated, along with the main questions that are addressed later on in the document; “Is there a plan of NRAs to implement the principles of Circular Economy (CE)?”; “What has been done so far to progress towards the execution of this plan?”; “How do NRAs implement then and communicate their implementation of CE and its principles?”

In ***Chapter 2***, the origins of the Circular Economy are thoroughly analysed by presenting the state-of-the-art on what actually Circular Economy is; and continuing by researching the meaning of CE in the context of transportation infrastructures and more specifically asphalt pavements, where 3 main directly applicable to the asphalt pavements principles of CE are defined. Some real-life practices and representative attempts towards CE in the asphalt paving industry are also presented.

Chapter 3 is focusing on the review of all the different documents that have been published by regional/national authorities within the “European Circular Economy Stakeholder Platform” (https://circulareconomy.europa.eu/platform/en/strategies?page=1). From the review of the latter, it could be deduced that there are no specific guidelines or even recommendations on how to implement circular economic principles tailored for the sector of road engineering; although generalised mentions about transportation infrastructures and asphalt recycling were detected within very few of the aforementioned published roadmaps towards CE, NRAs should invest in pushing towards the realisation of such guidelines.

Questionnaires covering the topic of CE, its principles, the level of its implementation and the limitations and challenges faced were distributed to 11 different NRAs. The results are summarised and tabulated, and findings are analysed in ***Chapter 4***. All the NRAs contacted are aware of the concept of CE and have at least minimum knowledge about what it is that it represents and seem to be familiar with the most commonly known and easily applicable principles of the CE. The most commonly applied practices that indicate the implementation of some of the CE principles are the removal of restrictions on asphalt recycling and the service life of the asphalt pavements extension, usually by means of preventive maintenance. It is worth mentioning that although the concept of CE is not totally new as analysed in the introduction and hence, some of its characteristics have already been practiced for years by National Road Authorities. Aspects such as recycling, resource efficiency and utilization of waste materials in foundation layers are not new topics and have been implemented by NRAs for years now. Indeed, these practices that have been adopted for a long time now are in line with the principles of CE and yet some of the NRAs do not project them as “supporting the CE”. In other words, although some NRAs might have stated that no specific principles of the CE are being implemented, they still recycle and trying to use their resources efficiently while extending the service life of their assets. This turns out to

be a matter of definitions. Some country might do nothing about sustainability or CE but do have legislation or targets for using waste in foundations and are thus, although they do not use the word itself, practicing CE. The challenges of implementing CE practices that the NRAs stated exist, are the inadequate technical and mechanical performance of recycled materials, technological, economic, and administrative limitations and the difficulty laying rules/legislations to support this effort. Finally, an online search has been undertaken within the official websites of the investigated NRAs, in order for different plans/roadmaps/route maps communicating CE to be identified. The search was undertaken in both English and the local language of each NRA.. However, so far most of the NRAs seem not to have invested in the communication of CE principles. Only 4 out of 10 have uploaded in their websites communicative material relevant to CE, while the rest are focusing in sustainability or nothing of the two researched keywords at all.

In Chapter 5, the knowledge gaps existing in NRAs were identified and the areas of knowledge development that NRAs should be focusing on are presented. *In addition,* two significantly relevant documents published by the European Commission are analysed and circular practices that could help the NRAs to transit to a more sustainable and circular way of operating are presented. In other words, it is presented in the NRAs what has already been done and it is there for them to follow; and finally, a step further is being made towards the circularity of NRAs by the development of the "Map of Circular Recommendations". Circular procurement, supply chain management, end of life strategies, applicable innovations and technical feasibility are the major knowledge gaps of the NRAs. The aforementioned map thus, could potentially help NRAs to make decisions and operate in a more circular and sustainable way, by fulfilling the principles of circular economy.

Finally, in ***Chapter 6*** a general discussion and final conclusions are presented. Wrapping up, it can be concluded than only a few NRAs have taken under consideration the potential benefits of CE in asphalt pavements, Thus, ***it can be said that in general, national road authorities so far have not invested into producing roadmaps/guidlines towards the implementation and communication of CE.*** This could be due to

- lack of budget, lack of experts in CE within the national road authorities and due to the uncertainty of the successful implementation of CE. This also incorporates the lack of well-structured and comprehensive circular business models and incentives for the stakeholders associated with the market of asphalt pavements.
- Another aspect is that NRAs also do not efficiently communicate their CE plans or their implementation of CE, if any. An online search was conducted within the websites of the NRAs, both in English and in their local languages, and the outcome was that only 4 out of 10 NRAs are actually communicating issues relevant to CE. Others focus only on sustainability while the rest do not seem to be communicating nothing relevant to CE at all.
- Moreover, having contacted several national road authorities it seems that all the NRAs are familiar with the concept of CE. In addition, most of them are also familiar with most of the principles it represents, but their majority is not implementing them. Most of the NRAs replied that are prioritizing the designing of the waste out of their products and that they attempt to prolong the life of their assets by conducting preventive maintenance. Some of the NRAs stated that they are not implementing such circular practices, but however, they do recycle, they do implement preventive

maintenance regimes and they do sometimes utilize waste materials as resources within the asphalt pavements that they construct and manage. This proves that all of the NRAs that have filled the questionnaire with one or another way implement practices that are aligned with the principles of CE, without though advertising it as so. *This could lead to the conclusion that more people with specialization in CE should be operating within the NRAs providing more accuracy, insights and knowledge in terms of CE implementation.* In addition, NRAs could follow the green procurement criteria published by the EU and are relevant to road construction, use and maintenance.

- Also, relevant and applicable to road pavements, documents published by the European Commission were presented in order to inform NRAs that many recommendations have already been published that could strengthen their attempt to become more circular by adopting the suggested principles. Another aspect that NRAs should consider is the technical report published again by the European Commission and is about the CE principles in buildings design. It is not something that addresses the circular challenges directly into the sector of road engineering but a lot of the principles in this report that have been presented in this deliverable could be immediately applicable to the road engineering sector and could help NRAs to become more circular.
- Finally, it could be said that more and more NRAs should allocate percentages of their budgets towards the development of circularity metrics and roadmaps/strategies towards the implementation of CE and the assessment of the levels of this implementation. This could help to monitor and evaluate the progress that is being made and develop a feasible and spherical framework of how they should actually be implementing CE in asphalt pavements in the best way possible, following the recommendations for knowledge development and the "Map of Circular Recommendations" presented in this deliverable.

1 Introduction

The debate of future availability of natural resources is lately once again in the centre of attention. Tremendous amounts of natural, non-renewable resources are being exploited in order for the needs of industries to be fulfilled. This leads to severe environmental, social and of course economic impacts that disturb the desirable equilibrium between what is that the three pillars of sustainability represent, as firstly proposed by E. Barbier in 1987 [1], [2]. According to the Roadmap to a Resource Efficiency Europe (RERM) , better construction and use of built infrastructure could help achieving significant resource savings: it could influence 42% of our final energy consumption and about 35% of our total GHG emissions, 50% of the extracted materials, and it could save up to 30% of water in some regions, when it comes to the construction industry [3], [4]. Admittedly, since transportation infrastructures - and road pavements in particular- consist one of the largest parts of built infrastructures, their contribution to the energy and water consumption, the extraction of virgin materials and the emission of GHGs is significantly elevated. A promising concept that has lately re-emerged and pledges to improve the situation and/or completely release the pressures on the environment, society and economy is the concept of Circular Economy. It could thus potentially provide an answer to the increasing demands because it actually aims to transform the function of resources in an economy [5]–[9]. In this perspective, the objective of this report is to present the findings of an attempt to answer two questions revolving around the Circular Economy and National Road Authorities (NRAs).

- Is there a plan of NRAs to implement the principles of Circular Economy?
- What has been done so far to progress towards the execution of this plan?

In order to do so, firstly the state-of-the-art of CE is analysed. Secondly, the roadmaps towards CE that have been published through the European CE Stakeholder Platform are reviewed. Finally, questionnaires including questions about CE and its level of implementation of National Road Authorities (NRAs) were produced and distributed to eleven different NRAs across Europe and one in the USA, and their inputs are thoroughly analysed. Conclusions, discussion and recommendations for knowledge development and circular practices can also be found on the last chapters of the report. Hence, it becomes obvious that part of the deliverable 6.2 of the work package 6 entitled “D6.2: European NRAs and Circular economy (03/2020 – M18)” - A review of the different approaches that NRAs currently use to implement and communicate circular economy principles, is also partially being developed and presented in this deliverable itself. However, it will be finalised within 6 months as planned in the project management timeline and delivered in combination with the current deliverable.

2 What is Circular Economy: State-of-the-art

One of the first publications that successfully managed to raise awareness about the issue of overloading earth’s natural sinks and overexploiting non-regenerative resources, was the report of Meadows et al. (1972), “The Limits to growth”, for the Club of Rome. The broader public was confronted with the thought that only limited growth is possible on a finite planet with finite resources [10]. The proposed model of Meadows and colleagues studied the

intertwined interactions between pollution, population, non-renewable resources, food and industrial output. According to their scenario, the system "failure" occurs due to pollution, even though -supposedly- society would have been able to effectively manage to conserve non-renewable resources [10]. However, B. Lomborg, questioned the objectivity and accuracy of the Meadows model, arguing that the human ingenuity and the strength of innovations were not taken under consideration in the described model [11]. A philosophy or concept that encompasses in its' core innovation and innovative business models as well, is the Circular Economy. It is a concept that made its first appearance as a proactive policy goal for numerous businesses and in political agendas in the late 1970s, mainly due to climate change and the acute concern of rising resource prices, raised by R. Carson and K. Boulding [12]–[16]. The Circular Economic concept encompasses the principles of multiple schools of thought, such as "industrial ecology and symbiosis", "performance economy", "biomimicry", "cradle to cradle", "blue economy", "regenerative design", "cleaner production", and "natural capitalism" [17], [18]. Although there is not a consensual and definitive definition of CE, one of the most widely accepted definitions is that of the Ellen MacArthur Foundation (EMF): "economy that is restorative and regenerative by design, and which aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" [19]. Two different types of products can be identified; products that after their lifecycle can either return into the technical cycle (durables), or into the biological cycle (consumables) [17]. This definition is based on three principles [9], [20]:

- **Design out waste and pollution:** This includes the detection and exclusion of the negative externalities of economic activities, which can cause damage to human health and ecosystems, by minimizing the emission of toxic substances, greenhouse gases, and eliminating water, air, and land pollution.
- **Keep products, components, and materials at their highest value and in use:** Adapting the design process to support the reuse, the remanufacturing, and the recycling of components and materials, biological or technical, in order to keep them in circulation within the same or another product system. In circular systems, it is possible to maximize the use and the value of various components that have been designed in such a way by cascading them into different applications or product systems [20].
- **Regenerate natural systems:** CE is able to support the flow of nutrients or technical materials within the same system, generating ideal conditions for regeneration, and thus, the enhancement of natural capital [20], [21].

Moreover, following this definition, Ellen MacArthur foundation supports the norm of thinking in systems and cascades. This comes as a natural continuity of the second aforementioned principle. Adopting a systemic thinking and a cascade approach, end-products, components and even materials can be repurposed, reutilised, recycled or have their service life extended while keeping their highest values. Another aspect that consists a core pillar of circular economy, is the utilization of renewable resources for the operation of production systems [19]–[22]. Moreover, the concept of CE has as an end target of providing a "marketable set of products and services capable of jointly fulfilling a user's needs" and not just end products to be solely sold to consumers [23], [24]. That would mean that retailers and manufacturers can maintain the ownership of their products and become their "service providers" [21], [25]. This is something that would be sensible, and it would be significantly beneficial if implemented to asphalt pavements and their holistic life-cycle management. The manufacturer of the road would also have to manage their asset in addition to just

constructing it [12]. Figure 1 summarises the main schools of thought that have contributed into shaping the philosophy of CE as known today.

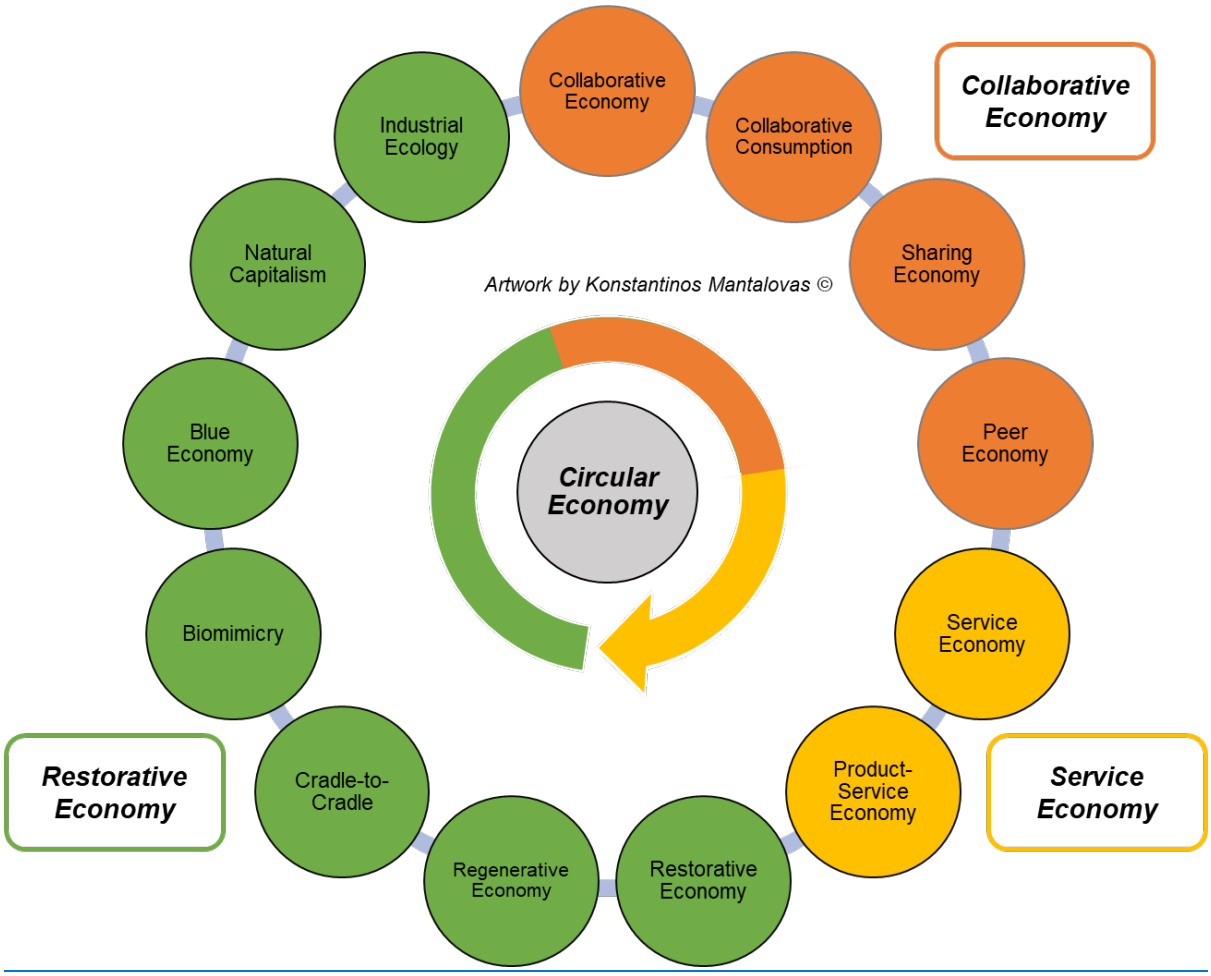


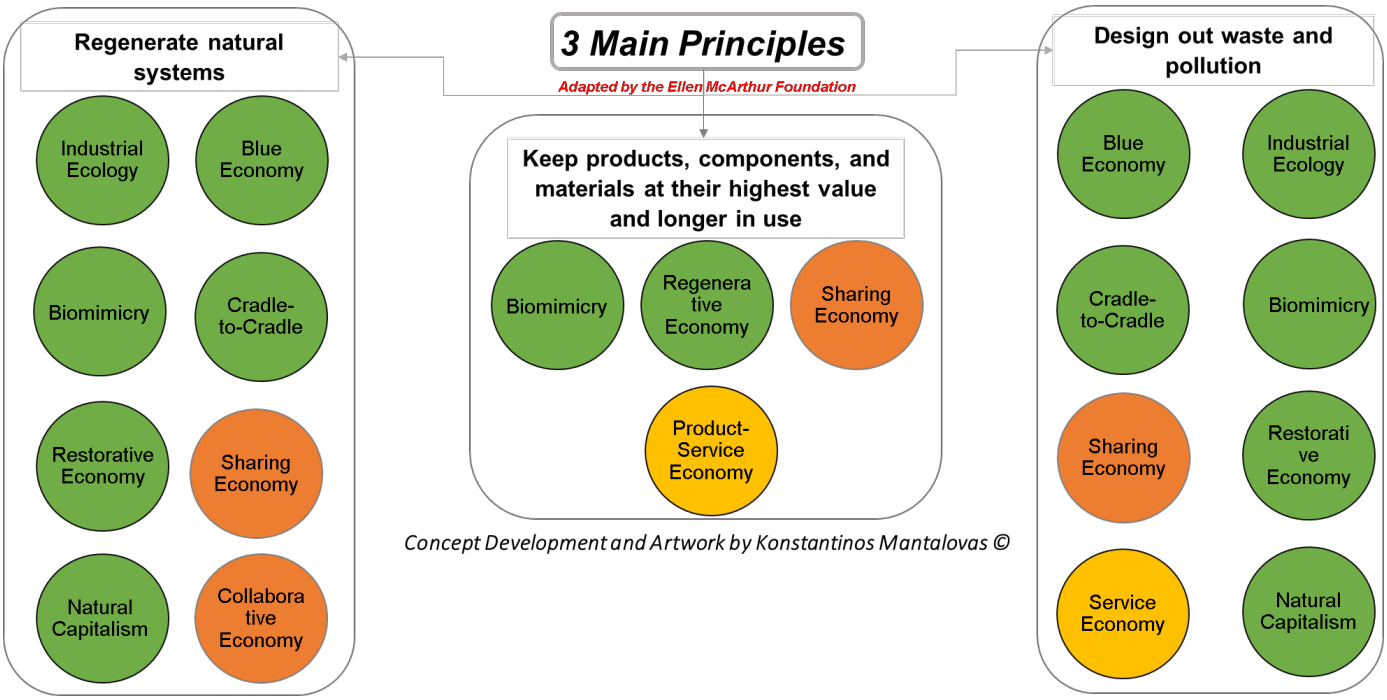
***Figure 1**. Schools of thought and economic approached forming the philosophy of CE*

Collaborative economy is a type of economy that has been decentralized and contains networks of individuals and communities instead of institutions. Th is type of economy aims to change the way of current production, consumption, finance and education [9], [26]. Different expressions that could describe this type of economy is “sharing economy/ peer economy” or even “collaborative consumption”. In the context of this type of economies, inventors and investors are brought together in order to compile the full procedure of sharing, selecting, producing and distributing new products. Moreover, the utilization of products through redistribution or shared access is a representative paradigm of this type of economies. Thus, the three main aspects of a collaborative economy can be described as:

1. A shift of power away from institutions towards networks of individual actors, 2.
2. Main drivers are technological innovation, shifting values, economic realities and environmental pressure and
3. Innovative and efficient product utilization [9], [19], [26].

Circular economy is a type of economy that integrates principles and approaches originating from all the different type of philosophies/approaches seen in Figure 1. Some of these

proposals date back to 1970 and the constant evolution of different, but with a similar end



goal, approaches have been developed since. CE was firstly mentioned in 1990 by Pearce and Turner who also modelled it [27]. After that, various researchers and economic approaches have helped CE to shape its principles and values as they are known today. In particular in Figure 2, the aforementioned schools of thought are being allocated to the three principles of CE defined for the asphalt pavements.

***Figure 2**. Schools of thoughts within the CE and how they can be allocated in help of defining the 3 main principles of CE*

Restorative Economy or "regenerative economy" represents the need for a new type of relationship to be created between the industrial systems and the ecosystems. This type of economy should be able to successfully and efficiently copy the natural mechanisms/practices of nature in order to restore the natural environment instead of degrading it. Products in the context of this economy should be accordingly designed so as to be able to be reused as material inputs to another system's lifecycle or to be easily deconstructed and reused or maintained with an ultimate goal of increasing biodiversity and not the opposite [9], [28]. Other similar approaches that have also been inspired by nature are: "cradle to cradle", "biomimicry", "blue economy", "industrial ecology" and "natural capitalism" [29]–[38]. The circular economy contains aspects of all three alternative economic models mentioned above. However, the concept distinguishes itself by focusing on the circularity of resources and the avoidance of waste.

Service economy supports the transition of procurement patterns from product purchasing to service purchasing. The consumer becomes a user, who pays for using a specific product instead of owning it. The term refers to an economic model where the importance is placed

on services and the majority of jobs are in service activities. By changing this economic pattern, the service provider not only has an incentive to cut down the resource expenditure but also to reduce the energy consumption in the production process [9], [38].

2.1 Benefits of a circular economic approach

The currently increasing demands for raw materials, the dependence on other countries, the increasing population and energy demand, and the impact on the planet consist the most crucial factors that lead to the belief that shifting towards such an economy can have great advantages. They are not just limited in environmental gains, but instead, the adoption of CE seems able to deliver economic benefits as well [9]. According to Su et al. 2013 [39] and Geng et al. 2012 [40] adoption of CE can lead to improved competitiveness of enterprises, more efficient use of materials and energy, increased competitive advantage and revenues from “waste” sales, and reduced environmental penalties. Preston (2012) and Park et al. (2010) state that implementation of CE can lead to more direct relationships with the consumers through collaborative consumption, while reducing the cost through the usage of recycled materials, the utilization of centralized waste management plans and the resale of used products, projecting a more positive corporate image [9], [41], [42]. Sinkin et al. (2008) identified the benefits of CE as reduced costs through less waste inefficiencies and pollution and increased profits and firm value. Kienbaum Management Consulting (2014) [43] published a report identifying the contribution of CE implementation as reduced costs through less waste inefficiencies and pollution, reduced material and energy costs and competitive advantage. Additional income streams from selling of refurbished products, reduced labour costs, enhanced customer value and differentiation are the most important benefits of CE according to Accenture (2014) [44]. Finally, through multiple publications of the Ellen MacArthur foundation the tremendous benefits of a transition to a CE in Europe are described as annual net material cost savings up to USD 630 billion in the European economy; reduced labour and energy costs, and costs for carbon emissions, along with improved customer interaction and dependency on resource prices. Finally, reduced product complexity and simpler lifecycles with reduced warranty risks and improved product design could be achieved [19], [21], [22]. It becomes thus apparent that the transition to CE is essential and stakeholders along with governmental bodies should aim towards the support and acceleration of this transition.

2.2 Circular Economy in Transportation Infrastructure

How can though circular economy principles be applied to take full advantage of such intelligent assets and help them contribute to wider smart city solutions? A large part of the answer lies in letting a highly networked transport system behave more like an ecosystem than a mechanism, relying less on top down control and more on local rules in an environment with rich feedback between vehicles and the infrastructure on which they rely. This could be achieved by “keeping the traffic and the information flowing”, “smart pricing and investing”, and “re-circulating the energy”. While digital technologies are transforming vehicles and how we interact with them, they are also reshaping city transport infrastructure. Smart infrastructure technologies, collectively known as intelligent transportation systems (ITS), are being embedded in traffic lights, car parks, toll-booths, roads and bridges, making them increasingly able to communicate with each other and with the vehicles that use them. Together these innovations offer the prospect of a transport infrastructure system that

suffers less congestion, is safer, and can be maintained predictively. However, this would not be a direct implementation of the three pre-defined principles of circular economy themselves in terms of material use, but instead a circular way of managing information and energy systems in order to satisfy a circular economic model aiming for more sustainable transportation infrastructure. Finally, it is worth mentioning that no specific and/or detailed guidelines are in place towards the transition to such integrated and intelligent systems.

2.3 Circular Economy in asphalt pavements

So far the most common practices that various national road authorities are implementing and are in line with the principles of circular economy are the recycling of reclaimed asphalt, the extension of the service life of their assets (preventive maintenance), the utilization of wastes in asphalt pavements, the attempt of increasing the allowed percentage of recycled materials inside the asphalt mixtures and partially the prioritization of regenerative energy sources. Sometimes however, these practices are actually implemented by the national road authorities not because they serve the principles of circular economy and are beneficial in terms of sustainability, but just because they are economically profitable and by the rule of thumb are considered as best practices. Again, nothing has been published in terms of asphalt pavements when it comes to legislative guidelines towards more circular pavements. This has not stopped though some individual stakeholders moving towards this direction. KRATON for example has moved forward by producing SYLVAROADTM RP1000; it is an additive derived from Crude Tall Oil (CTO), a renewable raw material, characterized as a by-product of the paper industry and developed by. It is able to increase the levels of RA incorporated into the asphalt mixtures while avoiding significant environmental burdens [12], [45]. Another noteworthy attempt towards more circular products has been made by Tarpaper Recycling, along with Super Asfalt, which have proposed the production of REC100. It is a mobile asphalt plant that ensures 100% utilization of the resources in roofing felt and asphalt waste, in order to produce asphalt mixtures incorporating 100% recycled resources. Unfortunately, though, the effort of the pavement engineering industry towards more circular and sustainable products can merely be characterized as adequate. More attempts thus should be made towards this direction. Finally, the extension of the application of the circular economy principles to an asset, such as road pavement, is a rather recent action also in the field of technical and scientific research; particularly, within the development of pavement management systems [46]. Only in recent years, the world of scientific research has begun dealing with the issue of the implementation of the circular economy in the production and treatment processes of bituminous mixtures in the road construction industry [47].

2.4 Life cycle boundary-crossing pavement materials and CE

System boundaries are defined by the LCA practitioner and thus, when strictly and precisely defined, materials will only be a part of the system boundary; namely the system boundary under study. If someone needs to consider the previous life cycle or some of the stages of the previous/next life cycle of the specific materials, then new system boundaries must be redefined. An allocation should be performed from the practitioner to define how much of the environmental burden was/will be projected in the previous/next life cycle, or stages of it, and how much in the system boundaries involved in the product system under investigation

Hence to accurately deal with “boundary-crossing” material flows the suggested strategy is:

- Precise Definition of the system boundaries under study.
- Material flow analysis [substance flow analysis] to determine the exact flow path of the materials.
- Perform allocation in order to identify the impacts of the boundary-crossing, desired materials.

2.5 Multi life cycle assessment for asphalt pavements in light of the CE

Through multiple reuses or remanufacturing after the end-of-life (EOL) stage, a product can experience more than one life cycle. Such products are referred to as multiple life cycle (MLC) products. MLCA so far in the current existing literature review has been applied to mechanical products that can be easily reclaimed -taken out of their use phase- and repaired, remanufactured, reused or reengineered in order to be reintroduced to the exact same product system, under the same functional unit. However, this is not the case in the asphalt pavement industry. If someone was to define an asphalt layer as a product, then in the case of asphalt pavements this product in order to be repaired for example, it is not taken out of the use phase reengineered and put back into the same exact place and composition to fulfil its FU purpose; but instead this could be a patching or a crack sealing process. Thus, my suggestion for someone that for his own reasons would like to use the MLCA approach to the road pavements industry would be to first define the following terms for the context of asphalt pavements:

- **Repair of an asphalt pavement**
- **Reuse of an asphalt pavement**
- **Reengineering of an asphalt pavement**
- **Recycling of an asphalt pavement**

This seems a bit unorthodox for asphalt pavements as you have probably realized by now. Thus my suggestion again is to maintain the use phase of the life cycle of an asphalt pavements as the stage B2: “maintenance” according to ISO 14040, 14044, EN15384; and THEN, only after having defined what end of of life means for your project and pavement, describe and define precisely the reclaiming procedure of the materials constituting the pavement and their reintroduction into the product system. This seems to be possible only if the materials are utilized again in the same product system and NOT in another similar or even identical. The same product system has to be utilized, so open loops are avoided. However since a lot of RA is being collected, stored and utilized in different locations and projects that would mean that the MLCA would have no beneficial and meaningful purpose to be used under these circumstances. It could be hence, in my personal opinion utilized if someone was to think that it is necessary during the end of life of a pavement only and only when reclaimed materials are going to be used for the same product system after the end of their usefulness. Moreover, designing an MLC product is an exemplary design approach for enhancing the sustainability of the product. A thoughtful design innovation at the design concept and embodiment stage can accomplish the objective of MLC products. However, for the asphalt pavements there is not a significant tendency towards more thoughtful design innovation actually in place, since the main principles of pavement design have been in use for a lot of years now, without fundamental alterations.

Another limitation that is devastating for the implementation of the Multi life cycle assessment for asphalt pavements is the lack of data. In the LCI phase, the remanufacturing and recycling related data are the most important variables in the MLCA study. The parameters in the MLC system are usually set based on the product material and the number of components which can be used for the next life cycle. However, currently there is not a plethora of available data about energy, resources and emissions during the re-utilisation of reclaimed materials in the pavement engineering field and thus, a multi life cycle analysis, although can be considered an attempt for an increased accuracy in the environmental impacts of a pavement, might end up being abused and extremely inaccurate and fairly approximate. Hence, what is actually recommended for the NRAs and the involved stake holders is to make a step further towards systematic data collection about every aspect of the life cycle of their assets. Moreover, lately a plethora of LCA case studies in asphalt mixtures and pavements has been recorded. Different assumptions, different system boundaries, different allocation and cut off rules are being implemented in different studies, leading to confusing results. It becomes in this way obvious that NRAs and people interested to invest in this knowledge gap, should push towards the development of a harmonized methodology to be utilized only for pavements. In this methodology the data collection procedures and requirements along with system boundaries and functional units, allocation procedures and cut off rules should be strictly defined. Finally, terms such as recycling, reusing, reengineering, refurbishing and repairing should be accurately defined before thinking of moving to multi life cycle assessment approaches. In other words, the single life cycle assessment exercises in the pavement engineering sector should firstly be "standardized" and then if someone sees a need for a system boundary extension to multi life cycle assessment, after having a defined framework, could move towards this direction easier.

2.6 CE and life cycle sustainability assessment

Life cycle sustainability assessment (LCSA) refers to the evaluation of all environmental, social and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle. Potential and future decision-makers, stakeholders, enterprises NRAs and consumers can benefit from LCSA in the following ways:

- LCSA enables practitioners to organize complex environmental, economic and social information and data in a structured form.
- LCSA helps in clarifying the trade-offs between the three sustainability pillars, life cycle stages and impacts, products and generations by providing a more comprehensive picture of the positive and negative impacts along the product life cycle.
- LCSA will show enterprises how to become more responsible for their business by taking into account the full spectrum of impacts associated with their products and services.
- LCSA promotes awareness in value chain actors on sustainability issues.
- LCSA supports enterprises and value chain actors in identifying weaknesses and enabling further improvements of a product life cycle. For instance, it supports decision-makers in enterprises in finding more sustainable means of production and in designing more sustainable products.

In general thus, LCSA can help decision makers to identify which is the most sustainable alternative when it comes to pavement design, mix design, transport, production, construction, maintenance, and end of life. In other worlds LCSA can assess and compare the overall impacts of all the processes included in the defined system boundaries during the life cycle of a pavements. Performing LCSA for multiple life cycles will be extremely inaccurate and biased since most of the NRAs and stakeholders cannot account for future maintenance regimes or cannot know about extreme events that may happen in the future and can damage the pavements which in turn would need a maintenance action. The majority of NRAs does not perform life cycle sustainability for the life cycles of their assets yet. Thus, it would be wise to define a framework of doing so and then after detecting the necessity to move towards multiple life cycle sustainability assessment and only then, they could invest in utilizing it after defining a wider and extended framework.

> ***All of the aforementioned are valid if the LCSA is used as a tool for sustainable decision making during the tender call for a project and during its design. If LCSA is to be used after something has been constructed and already in use is meaningless in the context of sustainable decision making and development.***

However, when sustainability meets the circular economy and the effort of the pavement engineering industry towards more sustainable and circular products, the environmental impacts of such an attempt have not been assessed yet. Circularity indicators are already integrated into various life cycle management tactics but not their environmental assessment. For example, Germany's resource efficiency plan[ProGress]. The Netherlands are now starting to follow the circularity indicator characterized as material circularity index within in the building assets, which can be extended to pavement applications [CB23 Plattform]. Circularity indicators can be integrated into the LCSA frameworks. For example: [https://doi.org/10.3390/su12020594], [https://doi.org/10.1016/j.resconrec.2018.10.002] . Simpler indicators can be used for NRAs as a first step, such as recycling rates of reclaimed materials.The framework of LCA is not taking under consideration the circularity of the end-product, and the frameworks of circularity assessment do not consider the environmental impacts of the corresponding production process. Thus, it appears necessary for an approach that merges both aspects to be adopted. In other words, CE-related initiatives should be carefully examined case-by-case; and in the context of asphalt mixtures, a composite approach that can identify and evaluate the impacts of the asphalt mixtures' increased circularity in the environment, needs to be adopted. An approach towards the integration of circularity within the framework of Life Cycle Sustainability Assessment has to be followed and supported. Hence, an integrated framework of environmental sustainability and circularity assessment of asphalt mixtures could be adopted. No previous attempts of the integration of circularity assessment within the sustainability assessment of asphalt mixtures have been recorded. Thus, naturally, the first step towards this integration is the combined assessment of the environmental impacts of the life cycle of asphalt mixtures along with their levels of circularity. The usefulness of such an assessment is inextricably correlated with the understanding of the underlying importance of the sustainability and circularity assessment coupling and the ability of NRAs and stakeholders to assess the sustainability of their CE implementation altogether. In other words NRAs that are eager to become more circular would be in this way able to assess if they are simultaneously sustainable as well circular and vice a versa. In some cases and under specific circumstances, a CE-related initiative could be unsustainable. The implementation of such methodology to asphalt mixtures could lead to increased

awareness of national road authorities and stakeholders belonging to the sphere of road engineering and the management sector, about the level of their businesses' circularity and environmental sustainability and could eventually constitute a tool for the involved decision-makers for evaluating how environmentally sustainable their circular practices and choices are.

Such a framework, referring to asphalt mixtures so far and can integrate the circularity and environmental sustainability assessment of them can be found here: https://doi.org/10.3390/su12020594. It can be utilized as a ranking tool between asphalt mixture alternatives based on their environmental impacts weighted by their own degree of circularity.

3 Current situation: Analysis of the Roadmaps produced by national/regional authorities towards Circular Economy

Policies that encourage the implementation of the principles of CE have already been introduced in some cases. The European Commission following the increasing pressures on natural resources launched the European Resource Efficiency Platform (EREP) in 2012 [48]. The target was actually to move towards a harmonized and controlled transition from linear economic patterns to circular ones. As described in the published manifesto the desirable adopted approach would be a transition towards a resource efficient and ultimately restorative circular economy. After the foundation of the aforementioned platform, which is composed by practitioners and politicians, guidelines have been publicly provided, in order for the implementation of "circular economy(-friendly)" approaches and frameworks to be widely adopted and finally implemented [3], [48]. Moreover, the United Kingdom acting as a pioneer in this context was the first European country to publish standards about the implementation of CE in 2017 [17]. France followed with the development of voluntary standards called XP X30, published by ANFOR in 2018. The title is "Circular economy - Circular economy project management system - Requirements and guidelines –" and the standards propose a common understanding grid, laying out the terms, principles, and practices relevant to CE. The development of the aforementioned standards led to the creation of a technical committee within the International Organization for Standardization (ISO TC 323) which is working on enriching and developing international standards for the field of circular economy. The proposed deliverables will apply to any organization or group of organizations wishing to implement circular economy projects, such as commercial organizations, public services and not-for-profit organizations. Specifications relevant to already covered and standardized aspects such as eco-design, life cycle assessment, environmental management and sustainable procurement will not be included in the standards. Moreover, in July 2019, Platform CB'23 from the Netherlands has published a framework for circular construction, focusing on the building works. The requirements for a uniform measurement method of circularity are emphasized and a circularity quantifying approach is proposed accordingly [49]. Finally, the European Union understanding the necessity of CE had officially adopted an action plan in 2015 to help accelerate Europe's transition towards a circular economy, boost global competitiveness, promote sustainable

economic growth and generate new jobs and in 2019 the Circular Economy Action Plan has been fully completed [50]. However, when it comes to transport infrastructures and asphalt pavements specifically, it becomes difficult to encompass and conceptualize all these principles in their life cycles. Indeed, there is a plethora of roadmaps towards circular economy that have been published attempting to pave the way towards achieving circularity in national levels but not a lot of effort has been made to specifically address the sector of road engineering. In Table 1, all the national plans and/or roadmaps published online through the European CE Stakeholder Platform can be found, along with the unique roadmap related directly with national road authorities.

Table 1. *National plans and/or roadmaps published online through the European CE Stakeholder Platform (https://circulareconomy.europa.eu/platform/en/strategies?page=1)*

A. The Danube goes Circular - Transnational Strategy to Accelerate Transition Towards a Circular Economy in the Danube Region (ENGLISH)	Austria, Bulgaria, Croatia, Czech Republic, Germany, Hungary, Romania, Slovak Republic, Slovenia, Ukraine, Moldova, Serbia, Montenegro, Bosnia and Herzegovina
B. Circular Flanders kick-off statement (ENGLISH)	Belgium
C. Regional plan for the circular economy, Brussels Capital Region (DUTCH, FRENCH)	Belgium
D. Leading the cycle - Finnish road map to a circular economy 2016–2025 (ENGLISH)	Finland
E. 50 Measures for a 100% Circular Economy (ENGLISH)	France
F. German Resource Efficiency Programme II (ENGLISH)	Germany
G. National Action Plan on Circular Economy (ENGLISH)	Greece
H. Towards a Model of Circular Economy for Italy - Overview and Strategic Framework (ENGLISH)	Italy
I. Luxembourg's National Waste and Resource Management Plan (FRENCH)	Luxemburg
J. Leading the transition: a circular economy action plan for Portugal (ENGLISH)	Portugal
K. Strategy for the Transition to the Circular Economy in the Municipality of Maribor (ENGLISH)	Slovenia
L. Roadmap towards the Circular Economy in	Slovenia

Slovenia (ENGLISH)	
M. Extremadura 2030 (SPANISH)	Spain
N. Strategy of the government of Catalonia: Promoting green and circular economy in Catalonia (SPANISH/CATALAN)	Spain
O. Circular the Hague: transition to a sustainable economy (DUTCH)	The Netherlands
P. A Circular Economy in the Netherlands by 2050 (ENGLISH)	The Netherlands
Q. Kernmethode voor het meten van circulariteit in de bouw (DUTCH)	The Netherlands
R. Making Things Last: a circular economy for Scotland (ENGLISH)	United Kingdom
S. London's Circular Economy Route Map (ENGLISH)	United Kingdom
T. Circular Economy Approach and Routemap* (ENGLISH)	United Kingdom

**It is worth mentioning that the only National Road Authority that has published a publicly available roadmap towards circular economy is Highways England in collaboration with AECOM and ATKINS.*

A: The Danube goes Circular - Transnational Strategy to Accelerate Transition Towards a Circular Economy in the Danube Region [51]**.** It is a strategic document prepared on the basis of studies, reports and analyses made by national and/or European organisations, with the purpose of setting the objectives to improve the framework conditions and policy instruments for eco-innovation and the transition to a circular economy [51]. The reference period is from 2019 until 2030 and the target groups that the document is aiming towards are National, regional and local public authorities, business support organisations, higher education and research organisations, private and public business entities [51]. In this strategic document a framework methodology for measuring circular performance of Danube region is explained. Few of the selected indicators refer to the quantification of the percentage of materials that have been reused (such as Circular material use (CMU) rate) and the framework can be linked to the built environment indeed, but not directly to road pavements. Furthermore, the key challenges were identified with regard to the transition of the Danube Region towards a circular economy are identified and strategic objectives and sets of recommendations are proposed, stressing the need for new circular business models [51].

B: Circular Flanders kick-off statement [52]**.** This kick-off statement was published by Vlaanderen Circulair and refers to the Flanders region. The document emphasizes the need for transition from a linear economy to a circular economy, outlining the benefits that the latter can provide. Their transition action plan is analysed, and it is based on three main principles: circular purchasing, circular cities and circular business. It is worth mentioning that the pillar of circular cities also includes built environment and thus transportation infrastructures, but without any further details relevant to road pavements [52].

D: Leading the cycle - Finnish road map to a circular economy 2016–2025 [53]. Published by SITRA in 2016, this roadmap covers the strategic action plan of Finland towards a circular economy from 2016 to 2025. Emphasis is given to the fact that for an actual transition to circular economy, systematic change is needed. The action plan is described and analysed and the circular economy targets for the economy, the society and the environment are defined. Moreover, the roadmap separates the actions needed into five main sectors: food systems, forest-based loops, technical loops, transportation and logistics, and common actions. Practices to implement CE within the built environment and transportation infrastructures are explained and promoted, without specific reference to road pavements [53].

E: 50 Measures for a 100% Circular Economy [54]. The roadmap was published by the French Ministry for an Ecological and Solidary Transition and Ministry for the Economy and Finance in 2018. It analyses the reasons behind the need for transition to a circular economy and provide the objectives of the published framework. The roadmap is divided in four major action areas (better production, better consumption, better management of wastes and mobilization of all the actors). Detailed description of the hey objectives of each are is being provided along with the key measures and the targeted audience. The roadmap includes the built environment and infrastructures, without direct mention to road pavements. However a plethora of the measures can be directly implemented to the latter [54].

F: German Resource Efficiency Programme II, Programme for the sustainable use and conservation of natural resources [55]. It is the second resource efficiency published by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). The first one was published in 2012 paving the road for resource efficiency from 2012 to 2015. However, the second resource efficiency program of Germany refers to energy efficiency as well. It emphasizes and describes the inclusion and interaction of other resources such as water, soil, air, living organisms, land and resources as food and feedstuff. Analytic indicators are presented in the document along with the desirable targets and the action areas under focus. It is worth mentioning that the specific resource efficiency programme takes under consideration the built environment, the transportation infrastructures and there are targeted mentions directly to asphalt recycling and re-circulation [55].

G: National Action Plan on Circular Economy [56]. The Greek national action plan on Circular Economy was published in the end of 2018 and analyses the compatibility of CE with the recently adopted development plan. In the document the policy axes to achieve a CE are described along with the main strategies and goals to be followed in the future. Finally, the operational and governance action plan with its regulatory and legislative reforms is presented. The specific action plan also refers to urban development and the built environment setting targets relevant to the construction sector, without being specific about road pavements though. It is worth mentioning that in 2017 the Greek government adopted a set of laws relevant to waste management and materials efficiency that supports in a legislative way the implementation of CE principles [56], [57].

H: Towards a Model of Circular Economy for Italy - Overview and Strategic Framework [58]. The Italian roadmap towards circular economy was published in 2017 by the “Ministero dell’Ambiente e della Tutela del Territorio e del Mare and the “Ministero dello Sviluppo Economico”. It describes the current situation in Europe and specifically in Italy while stressing that for an effective transition to CE, the companies, the consumers and also the fiscal and economic instruments have to walk towards the same direction. In order for this

transition to be ensured, indicators measuring circularity are analysed along with emphasis given in the importance of the traceability of the resources and the production chains and the promotion of sustainable production and consumption models. The roadmap includes recommendations for the construction sector, but nothing specifically addressed to transportation infrastructures and/or road pavements.

J: Leading the transition: a circular economy action plan for Portugal [59]. It is an action plan published in 2017 that presents a constitute proposal for action towards the implementation of CE. Within the published action plan the importance of a CE is emphasized and the approach of achieving a CE is analysed. The aim is to introduce CE principles in three levels: macro, meso and micro. It is worth mentioning that according to the action plan, guidelines for the most important and environmentally relevant sectors will be developed and detailed goals and complementary indicators will be present, monitoring the progress. Guidelines will be developed also specifically for the built infrastructures and roads, covered by the complementary indicators [59].

K: Strategy for the Transition to the Circular Economy in the Municipality of Maribor [60]**.** This strategy is in reality the analysis of an innovative models as a system for managing all the resources available in the Municipality of Maribor and the wider urban area. The purpose of the Strategy is cross-sectoral cooperation in handling, processing, re-use and development of resources, which deals with the circular economy in Maribor in seven selected sectors. The model and its' horizontal and vertical deployment are analysed and there are strategic measures referring to build environment and transportation infrastructure. However, no indicators for measuring the expected circularity are being developed but mentions exist about the importance of improved energy and resource efficiency in each analysed sector [60].

L: Roadmap towards the Circular Economy in Slovenia [61]. This roadmap was published in 2018 and it is a part of Slovenia's strategic development priorities. It emphasizes that the transition to CE is not a trend but a civilizational necessity instead. It defines and analyses the circular triangle, which is based on Circular Culture (citizens as the core), Circular Change (public sector as the core) and Circular Economy (companies as the core). Moreover, all the areas in which the transition should be prioritized are recognized and the potentials occurring due to CE within these areas are analysed. One of the strategic areas is "mobility"; within this area transportation infrastructures are included, and recommendations are given towards more circular practices. However, no direct mention exists about road pavements specifically [61].

P: A Circular Economy in the Netherlands by 2050 [62]. It is more in reality a government-wide programme for the transition of the Netherlands to a CE, published in 2016. In the document the promising prospects of the implementation of CE are analysed along with the necessity for the transition towards such an economy. Moreover, the economic opportunities of reusing materials are described and the vision along with the goals of the programmed are mentioned. Generic and specific policies for change for each sector and/or value chain are provided and an attempt towards fostering legislations and removing obstacles is made. In the document the prioritized sectors of biomass and food, plastics, the manufacturing industry, consumer good and construction sector, are explained along with the action plan for each one of them. It is worth mentioning that within the construction sector, asphalt pavements and the reuse and/or the recycling of asphalt are

mentioned and promoted, supported by best practices paradigms and finally the anticipated strategic goals [62].

Q: Kernmethode voor het meten van circulariteit in de bouw [49]. It is worth mentioning that the specific document was not found in the European CE Stakeholder Platform, but instead was published by Platform CB'23. It was reviewed due to the fact that it consists one of the most analytic and comprehensive approaches towards the implementation of CE within the construction sector holistically; meaning that every time of built infrastructure could benefit by following the proposed approach and methodology. It focuses on the material aspects of circularity in an attempt to promote the integral sustainability that The Netherlands is already pursuing as already declared in "A CE in the Netherlands by 2050" [62]. It is focusing in the built environment, referring thus to the transportation infrastructure as well. To do so, within this report, it is described how to develop "passports for construction" that represent a digital representation of a construction work and it depends on the life phase of the work itself and the value that than can be created with this data. Life Cycle Assessment is coupled with the creation of a passport and the metrics of alternative passports are compared. Moreover, an approach to quantify the circularity of construction works is defined and direct mentions exist about transportation infrastructures and asphalt based material [49].

R: Making Things Last: a circular economy for Scotland [63]. It was published in 2016 by the Scottish government and it is a strategy that sets Scotland's priorities for moving towards a more circular economy. It builds on Scotland's progress in the zero waste and resource efficiency agendas. In the document the environmental, economic and societal benefits emerging through the implementation of CE are analysed. Moreover, it is explained that in order for the transition to CE to be achieved priority should be given to the following aspects: waste prevention, design, reuse, repair, remanufacture, recycling, producer responsibility for reuse and recycling, recovering value from biological resources, energy recovery, and landfilling. In addition, the built environment along with the construction sector and transportation infrastructures are mentioned but without focus on road pavements. Finally, targets are being set and metrics such as waste reduction, recycling rates and re-use rates are set as indicators [63].

S: London's Circular Economy Route Map [64]. The London waste and recycling board published this route map in 2017. It is a route map attempting to accelerate the growth and development of CE across London, whilst setting out an ambitious plan of action. Sectors such as food, textiles, electrical, plastics and built environment are analysed and recommendations along with an action plan for each are provided. Focus is given to the built environment and the buildings sector and then transportation infrastructure indeed, without specific mentions of asphalt roads [64].

T: Circular Economy Approach and Route map* [65]. This route map is the only one published by a national road authority. It was published in 2016 by Highways England in collaboration with AECOM and ATKINS. Its' objectives are described as: the development of a corporate circular economy strategy within the context of the Highways England Sustainable Development strategy; the definition of what circularity means for Highways England; the shift towards a fully optimised resource use on Highways England's projects and operations and to deliver a plan to embed a culture of resource efficiency across the organisation and Highways England's supply chain. It is separated in 4 core components: governance, procurement, monitoring and reporting, tools and guidance. Resource efficiency, utilisation of waste and minimisation of resources exploitation are the cores of the

proposed actions of this report. It is worth mentioning that direct mention to transportation infrastructures in general and to asphalt pavements in specific can be found, stating that the wastes originating from the life cycle management of roads should be exploited with utmost efficiency. Finally, some case studies are presented, indicating the usefulness of this roadmap and the implementation of CE. However, specific indicators and metrics have not been developed for the quantification of the circularity, but instead key performance-based indicators are mentioned.

3.1 Circular Economy roadmaps: Analysis and discussion of the reviewed documents

Reviewing the documents collected from the European Circular Economy Stakeholder Platform, it becomes obvious that the principles of CE within the transportation sector are not well established yet. It is worth mentioning that only one of the reviewed documents has officially been published by a national road authority i.e. Highways England, while the rest of them have been published by governmental bodies, ministries, companies and/or groups and platforms formed to promote circular thinking. Not all of them however are analytical and comprehensive delivering a specific set of strategic actions and indicators, metrics or desirable targets to be reached. Some of the most detailed publications are providing specified action plans for each sector to be followed and targets that need to be fulfilled under specific timetables in order for the transition to a CE to be actually realised. The most common points that can be found in the documents are initiatives such as more effective waste management and minimisation, utilisation of waste as resources to parallel industries, minimisation of CO2 emissions under predefined time horizon and resource and energy efficiency. When it comes to pavements however not specific mentions can be found in the documents apart from the ones published by the Highways England (United Kingdom), the Dutch government and Platform CB'23 (The Netherlands) and the Portuguese government (Portugal). There are examples of CE implementation that entails the promotion of asphalt recycling, the attempt to surpass legislations that restrict the massive recycling of asphalt, the common effort towards constructing and managing longer-lasting pavements and the plan towards the utilisation of renewable energy sources for the production, construction and maintenance of asphalt pavements. To sum up, it can be said that in general national road authorities so far have not invested into producing roadmaps towards the implementation of CE. As it is going to be analysed in the following chapter, this is happening due to lack of budget, lack of experts in CE within the national road authorities and due to the uncertainty of the successful implementation of CE, which also incorporates the lack of well-structured and comprehensive circular business models and incentives for the stakeholders associated with the market of asphalt pavements.

4 Current Situation: The perspective of the National Road Authorities

4.1 Tabulated results of the questionnaires

Questionnaires have been sent to a number of national road authorities in an attempt to gather knowledge in matters relevant to circular economy and the level of its implementation by them. The countries and their corresponding national road authorities, along with the replies in the questionnaires that have been sent, can be seen in Table 2. In addition, the complete section of the questionnaire that is relevant to the CE and analysed in this deliverable can be found in Appendix A.

Table 2. *Summarized results of the replies relevant to CE, provided for the questionnaire by the contacted national road authorities*

COUNTRY	**Austria**	**Belgium**	**Denmark**	**Germany**	**United Kingdom**	**Lithuania**	**Norway**	**Slovenia**	**Sweden**	**Netherlands**
Awareness about CE	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
Principles of CE that the NRA is familiar with	Design out/minimize waste	-	Preserve and extend what is already made	Design out/minimize waste	Design out/minimize waste	Design out/minimize waste	Design out/minimize waste	Design out/minimize waste	Efficient use of existing and renewable resources where material flows are recirculated.	Design out/minimize waste
	Use waste as resource			Use waste as resource	Use waste as resource	Use waste as resource	Preserve and extend what is already made	Use waste as resource		Use waste as a resource
	Prioritize regenerative resources			-	Preserve and extend what is already made	-	-	-		Prioritize regenerative resources
	Preserve and extend what is already made				-				Use waste as resource	Preserve and extend what is already made
Implemented CE principles	Design out/minimize waste	-	Preserve and extend what is already made	Use waste as resource	Design out/minimise waste	-	-	Use waste as resource	Preserve and extend what is already made	Use waste as a resource
	Use waste as resource				Use waste as resource					Preserve and extend what is already made
	Prioritize regenerative resources				Preserve and extend what is already made (limited degree through					-

					preventive maintenance)					
CE practices	Specifications in guidelines and internal planning manuals	Lifetime Enhancing Maintenance (incipient)	Preserve the road condition to extend the life-time using proper maintenance strategies.	Circular economy is largely based on waste legislation (Kreislaufwirtschaftsgesetz national law of EU directive 2008/98/EG)	Preventive maintenance Use waste as resource	Trying out and testing materials from waste in trial sections to find out their potential use and limitations in road structures. Existing materials are being evaluated during design phase to maximize their second use and minimize waste	-	Recycling and reusing of asphalt	Removing restrictions on asphalt recycling.	Incorporation of recycled material in asphalt mixtures (foundation layers as well as pavement layers), periodic maintenance to repair aged spots of the pavement and preventive maintenance with the use of rejuvenators
Challenges of implementing CE practices	Reasons for non-implementation is when a certain lifetime or required requirements cannot be achieved.	-	-	-	-	In some cases, there are technology limitations. A limiting factor is that LRA is administration body and its rights are regulated very strictly	-	-	Difficult to avoid downgrading.	The durability of recycled materials or bio-based is a challenge. Shorter durability is undesirable as it will cause cost, environmental impact and nuisance for the road user. As it takes too long to find out in practice what durability performance is achieved, other test methods are needed
CE	**YES**	**NO**	**NO**	**YES**	**NO**	**NO**	**NO**	**-**	**NO**	**NO**

indicators/ metrics	End of Life recycling input rate Resource Efficiency	-	-	Quota of reuse of RAP in hot mix asphalt. (87 % in 2016)	-	-	-	-	-	-
Challenges of developing indicators/ metrics	-	-	The problem is the budget	-	This would be led by others within Highways England, rather than the Pavements Team specifically.	No clear rules	-	-	-	-
Existing Roadmap towards CE	**YES* (Sustainability Strategy)**	**YES*** (Not published by an NRA)	**NO**	**NO**	**YES**	**NO**	**NO**	-	**-**	**YES**
Publicly available	https://www.asfinag.at/media/3077/asfinag-nachhaltigkeitsbericht_2017.pdf	https://vlaanderen-circulair.be/en	-	-	https://s3.eu-west-2.amazonaws.com/assets.highwaysengland.co.uk/specialist-information/knowledge-compendium/Circular+Economy+-+Approach+and+Routemap.pdf	-	-	-	-	https://platformcb23.nl/leidraden (referring to Construction works)
Challenges of developing a Roadmap towards CE	-	-	The change in policy and lack of common point of view which does allow to combine efforts	The incentive for reuse is industry driven.	The above is not specific to pavements – interpretation of what the circular economy means specifically for road pavements would be useful	There are no incentives for a roadmap development.	-	-	-	-

4.2 Analysis of the questionnaire findings

Following Table 2, it can be seen that all the NRAs contacted are aware of the concept of CE and have at least minimum knowledge about what it is that it represents. All the NRAs seem to be familiar with the most commonly known and easily applicable principles of the CE, apart from the NRA that represents Belgium. Austria's and the Netherlands' NRAs seem to be the most informed in terms of CE knowledge, exhibiting the higher number of CE principles that they are familiar with. Among all the NRAs to which the questionnaire was sent, the most commonly known principles of CE are:

- Design out/minimize waste
- Use waste as resource
- Preserve and extend what is already made (usually translated as "preventive maintenance")

When the NRAs were asked about which principles of the CE are implementing, Belgium, Norway and Lithuania replied that none of them is currently being implemented. However, among the remaining NRAs the most common answers that were received in terms of implemented CE principles are:

- Preserve and extend what is already made
- Design out/minimize waste

In the question about which are the applied practices that indicate the implementation of some of the CE principles, Austria's NRA replied with specifications in guidelines and internal planning manuals, similarly to Germany's NRA which is following the waste legislation (Kreislaufwirtschaftsgesetz national law of EU directive 2008/98/EG), Belgium's, United Kingdom's and Denmark's NRAs stated that are preserving the road condition and extending its service life. Lithuania is trying to test waste materials in trial sections in order to promote the use of waste as a resource, while Slovenia and Slovakia are marching towards removing restrictions on asphalt recycling and keep recycling and reusing asphalt. Finally, the Netherlands are incorporating recycled materials in asphalt mixtures and extensively perform periodic preventive maintenance to extend the lifecycle of the asphalt pavements. Thus, the most commonly applied practices that indicate the implementation of some of the aforementioned principles are:

- Removing restrictions on asphalt recycling
- Extending the service life of the asphalt pavements, usually by preventive maintenance
- Testing waste materials for potential utilization as resources on asphalt pavements

In this point it is worth mentioning that although the concept of CE is not totally new as analysed in the introduction and hence, some of its characteristics have already been practiced for years by National Road Authorities. Aspects such as recycling, resource efficiency and utilization of waste materials in foundation layers are not new topics and have been implemented by NRAs for years now. Indeed, these practices that have been adopted for a long time now are in line with the principles of CE and yet some of the NRAs do not project them as "supporting the CE". In other words, although some NRAs might have stated that no specific principles of the CE are being implemented, they still recycle and trying to use their resources efficiently while extending the service life of their assets. This turns out to

be a matter of definitions. Some country might do nothing about sustainability or CE but do have legislation or targets for using waste in foundations and are thus, although they do not use the word itself, practicing CE. Moving on, the challenges of implementing CE practices that the NRAs stated exist are the inadequate technical and mechanical performance of recycled materials, technological and administrative limitations and the difficulty laying upon the downgrading of recyclable materials. When it comes to CE indicators and/or metrics, only the NRAs of Austria and Germany are implementing some of them. In detail, Austria's NRA is utilizing the end of life recycling input, while Germany's the quota of reuse of Reclaimed asphalt pavement in the production of hot mix asphalt.

The rest of the NRAs state that the challenges encountered towards developing or implementing circularity metrics are the budget restrictions along with the lack of clear rules/legislations to support this effort. Finally, the only NRA that has officially published a roadmap or a strategy towards the implementation of CE is the one of United Kingdom's. However, Austria's NRA is following the national sustainability strategy, Belgium's has adopted the circular roadmap published by the "Circular Flanders", and the Netherlands' is following the guidelines towards circularity, recently published by Platform B23. The challenges of doing so as well, that most of the remaining NRAs are encountering are the changes in policy and lack of common points of view which does allow to combine efforts, the lack of incentives and the fact that the existing incentives foe the reuse of asphalt is mostly industry driven.

4.3 CE communication of National Road Authorities

In order to identify the ways that different NRAs utilise in order to communicate CE, an online search has been undertaken The search has been conducted online in English and in the local languages of the NRAs. The websites of the listed NARs in Table 3. have been visited and in their "search" function, the words "circular economy" and "sustainability were searched. The results of the search have been tabulated in Table 3.

Table 3. *Ways that NRAs are implementing and communicating CE*

National Road Authority per Country	***CE Implementation Plan and communication***
Austria [ASFiNAG]	Sustainability strategies and reports / nothing related to CE
Belgium [Agency for roads and traffic / Wallonia General Direction for roads and traffic]	Sustainability related research and reporting / nothing related to CE
Denmark [Danish Road Directorate - Vejdirektoratet]	Environmental Assessment reports, Sustainability related research and reporting / nothing related to CE
Germany [Federal Ministry of Transport, Building and Urban Development - Bundesministerium für Verkehr und digitale Infrastruktur]	Climate Action Program 2030 / CE related: preservation of resources, maximization of resource efficiency, resource cycle management/bioeconomy
United Kingdom [Highways England, Transport Scotland, Welsh Government, Roads Service	Circular Economy Approach and Route map
Lithuania [Lithuanian Road Administration and family of road engineers]	Nothing related to CE

Norway [Norwegian Public Roads Administration -NPRA]	Sustainability related research and reporting / nothing related to CE
Slovenia [Slovenian Roads & Infrastructure Agency]	Conferences organized, JRC collaborations for circular economy implementation / Slovenian development days to promote CE
Sweden [Swedish Transport Administration-Trafikverket]	Sustainability related research and reporting / nothing related to CE
Netherlands [Rijkswaterstaat, State advisors for urban development & infrastructure]	Circular Public Procurement / Resource Efficient business models / National Waste management Plan

As can be observed, only 4 out of 10 investigated NRAs are attempting to communicate the ways that CE principles are projected through their operational patterns. The only NRA that has published an "Approach and Route Map" towards circular economy is the Highways England. In which future visions and plans that are aligned with the implementation of CE are described. Moreover, Germany's NRA seems to be in a similar path since it has developed a plan called Climate Action Program 2030, which contributes towards the implementation of more circular and sustainable practices. In addition to that, practices relevant to the preservation of resources, maximization of resource efficiency, resource cycle management and bio economy are strongly supported and communicated. It can be seen however that the majority of the investigated NRAs is publishing sustainability reports and communicating their plans in terms of sustainability, but CE is still not a matter that seems to be under their attention. There is still thus, a significant opportunity for knowledge development in the field of road engineering agencies and on the topic of CE.

5 Suggestions and recommendations for strategies towards the implementation of CE principles and knowledge development

5.1 Green Public Procurement for road design, construction and maintenance [66]

The European commission has invested into CE and sustainability in every sector. For the pavement engineering and road construction and maintenance sectors, a technical report has been published in 2016, detailing the practices that NRAs and involved stakeholders should be implementing for more sustainable and circular approaches. Moreover, a set of criteria has been developed, that can help stakeholders act immediately even without having a deep knowledge of CE and sustainability. EU commission has identified some of the most impactful stages and aspects of a road's lifecycle that when modified accordingly can be significantly beneficial for the environment and the economy, based on the principles of green procurement and CE. The stages/aspects identified are:

- **Pavement vehicle interaction (Mean Profile Depth [MPD], [International Roughness Index [IRI]:** higher fuel consumption has been detected with higher values of these two indicators and thus, lowest possible and acceptable values are suggested.
- **Resource efficient construction:** Since it has been found that by increasing the

resource efficiency during the construction and maintenance phases, can lead to decreased environmental impacts, the EU commission is suggesting the implementation of Life cycle assessment for every stage of the road construction and maintenance phases, along with increased attention to the embodied impacts of the transportation distances of the materials.

- **Recycled content:** Materials that able to be recycled within a closed loop perspective seem to be crucially beneficial for the environment. In this regard, it is suggested that high percentages of materials are recycled into the asphalt pavements while, however, complying with the performance requirements for the road pavement. It is highlighted that the transportation distance of the recycled materials should be assessed in order not to end up transporting materials to be recycled in such distances that in the end will impact the environment in a higher degree.
- **Materials transportation:** Significant focus is being given to the total transportation of the materials wither they are virgin are recycled. Transport distance can impose a significant environmental burden when an environmental assessment has not been undertaken. It is suggested that NRAs should adopt an indicator that is able to express the CO2eq per tonne of transported materials and thus can optimise the location of the plants and quarries in order to minimise the environmental impacts originating from the energy consumption during the transportation of the materials.
- **Excavated materials, soil and wastes management:** It is highly recommended that excavated materials such as soils and wastes that are not labelled as hazardous are reused on site. Moreover, it is proposed that tracking of the waste production is undertaken and recorded.
- **Water and habitat conservation:** Road drainage systems must comply with minimum technical requirements in order to adequately drain both stormwater from the road surface and sub-surface water from groundwater flows that may impact on the sub-base. Moreover, it is suggested that SUDS [Sustainable Urban Drainage Systems] are promoted and utilized in the asphalt pavements, while the addition of drainage components assisting the removal of sediment and solid particles is supported.

  Noise: Although both low-noise road surfaces and noise barriers contribute positively to the reduction of noise levels in targeted areas, whether one type of approach or the other, or a combination of both is the optimum solution, will depend very much upon. It is thus suggested, that noise emissions are monitored during the construction, use and maintenance phases and desirable thresholds should be set [ISO/DIS 11819-2]. Namely:

  - 87 dB(A) at 50 kph, and/or
  - 92 dB(A) at 70 kph, and/or
  - 95 dB(A) at 90 kph.
- **Congestion:** In order for extra potential environmental impacts due to congestion, fuel usage and lack planning to be avoided, traffic mitigation plans are suggested to be developed, not only during the construction stage of and asphalt road but also during its use and maintenance.
- **Maintenance and rehabilitation strategies:** The design team or the Design and Build tenderer or the Design Build and Operate tenderer shall include a Maintenance

& Rehabilitation Plan, that follows all the aforementioned suggestions, in the detailed design. For each section of road specifically characterised by specific construction methods, materials, environmental conditions, meteorological conditions and use, the M&R Plan shall, as a minimum:

- Include routine, preventive and rehabilitation actions;
- Optimise the cost-benefit ratio of the maintenance works;
- Declare the environmental performance of any routine, preventive and rehabilitation action/strategy
- Include the cost, expected intervals between maintenance activities, the Traffic Congestion Mitigation Plan and the Demolition Waste Management Plan for each action.

All the aforementioned suggestions and recommendations relevant to different stages and/or aspects of the construction, use and maintenance of a road can be seen summarised in Figure 3.

Figure 3 Suggestions and criteria to be fulfilled for the construction, use and maintenance of a road for a more sustainable and circular approach according to the European commission [64]

5.2 "Circular Economy: Principles for Buildings Design" [67]

Moreover, the European Commission has also published a document entitled "Circular Economy: Principles for Buildings Design" [67] and details the general principles that should be implemented if a more circular approach is to be adopted in the building sector. The document is specifically focused on buildings, but the main defined principles are presented here due to the fact that a lot of similarities exist between buildings and roads.

- **Design principles of circular economy and sustainable buildings are applicable**

to all actors along the value chain.

- **Sustainable choices must consider total life cycle costs, financial and non-financial return on investments.**
- **Viable business models must exist or be developed for each economic operator in the supply or value chain.**
- **Principles need to be applied considering proportionality - benefits should outweigh the costs.**
- **Better knowledge is needed about construction techniques to facilitate deconstruction and to enhance durability and adaptability of a building.**
- **Durability of buildings depends on better design, improved performance of construction products and information sharing.**
- **Prevent premature building demolishment by developing a new design culture.**
- **Design products and systems so that they can be easily reused, repaired, recycled or recovered.**

As aforementioned these principles are referring to buildings, but the majority of them can easily and immediately be transferred into the road sector and.

5.3 Targeted knowledge development of NRAs

Having identified the most commonly accepted definition of the CE, it shall thus mean that it would be time to attempt and translate it in the context of asphalt pavements. As mentioned in chapter 2, the three main principles of the CE are:

- *Design out waste and pollution*
- *Keep products, components, and materials at their highest value and in use*
- *Regenerate natural systems*

And hence, practical recommendations for the NRAs would have to be focusing on translating actions and approaches into an eligible hodgepodge of measurable outputs towards the implementation of the aforementioned principles. Moreover, challenges related to the transition of the road engineering industry have been presented in chapter 3 and 4. The combination of these pieces of information while keeping the sustainability assessment of asphalt pavements in mind are inevitably leading towards identifying areas of knowledge that if developed, could lead to a better understanding of CE and a more informed implementation of its principles in the context of asphalt pavements. The areas for knowledge development that have been identified by the author and could potentially improve the understanding and the implementation of circular economy by the NRAs are presented in Table 4, along with the pre-defined principles of CE that they fulfil. However, in this point it is worth mentioning that apart from working towards the implementation of CE and the sustainability of asphalt pavements its important for the various NRAs to also find more attractive and innovative ways of communicating their status in terms of circularity, since appropriate communication of an organisation's business patterns combined with the knowledge of the CE "jargon" can play an essential role towards the implementation and dissemination of CE practices.

Table 4. Areas proposed to the NRAs for knowledge development

Knowledge Development Areas	***CE principles***
Alternative energy sources	[1], [3]
Technical feasibility	[1], [2], [3]
Increased yield	[1], [3]
Circular procurement	[1], [2], [3]
End of life strategies	[1]
Lifecycle extension	[1], [2]
Circularity + Environmental metrics	[1]
Supply chain management	[2]
Material flows	[1], [2], [3]
Waste Management	[1], [3]
Sustainable Development Goals	[1], [2], [3]
Supply chain management	[1], [3]
Innovation	[1], [2], [3]
Where: [1] Design out waste and pollution; [2] Keep products, components, and materials at their highest value and in use; [3] Regenerate natural systems	

In a more analytic perspective and considering that NRAs can usually be in collaboration with different stakeholders relevant to the production of asphalt mixtures and the maintenance of asphalt pavements, Figure 4 attempts to illustrate how different stakeholders and different lifecycle stages of asphalt pavements can be influenced by the proposed knowledge development areas. In other words, assuming that most NRAs represent the area of a “Cluster”, it can be seen that even if by themselves develop the knowledge in the suggested areas, for a holistic life cycle approach, various other stakeholders will have to be a committed part of the equation -as well- in order to collectively progress towards a systemic regional circular economy. This is why it is worth reiterating that communication, transparent supply chains and stakeholders’ engagement are key components towards a CE.

Figure 4. Stakeholders and areas in need of knowledge development mapping

5.4 Map of Circular recommendations & practices

Now, after the identification of the potentially most relevant areas of knowledge development, a map of recommendations is also presented in this chapter. It is not the ultimate goal of the deliverable, but it can be utilised by the NRAs in order to proceed to actions/practices that could fulfil the three pre-defined circular economy principles. The purpose of this maps is to allow NRAs to detect their internal opportunities that could be exploited towards the transition to a more circular way of operating. As mentioned above, the three principles of the CE that can be projected in the context of asphalt pavements are presented in green colour within Figure 5. It is worth mentioning though, that for an organisation or an NRA in this case the first 4 steps that can in a way be considered as prerequisites are the stakeholder's engagement, the transparent and safe communication with the supply chain, the corporal social responsibility reporting and finally the push towards regional, circular procurement policies. The map starts with the 3 principles of CE defined (green boxes). Further on, the blue boxes represent some of the practices that can assist on fulfilling the CE principle that are related to. After that, the grey boxes are different alternative processes -that do not recant each other- which can be implemented and lead towards increased circularity. Hence, some of the most immediately applicable recommendations that can be given to NRAs towards the implementation of CE are:

- Establish compulsory and regulated end of life strategies
- Optimise pavement design standards towards thinner layers
- Optimise preventive maintenance strategies by implementing a holistic sustainable pavement management system
- Use material flows and material passports to track the life cycles of materials
- Use of biomaterials as main paving materials through reusing and recycling
- Maximise the use of Reclaimed asphalt and increase the reuse of secondary

materials. Shifting towards use of lower percentages of virgin materials should be established as the norm and thus;

- Target setting towards the exploitation of all the available Reclaimed Asphalt
- Replacement of diesel with biodiesel or other available cleaner energy sources
- Use of renewable energy sources
- Change utilisation patters [sharing models, product as service]
- Minimise the construction of new road networks by optimising the layouts of existing ones

Figure 5. Circular Map of recommendations for the implementation of CE by NRAs

6 Discussion and Conclusions

Within the perspective of a road engineering industry, based upon the principles of sustainability and circular economy, the approaches in constructing and managing asphalt pavements play a key role. Lately, NRAs are directly or indirectly being pushed towards implementing more sustainable and circular operational patterns, this is achieved either by complying to existing legislations, or via trying to promote a more sustainable way of doing business out of environmental, social or mostly economic concerns. Moreover, the necessity for the NRAs to shift towards a more sustainable and circular way of operating has been analysed. As seen in Chapter 1, CE is not something new, but the natural evolution of concepts that attempt to lead humanity into achieving a more sustainable living and development within the boundaries of the planet earth.

The Pavement Management System (PMS) is a hierarchic process composed by four levels of implementation, aimed at reaching several technical and economic performance targets. It is time that NRAs and stakeholders to also set environmental targets within their PMS and not only focus on the economic and technical performances. NRAs should be exploiting for the management of their assets the PMS while setting economic, technical and environmental targets. The integration of sustainability and CE principles in the PMS could lead to vast benefits in every pillar of sustainability. The implementation of circular economy models can be integrated into the PMS in to two different levels depending on the scale of the domain: Project Level and Network Level. Obviously the latter approach is more ambitious and consequently the potential outcomes of its implementation could be more profitable. However, a profitable and pragmatic operational strategy could be implemented by intervening in the local area (project scale test) and evaluating the results; and only in a second phase, in the basis of achievements, to extend the domain of application (network scale). In a network level application it is necessary to fully analyse through modelling techniques (i.e. system dynamics) the economic, environmental and social effects on the network-wide spectrum from raw materials supply to asphalt pavement recycling,

In order to identify the ways that the investigated NRAs are implementing and communicating CE and its principles an online search was conducted on the official websites of the NRAs, relevant to documents or initiatives undertaken to promote CE. As it can be seen from the analysis, the majority of the NRAs is not currently communicating any CE related advances or implementation actions. Moreover, analysing the results obtained from the questionnaires sent to the NRAs, it seems that all the NRAs are familiar with the concept of CE and most of them are also familiar with most of the principles it represents, but their majority is not implementing them thoroughly. Most of the NRAs replied that are

- ***prioritizing the "designing out" of the waste of their products*** and that they
- ***attempt to prolong the life of their assets by conducting preventive maintenance***.

Some of the NRAs stated that they are not implementing such circular practices, but however, they do recycle, they do implement preventive maintenance regimes and they do sometimes utilize waste materials as resources within the asphalt pavements that they construct and manage. This proves that all of the NRAs that have filled the questionnaire

with one or another way, do implement practices that are aligned with the principles of CE. This could lead to the conclusion that more people with specialization in CE should be operating within the NRAs providing higher accuracy, more insights and knowledge in terms of CE implementation.

Recommendations and best practices that would be able to provide NRAs a more sustainable and circular operating angle have been presented in chapter 4. The most immediate actions that NRAs could undertake in order to move towards this direction are:

- The rethinking of their designs, minimising the use of materials and improving the durability of the asphalt pavements
- The utilisation of end of life materials such as biomaterials, reclaimed asphalt and by products in general that are considered wastes.
- The utilisation of life-cycle based techniques at both design and management of their assets, quantifying the potential environmental impacts and thus proceeding with the most preferable options
- The investment in research and development of alternative, more environmentally friendly construction methods
- Design products and systems so that they can be easily reused, repaired, recycled or recovered.
- Communication and transparent relations with the whole value and supply chain
- Development of circular business models that will benefit both the NRAs and the stakeholders along with the users
- The utilization of material flow mapping, along with the utilization of soil and wastes during the construction and maintenance phases as useful materials
- Development of methodised end of life strategies, focusing on the possibility of closed loop approaches and/or upcycling.

Finally, more and more NRAs should allocate percentages of their budgets towards the development of circularity metrics and roadmaps/strategies towards the implementation of CE and the assessment of the levels of this implementation. This could help to monitor and evaluate the progress that is being made and finally develop a feasible and spherical framework of how they should actually be implementing CE in asphalt pavements in the best way possible. This way could be complimented by following the recommendations for knowledge development and the “Map of Circular Recommendations” deployed in previous chapters, in order for a Sustainable & Circular Life Cycle Management approach to be achieved. Figure 4 is able to pinpoint that the implementation of CE is not a simple and instant process. It highlights that in order for circularity to be achieved within an organisation or an authority in this case, knowledge development has to occur in different layers of stakeholders divisions and not just the organisational territory itself. Furthermore, the aforementioned map provides recommendations on a strategic level that are able to satisfy the 3 principles of CE as defined in Chapter 2. Further in-detail structured processes are identified that when implemented, either individually or in combination, address the CE principles.

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Appendix A [QUESTIONNAIRE]

Questionnaire about Circular Economy

SECTION 0. INTRODUCTION

What is Sustainability Assessment of Civil Engineering Works?

"Combination of the assessments of **environmental performance, social performance and economic performance** taking into account the technical requirements and functional requirements of a civil engineering work or an assembled system (part of works), expressed at the civil engineering works level." – **EN 15643-5:2017**

What is PavementLCM Project?

Road pavements are complex and dynamic systems which need to be properly managed during their whole life cycle to ensure they deliver their function to society. From this point of view, Life Cycle Assessment (LCA), Life cycle costing (LCC) and life cycle approached looking at social aspects are becoming popular techniques aimed at helping the different stakeholders in the process. However, the lack of a standard framework to perform Life Cycle Management (LCM) of road infrastructures means

decisions are very much dependent on the analyst's work and assumptions, which can lead to considerable differences amongst methodologies and finally results cannot be comparable from one case to another. This is not least the case for assumptions concerning the durability of new materials, which is a necessary part of any life cycle analysis. However, discrepancies are still present within National Road Authorities (NRAs) but even amongst researchers and it is in the interest of every stakeholder that a harmonised framework and clear user-friendly guidelines are created to allow LCM analyses to be made with confidence.

PavementLCM is a 2-year international project which will be carried out by a multi sectoral consortium to deliver a complete package to allow NRAs to carry out harmonised LCM exercises for Green Asphalt, as well as providing training and user-friendly guidelines to support their widespread use. The specific objectives of PavementLCM are:

- To create a general LCM framework with templates and case studies to carry out harmonised sustainability assessments of both asphalt mixtures and road pavements and to transfer the knowledge with a training tailored to NRAs.
- To create the Pavement LCM lookup tool as a user-friendly tool to help members of NRAs to find most appropriate datasets, methodologies and results of previous LCM studies for a specific situation.
- To produce datasets of sustainability data and durability data of identified Green Asphalts for selected case studies, based on existing sustainability datasets and novel durability testing.
- To provide NRAs with a methodology and recommendations for coping with uncertainty of datasets of LCM exercises, both inputs and results, as well as roadmaps towards data harmonization at EU level.
- To produce guidelines and recommendations towards using LCM results within a multicriteria sustainability assessment (complying with CWA 17089 and EN15804).

SECTION 6. CIRCULAR ECONOMY

Are you familiar with the concept of Circular Economy and its principles?

Yes	No

If yes, which principles of Circular Economy are you familiar with? (tick as many as needed)

Design out/minimise waste

Use waste as resource (recycle, reuse)

Prioritize regenerative resources

Preserve and extend what is already made

Other, please specify:

Which of those principles have already been introduced within established pavement life cycle management practices?

Design out/minimise waste

Use waste as resource (recycle, reuse)

Prioritize regenerative resources

Preserve and extend what is already made

Other, please specify:

Which practices are you using to implement those principles for Circular Economy?

If these principles are currently not implemented into practices, which reasons/challenges are impeding it? Is there a future strategy to implement them?

Are there any current metrics/indicators to assess the level of circularity of these practices and/or the pavement management process?

Yes	No

If yes, which are these metrics/indicators?

- Product Material Circularity Index (MCIP) [Ellen MacArthur foundation (EMF)]
- Company Material Circularity Index (MCIC) [Ellen MacArthur foundation (EMF)]
- End of Life recycling input rate [Available in the EU's Raw Material Scoreboard and in EC Monitoring framework for the CE (under development)]
- Resource Efficiency [EU Resource Efficiency scoreboard (EURES)]

Other, please specify:

If no, which reasons/challenges are impeding their development? Is there a future strategy to define them?

Has a “Roadmap” towards Circular Economy been produced/published, to achieve more sustainable and circular management of asphalt pavements?

Yes	No

If yes, could you please provide us with a copy or link to find it

If not, which are the current challenges, posing as obstacles towards the production of such a roadmap? Is there a future strategy to produce one?
