National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Recycling of materials

Needs and considerations in the assessment
of safety and sustainability

RIVM letter report 2022-0029

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Synopsis

Recycling of materials

Needs and considerations in the assessment of safety and sustainability

The government aims for a circular economy by 2050. In a circular economy we no longer refer to waste, but rather to material flows. In order to continue to use these materials, they need to be recycled safely. And in such a way that they have less impact on the environment than materials produced virgin resources.
In 2018, RIVM developed a method that assesses the extent to which initiatives to recycle material flows result in safe and sustainable processing methods and products. The goal of the study is to further develop this method and better match user requirements. In order to be able to do so, stakeholders , such as permit providers and material processors, were asked what they need to assess the safety of a material flow and the contribution to sustainability. Moreover, RIVM elaborated on two case studies in collaboration with material processors and discussed with them how the framework can be improved. Additionally an element was added to assess radiation in recycled materials.

In particular, permit providers and material processors want to work with an assessment method that includes the legal criteria for safety, supplemented by a risk assessment for recycling waste. When new materials and products are made from waste, questions about exposure to chemicals, pathogens and radiation and related risks can arise when no criteria are in place so far. Secondly, stakeholders need a database providing information on the composition of material flows and on criteria for testing safety. Finally, permit providers want to share knowledge and learn from each other's experiences. That is why RIVM recommends organising a national platform.

In addition to the general suggestions mentioned above, there are opportunities for improving the RIVM assessment method. First, it is important to determine what part of the material chain should be included in the assessment and what products are produced from it. Second, weighing the results related to safety and sustainability in order to come to an overall assessment would be a valuable addition.

Keywords: waste, risk, safety, sustainability, assessment, recycling

Publiekssamenvatting

Recycling van materialen

Behoeften en aandachtspunten bij de beoordeling van veiligheid en duurzaamheid

De overheid streeft naar een circulaire economie in 2050. Daarbij praten we niet meer over afval, maar over materiaalstromen. Om deze materialen hierin te kunnen blijven gebruiken, is het nodig dat ze veilig worden gerecycled. En dan zo dat ze het milieu minder belasten dan wanneer materialen uit nieuwe grondstoffen worden gemaakt.

Het RIVM ontwikkelde in 2018 een methode die beoordeelt in hoeverre initiatieven om materiaalstromen te recyclen leiden tot veilige en duurzame verwerkingsmethoden en producten. Het RIVM wil deze methode verder ontwikkelen en beter laten aansluiten bij de wensen van gebruikers. Om dat te kunnen doen heeft het betrokkenen, zoals vergunningverleners en materiaalverwerkers, gevraagd wat zij nodig hebben om de veiligheid van een materiaalstroom en de verandering van de milieubelasting te kunnen beoordelen. Ook zijn twee situaties uit de praktijk uitgewerkt in samenwerking met materiaalverwerkers en is met hen besproken hoe het raamwerk kan worden verbeterd. En er is een onderdeel toegevoegd om straling in gerecyclede materialen te beoordelen.

Vergunningverleners en materiaalverwerkers willen vooral met een beoordelingsmethode werken die de wettelijke criteria voor veiligheid bevat, aangevuld met een risicobeoordeling voor recycling van materiaalstromen. Als er nieuwe materialen en producten van worden gemaakt, kunnen namelijk vragen over blootstelling aan chemische stoffen, pathogenen en straling ontstaan waar de regels van nu niet voor zijn gemaakt. Als tweede hebben de betrokkenen behoefte aan een database met informatie over de samenstelling van materiaalstromen en over criteria om de veiligheid te toetsen. Ten slotte willen vergunningverleners kennis delen om van elkaars ervaringen te leren. Daarom beveelt het RIVM aan een nationaal platform te organiseren.

Naast de hierboven genoemde algemene suggesties ziet het RIVM ook mogelijkheden voor verbetering van de RIVM beoordelingsmethode. Ten eerste blijkt het belangrijk om te bepalen welk deel van de materiaalketen precies in de beoordeling wordt meegenomen en welke producten daarvan worden gemaakt. De tweede verbetering is de uitkomsten over veiligheid en duurzaamheid af te wegen om tot één eindoordeel te komen.

Kernwoorden: afval, risico, veiligheid, duurzaamheid, beoordeling, recycling

Contents

Summary

To contribute to the transition towards a circular economy and the need for safe and sustainable recycling of residual flows or waste the National Institute for Public health and the Environment (RIVM) developed the framework 'Safe and Sustainable Material Loops' (SSML) in 2018 to assess the processing of residual material flows with recycling technologies for safety and for their contribution to sustainability. The framework is meant to support waste recyclers, competent authorities and experts, helping them to assess the safety and sustainability of waste recycling and to support them in the process of licensing. More recycling and circularity contributes to the programme of the Dutch Government aiming for a Circular Dutch Economy by 2050. Additionally, the European Circular Economy Action Plan encourages and stimulates recycling of waste streams to secondary materials, within the criteria of the Waste Framework Directive.

The aim of this study is to test SSML from the perspective of user-friendliness and suitability for analysing innovative recycling options for waste streams. The first part of this study aimed at exploring the needs and expectations of its potential users: the competent authorities and waste processors. For this purpose, we organised a workshop and interviews. Recommendations based on the needs and expectations of competent authorities and waste processors focus on three aspects.

First, because waste handling is subjected to legislation, stakeholders emphasize a strong need for guidance on how to comply with this legislation and on how to act when legal or product safety criteria are incomplete or do not cover all relevant safety aspects. It should be made more transparent in what situations a tool for hazard and risk assessment, like SSML, can be used. We recommend including both the legal approach which is relevant for legislative requirements of a recycling initiative and to include a risk-based approach in the safety modules of SSML, where possible. Attention should be paid to the link between legal standards and a hazard/risk based approach. Stakeholders also confirm there is a need for tools to assess the contribution of recycling initiatives to circularity and sustainability.

Second, both competent authorities and waste processors also have a strong need for information on composition of materials/waste flows (in particular substances of concern), on relevant legislation, on previous legal judgements of cases and on methodologies for the detection and quantification of chemical and biological hazards. We recommend to the National Government to build or further develop a database with this information and to write guidance for its use.

Third, there is a strong need for the exchange of knowledge and experiences. We recommend to organise a national platform for exchanging information, discussing specific cases and general legal issues or safety aspects. The umbrella association of the regional Environmental agencies (Omgevingsdienst-NL) and the The Human Environment and Transport Inspectorate (ILT) could be the central

stakeholders to initiate that. RIVM could be one of the organisations to provide or develop knowledge on relevant aspects.

The second part of this study aimed at further developing the methodology of SSML and to test its user-friendliness. We developed a new module for assessing recycling of waste containing natural or artificial radioactive material and we tested SSML in three case studies. The first case study was related to the decommissioning of radioactive concrete of a cyclotron vault. In the second case, the recovery of cellulose from waste water was assessed and in the third case the recycling of PET, both in cooperation with the stakeholders involved in these recycling initiatives. In addition, we consulted RIVM-experts for their experiences with the different modules in other case studies.

Based on the experiences of stakeholders in the case studies and on the experiences of RIVM experts using SSML, we listed general lessons and points for improvement for modules of the framework. With some assistance the stakeholder were able to retrieve the data and perform the first parts of the modules. A general lesson was that clearly defining the scope of the sustainability and risk modules is very important. It strongly helps if recyclers first make a description of the production chain or life cycle, including: the input material/waste stream, recycling method, emissions and use of resources during the process, the output material and waste flows, and application in product(s).
We recommend to include more guidance on setting the scope and to use one scope for the whole assessment in SSML. When the scope needs to be adjusted for specific modules this should be explained. Secondly, we recommend to make a user-friendly version of SSML and to write a guidance for users including relevant legislation, explanation of indicators, data requirements, and instructions when legal criteria do not exist.
Hazards and benefits are quantified in SSML, but the outcomes are not weighed leading to an integrated value. We recommend to explore methods and possibilities to make an integrated assessment of different risks and environmental benefits.
We recommended to further develop the assessment framework in cooperation with stakeholders. To do this a diversity of lessons and recommendations has been identified regarding the assessment of sustainability and safety modules. Some of these and the aforementioned improvements need more scientific basis, while others need user consultation.

1 Introduction

1.1 Context

The Netherlands is aiming for a circular economy by 2050. Amongst the many systematic changes that are needed to achieve this, existing waste flows (or residual flows), now being incinerated, used as landfill or disposed of, need to be brought back in the economy.

The government-wide programme for a Circular Dutch Economy by 2050 (IenM 2016) outlines how the Dutch Government wants to transform the economy into a sustainable, fully circular economy by 2050. The government has set out three goals aimed at making the Dutch economy circular as quickly as possible:

1. Ensure production processes use raw materials more efficiently. This can lead to less need for raw materials.
2. When new raw materials are needed, use sustainably produced renewable (biomass) and widely available raw materials (e.g. iron, calcium and hydrogen). This will make the Netherlands less dependent on (import of) fossil resources and preserves the natural capital.
3. Develop new production methods and design new products to be circular.

The programme and the yearly revised implementation programmes [1] (IenW 2021) describe what we will need to do to ensure we use raw materials, products and services in a smarter and more efficient way. Many actions have been formulated in yearly updates of the programme to reach these goals. Safe recycling in order to maintain the value of residual flows -amongst others- is also stimulated.

Recycling of waste can reduce the use of primary raw materials and in this way contribute to sustainability including climate goals. Recycling of materials and reuse of products could benefit the environment, but it could also lead to an increased human and environmental exposure to chemical and biological hazards. The third (Dutch) National Waste Plan (IenW 2020, Rijkswaterstaat 2020) (LAP3[2] being in line with the EU Waste Framework Directive(EC 2000)), covers how to deal with waste streams containing ZZS (the Dutch variant of SVHC, using the same SVHC criteria as REACH next to some lists of priority substances like POP) in the perspective of recycling. In section 1.5 more background is given on legislation. When dealing with recycling initiatives, sometimes questions arise on the safety for man and environment, especially when product or environmental quality criteria are lacking.

New and safe recycling technologies can help to close the material chain. in 2019 RIVM published the framework 'Safe and Sustainable Material Loops' (SSML)(Quik, Lijzen et al. 2019) to assess recycling technologies for safety and for their contribution to sustainability. The aim of this framework is to standardise the assessment of safety and

1 IenW+Uitvoeringsprogramma+Circulaire+Economie.pdf
2 https://lap3.nl/

sustainability in the context of a circular economy instead of a case by case approach.

1.2 Aim of the study

This study was part of the 'REcycling techNologies for Existing Waste' (RENEW) project, carried out within the Strategic Programme RIVM. Two main goals were set. The first goal, reported in a separate report, was to give an overview of the innovative technologies for recycling waste containing substances of concern (SoC)(Zweers 2021). The most relevant waste flows regarding SoC-content and potential for more circularity were selected and innovative recycling technologies were identified. The second goal, the subject of this study, is to test and improve the assessment framework SSML (described in (Quik, Lijzen et al. 2019) from the perspective of user-friendliness and suitability for analysing innovative recycling options for waste flows (see 1.4).

1.3 Short description of the SSML framework

SSML helps to make more consistent and quick assessments on safety and sustainability. The framework integrates legally established rules, existing risk limits and new methods into one coherent, tiered system. In this way, it supports the Dutch government's basic principle of dealing efficiently with raw materials and reducing the burden on the environment. Safety for man and the environment is a precondition for the transition to the circular economy; an economy which maximizes the reuse of materials from waste streams wherever possible. Material that is recycled may present risks to man and the environment if it contains substances of very high concern (ZZS), drug residues, pesticides or pathogens. SSML currently consists of seven modules, five on risks for man and the environment and two on the contribution to sustainability (see Figure 1.1):

- Substances of concern (SoC),
- Pesticides,
- Pharmaceutical residues,
- Antibiotic Resistance,
- Pathogens,
- Circularity and
- Environmental impact (Energy & land use).

In each module a tiered approach is followed in order to keep it simple (with limited data) when possible and do it more intensive when needed.

Figure 1.1 Modules of the SSML framework as shown in the Material safety and sustainability data sheet, giving an overview of the outcome of the Safe & Sustainable Material Loops (SSML) framework(Quik, Lijzen et al. 2019).

1.4 Research questions of this study

Apart from RIVM expert use, the applicability of SSML for practical questions of stakeholders (legal authorities and recyclers) is still unknown. To improve the framework from the user perspective and identify innovative and safe recycling options we formulated several research questions on four topics.

The first goal was to make an overview of the demands and needs of potential users, resulting in recommendations for the assessment of risks of recycling initiatives and for improvements of SSML . We therefore focused on the following questions:

- What information is needed by stakeholders to decide on recycling of a residual flow and to assess the safety of materials and the recycling process?
- What are the demands of stakeholders on data availability when assessing the safety and/or sustainability?
- How should the current SSML framework or specific modules be improved?

In a next step the results should lead to improving the applicability of the framework.

Secondly, the question was if it is possible to develop a SSML-module for assessing radiological risks, considering natural and artificial radiation in waste flows.

Thirdly, innovative and relevant case studies were selected to test the existing SSML framework with stakeholders to learn how the framework can be improved. The criteria for selection of cases are given in section 2. The research questions for three cases were:

- Do the cases and the available data fit in the framework and modules; what changes of or additions to the modules would improve the assessment?
- How user-friendly are tier 0 and tier 1 for recyclers and licensing authorities and can these tiers be further developed so that stakeholders can perform these tiers themselves?
- What suggestions for improving and extending the assessment framework can be given based on these cases?

On the selected innovative recycling cases with residual flows, we will test the relevant safety modules of SSML. The module on environmental impact and on circularity will be applied on all cases. Based on the available information conclusions are drawn.

Fourthly, RIVM experts involved in former case studies were consulted on their experiences with working with the SSML-framework and asked to share possible adjustments for improvement and to make it more user-friendly.

1.5 Background information

1.5.1 Substances of Concern (SoC) and ZZS

This report includes different type of hazards, in particular coming from Substances of Concern, pathogens and radiation. An important group of SoC in The Netherlands is classified as ZZS: 'zeer zorgwekkende stoffen' (Herwijnen 2013, De Poorter 2017).The direct English translation of the term ZZS is 'substances of high concern'. But the substance list of ZZS does *not* contain the same set of substances as the European/REACH list of substances of very high concern (SVHC) does. To avoid confusion the Dutch term of ZZS is left untranslated in this report. This is illustrated in Figure 1.2.

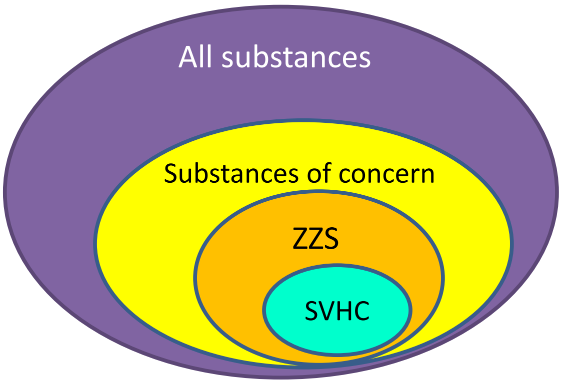

Figure 1.2 Illustration of the chemical subsets 'Substances of Concern' (SoC), ZZS as defined in the Netherlands (substances fulfilling criteria of REACH Article 57) and SVHC identified under REACH.

The concept of ZZS is used in the Netherlands in a national context. Substances fulfilling at least one of the hazard criteria of REACH article 57 are included (Traas 2021):

- Carcinogenic category 1A or 1B according to Regulation 1272/2008/EC.
- Mutagenic category 1A or 1B according to Regulation 1272/2008/EC.
- Toxic for reproduction category 1A or 1B according to Regulation 1272/2008/EC.
- Persistent, Bioaccumulative and Toxic in accordance with the criteria set out in REACH Annex XIII.
- Very Persistent and Very Bioaccumulative in accordance with the criteria set out in REACH Annex XIII.
- Substances for which there is scientific evidence of probable serious effects to human health or the environment which give rise to an equivalent level of concern to the criteria listed above.

Substances on which one or more of these criteria apply, are regulated by specific product and waste legislations (see section 1.5.2). The RIVM compiles a non-limitative list[3] of these substances which is updated twice a year, the ZZS-list. By January 2021 this list contains 1564 substances[4]. The sources of the ZZS-list are in particular:

- Substances on the so-called Candidate list; these substances have been identified as Substances of Very High concern (SVHC) and are candidates for authorisation (REACH Annex XIV).
- Substances in Annex XVII of REACH that are restricted due to their ZZS properties as listed above.
- Substances listed in Annex IV the POP Regulation 850/2004/EC.
- Priority Hazardous Substances according to the Water Framework Directive 2000/60/EC.
- The OSPAR list of substances for priority action.
- CLP annex VI.

Next to ZZS also the broader area of substances of concern (SoC) have attention in this report. Pharmaceutical residues, pesticides and pathogens are examples of SoC.

1.5.2 *National legislation on waste*

In the Netherlands the European Waste Framework Directive (2008/98/EC) is implemented in the third National Waste Management Plan, called LAP3 (Rijkswaterstaat 2020). In LAP3 85 sector plans were developed for 85 different waste streams. For each waste stream a 'minimum standard' has been defined, giving an indication of how a specific waste material may be processed. With a permitting system, the minimum standard ensures that waste is not processed to a lower standard than is desirable (Zweers 2021). This system should help to keep materials with a 'high value' in the loop instead of recycling applications by which material quickly degrades ('downcycling'). LAP3 differentiates between three types of recycling, as mentioned in the

[3] https://rvs.rivm.nl/stoffenlijsten/Zeer-Zorgwekkende-Stoffen
[4] https://rvszoeksysteem.rivm.nl/ZZSlijst/TotaleLijst

waste hierarchy:
- c1. recycling the original functional material in an identical or comparable application.
- c2. recycling the original functional material in a different or non-comparable application.
- c3. chemical recycling.

Additionally, a recycling option can be designated as 'preferred recycling', when it is determined to be significantly better. This can be established using the Life Cycle Analysis methodology that is included in Annex 9 of LAP3.

Concerning SoC the LAP3 addresses the handling of waste streams containing ZZS in section B14 and Annex F11. The LAP3 states that when ZZS are present in waste streams above the generic limit concentration value of 0.1%, or above the specific limit values as provided by the specific framework for the new foreseen application, a risk analysis should be performed. By performing the risk analysis, it should become clear whether the ZZS hamper a permit for the foreseen new application (Zweers 2021). A guidance on the risk analysis for ZZS in waste has been developed by Rijkswaterstaat (Rijkswaterstaat 2018). This is based on an advisory report by RIVM (Zweers, Verhoeven et al. 2018). The methodology of this advisory report has also been included in the Safe and Sustainable Material Loops (SSML) framework (Quik, Lijzen et al. 2019). In the SSML framework also other types of SoC are included.

1.6 Outline

Chapter 2 describes the methodology that was followed for answering the research questions. In chapter 3 the results of the stakeholder consultation are described. Chapter 4 elaborates about the newly developed module on radiation and the application on an example case. Chapter 5 describes the results of the case of recycling of cellulose from waste water and the results of the case of recycling of PET is described in chapter 6. Chapter 7 gives an overview of the lessons learned and recommendations coming from the three cases and earlier cases. In chapter 8 the main conclusions and recommendations are given for further development of the assessment of safety and sustainability of recycling initiatives are given.

2 Methodology

First the need for information and tools and the suggestions for improvement (goal 1) were gathered from a stakeholder consultation in a workshop and was based on interviews (section 2.1 and 2.2). Secondly the case studies were carried out (section 2.3), in which the current version of the SSML framework was used for assessing safety and sustainability of recycling technologies.

2.1 Workshop

The first stakeholder meeting, a workshop for governmental representatives involved in the licensing of recycling applications, was organized in February 2020, in Utrecht. Invitations (20) were sent to people from familiar networks, representing various governmental organizations. The invitation included several questions, shown in the textbox below.

- What type of waste streams do you have to deal with in your daily practice?
- How do you assess an application for an environmental permit, what criteria do you use ?
- Based on what data or information do you make a decision for licensing recycling?
- What questions do you encounter during the assessment?
- What do you do when information is lacking?
- How do you assess safety and sustainability of a recycling initiative of a stakeholder?
- Do you want to present your own experiences during the workshop?

Ultimately, in addition to four RIVM representatives, 12 persons from 8 national and regional governmental organizations (RWS, ANVS, OD Twente, DCMR, PZH, OD West Brabant, province of Brabant and OD Haaglanden) participated in the workshop.

The programme of the workshop included four items. After a general introduction to the workshop (1), participants were asked for their needs when dealing with applications for recycling waste materials (2). Next, participants were introduced in SSML: assessing safety and sustainability of recycling (3). Finally, participants were asked to come up with suggestions for improvement (4). By doing so, we tried to gather more detailed information on:

- the possibilities and chances to recycle,
- factors hampering the recycling of waste materials flows,
- the quality, risks and sustainability of recycling technologies,
- what information is needed to support their decisions,
- their motivations and
- what do stakeholders or innovators need to make the decision to recycle or how should different regulations be aligned (a full circular economy with known risks, or a partial circular economy with no unacceptable risks)?

- What are the demands of stakeholders of an assessment method and makes it beneficial for them to use a method, and
- how can the current SSML framework be transformed into a user-friendly version?

A more detailed description of the contents and methodologies used during the workshop are giving in annex 1 (in Dutch).

2.2 Interviews

In a second step stakeholder interviews were performed to have more specific information on the results of the workshop. Due to the Covid-19 outbreak, these interviews were done in video meetings.
Workshop participants from RWS and OD's (DCMR, ODNZK, ODTwente and ODMWB) were interviewed. Additionally, we interviewed stakeholders working in technological consultancy for the perspective of companies (TNO, RH-DHV).

Mostly, two organisation representatives and two RIVM colleagues were present during each interview. The interviews aimed to focus on the main issues and findings of the initial workshop:
- the need for a central database,
- the use and needs for tools to assess risks/benefits,
- the need for a regular, central consultation structure.

The list of interview questions is shown in annex 1 (in Dutch). Additionally, questions focused on the specific tasks of each organisation.

2.3 Development of a radioactivity module

The original SSML framework consists of 7 modules, of which 5 hazard modules. Because the assessment of natural and artificial radiation was lacking, an additional module for radioactivity was developed as part of the project. Such a module is expected to be relevant for the dismantling of locations with artificial radiation (like cyclotrons) and on the other hand for materials from natural origin with elevated activity (like cole and fly ash).

2.4 Selection of case studies and applied method

To test the framework and obtain suggestions for improvement of the SSML approach and modules, we selected three case studies. The first two criteria for selection are based on(Zweers 2021). We used the following criteria:
- the use of innovative recycling technology.
- the material flows with large impact.
- feasibility of the participation of a stakeholder.
- the possibility of testing more modules and the additional radiation module.
- diversity in type of streams (both biotic and abiotic materials).

Application of these criteria led to the selection of the following cases:
- A plastic recycling case (short plastic cycle; modules: SoC, environmental impact, and circularity; feasibility: contacts and information available from WP3),

- a case on recycling of cellulose from waste water (short cycle; modules: environmental impact, circularity, pharmaceuticals, pathogens and AMR; feasibility: stakeholders are already participating in the cellulose case in the regular programme 'Biotic waste flows').
- For testing the newly developed radiation module a building material case; the re-use of activated concrete (long cycle; modules: environmental impact, circularity, radiation). It was in this stage not feasible to receive data about dismantling from stakeholders. Therefore, data from dismantling of the concrete chamber of a cyclotron from literature was used.

2.5 Lessons learned from former case studies.

Besides the cases within this study, in recent years also other cases studies are carried out. To learn also from these studies, we consulted the experts that performed these studies for their experiences and recommendations.

3 Stakeholder expectations

3.1 Workshop results

3.1.1 Introduction

The main focus of the workshop was on the aim to gather information about the demands and needs of competent authorities for permits for recycling initiatives applications.
Secondly the aim was to check the applicability/usefulness of the existing SSML-framework and to gather suggestions for improvement of SSML. As described in paragraph 1.3 SSML is a modular framework and uses a tiered approach. The separate modules deal with 5 different hazards and 2 sustainability aspects. Each module uses a tiered approach, starting from a relatively simple tier 1 to a more complicated tier 3. For applicability the following questions were discussed on the approach: Is the approach of SSML clear? Which tier can be handled without support, where is support required? Does the framework cover all possible hazards? Is the result useful?

3.1.2 Results from the workshop.

The participants mentioned a large number of demands and needs for the assessment of the safety and sustainability in issuing permits of recycling initiatives. From these reactions during the workshop, three main needs clearly came forward:

1. The need for a central database, which preferably should contain information on composition of waste flows, including substances of concern (SoC) present, on relevant rules and legislation, and on earlier case studies.
2. A decision tool based on legal criteria and risks for any initiative for recycling of residual streams. The outcome should preferably be simple (yes/no/more information required).
3. A national platform for exchange of information, possibly through a central, regular meeting.

A large part of the discussions dealt with the importance of a central database and on relevant rules and regulations. It appeared that although many sources of information are known, its consistency and applicability is yet unclear. Which source of information should be used, and which rules and legislation apply[5]? Mentioned data sources were:

- International Atomic Energy Agency (IAEA),
- Nuclear Research and consultancy Group (NRG),
- National Institute of Public Health and the Environment (RIVM)
- Rijkswaterstaat Environment (Kenniscentrum Infomil),
- The European List of Waste (Europese afvalstoffenlijst, Eural)
- Best Available Technology (in Dutch BBT, at Infomil),
- BBT Reference documents (BREF’s, see Infomil),
- National Waste Management Plan (Landelijk Afvalbeheer Plan , LAP3),

[5]: During a ‘Veluweberaad’ meeting, the need for clear rules and procedures was also expressed. This led to the development of a short guidance (‘werkwijzer’), an RIVM product aiming to inform recyclers and governmental authorities about the steps to take when judging a license application for recycling. The ‘werkwijzer’ also shows where information can be found.

- Waste Shipment Regulation (Voorschriften in Europese Verordening Overbrenging Afvalstoffen, EVOA),
- Other (environmental) EU legislation Fertilizer legislation

A need for a national platform was expressed during the workshop. A platform where representatives from different organisations (government, recyclers, experts, legal advisers) come together to discuss specific cases and the items mentioned above.

Only limited time was spent on aims 2 and 3, for checking the usefulness of SSML. Workshop participants mentioned that existing legislation mainly focuses on presence and safety of SoC (legally required), whereas other hazards can also be identified. For these hazards SSML was mentioned to be useful (also radioactivity and exotic species were mentioned). With respect to a radiation module, participants indicated that it would be helpful to include a link to legislation, to the National Waste Management Plan (LAP) and that there is a need for an outcome of the radiation module that can easily be applied.

Other, more general suggestions were:
- Pay more attention to waste materials of unknown composition
- Include a compulsory meeting with recyclers in the process of licensing.
- In SSML, be more consistent in using the terms, specifically when it comes to hazard and risk (risk= hazard x exposure).
- Pay attention to prevention.
- Even a simple tool requires a lot of information.
- Use standard terminology.
- Make SSML accessible for recyclers.
- Remove the module for SoC from SSML as legal criteria on SoC are largely covered by LAP3.
- Also include quality of the recovered material in assessing sustainability.

3.2 Interview results

3.2.1 Focus of interviews

As mentioned, during the workshop, three major needs clearly came up:
1. The need for a central database,
2. A decision tool for legally judging any initiative for recycling. The outcome must be simple (yes/no/more information required).
3. A central, regular meeting for exchange of information.

To gather more detailed information about these needs, some workshop participants were asked to further cooperate by giving an interview. To also include the perspective of recyclers and innovators in recycling, we additionally interviewed representatives of two organisations: TNO and the consultancy RH-DHV.
During all seven interviews we focused on practical experiences and needs when dealing with recycling. The three central questions were:
1. What kind of information is used?
2. Which tools are used for the assessment of safety and sustainability of an initiative?, and

3. Is there a need for a regular national platform for discussing and exchanging experiences and questions?

The full list of questions used in the interviews is available from Annex 1.

Regulatory frameworks
The re-use and recycling of waste streams must comply with different rules and regulations. Relevant rules and regulations are described in the National Waste Management Plan (LAP version 3, see section 1.5.2). According to LAP3 (and in line with the Waste Framework Directive, WFD), the re-use or recycling of any waste material must be legitimate (at least must be safe for man and environment) and sufficiently contribute to sustainability. In addition, emissions released during processing waste materials must comply with the Environmental Management Act (Wet Milieubeheer, WM) and products made should comply with relevant product regulations. When assessing compliance of re-use/recycling technologies with these rules and regulations, information is needed. The first set of questions of the interview dealt with sources of information.

3.2.2 Database and sources of information (1)
To check for compliance with the relevant regulations, different types of data are required. During the interviews, participants were asked which data sources they used most frequently when assessing safety and sustainability. The sources of information mentioned are given in Table 3.1.

Table 3.1 Sources of information mentioned to assess the safety and sustainability of recycling initiatives and compliance with regulations

Source	**Reference**
SGS Intron ZZS report	https://lap3.nl/achtergrond/documenten/gevaarlijk/
Guidance 'waste or product' , 2021 (in Dutch)	https://lap3.nl/achtergrond/documenten/beleid/
RIVM ZZS substances site	https://rvszoeksysteem.rivm.nl/ZZSlijst/TotaleLijst
RIVM tools (e.g. ZZS navigator)	https://rvszoeksysteem.rivm.nl/ZzsNavigator
Infomil-website 'waste and ZZS' (in Dutch)	https://www.infomil.nl/onderwerpen/lucht-water/zeer-zorgwekkende/afval-en-zzs/
RWS-website 'waste circular'	https://www.afvalcirculair.nl/
Colleague's own databases	n.a.
REACH data	https://www.echa.europa.eu/information-on-chemicals/registered-substances
AMICe (National coordination wasteflows; landelijk	https://amice.lma.nl/Amice.WebApp/Home

Source	Reference
meldpunt afvalstoffen, LMA)	
EU-ECHA SCIP-database	https://echa.europa.eu/nl/scip-database
EURAL	https://www.afvalcirculair.nl/onderwerpen/afvalregelgeving/eural/
LAP3	https://lap3.nl/beleidskader/
Fertiliser law, Appendix AA	https://iplo.nl/praktijksituaties/veehouderijen/covergisten-mest/bijlage-aa/
Rekentool DCMR	n.a.
EXIObase	https://www.exiobase.eu/index.php/about-exiobase
Activiteitenbesluit	https://rwsenvironment.eu/subjects/environmental-0/activities-decree/
Literatuur, Bedrijfsinfo	n.a.
Productnormen	n.a.

The interviewees mentioned that a central overview of thesubstances that need to be considered for a residual stream as substances of concern (SoC or ZZS in Dutch) is missing. When available, information is scattered and sometimes contradictive. SoC is one category, potential SoC is another one. The current list of ZZS to be considered is too short (not only SVHC). Not only information on classification, hazard and expected concentrations is required, information on items like thermic value would also be helpful. Material waste streams can have varying composition. A database to which information on applied recycling processes and emissions is added would further help in making informed decisions by legal authorities.

Moreover, there is also a need for a national, central database harbouring existing licenses, different types of legal documents, and information on chemicals and mixed waste streams. The existence and use of one (or related) database would contribute to uniformity of assessments. At this moment, gathered information is stored and managed locally, within different organisations. Sometimes, available information is shared but not each organisation has its own database or has access to an external database. A digital, open access database is most needed, considering confidentiality of documents.

3.2.3 *Assessments and frameworks (2)*

Any technology for re-using or recycling waste materials must comply with relevant regulations, with legal frameworks. We asked interviewed persons within what legal frameworks their work is carried out. The mentioned frameworks included:
National Waste Management Plan (LAP3), Dutch Environment and Planning Act (Omgevingswet), the Environmental Management Act (Wet Milieubeheer, WM), Guidance 'Waste or product' (Leidraad 'Afvalstof of product', keurkompost[6], Wet algemene bepalingen omgevingsrecht (Wabo). the Waste Framework Directive (WFD), Working Conditions Act (ARBO Wet).

[6] https://keurcompost.nl/beoordelingsrichtlijn/

It was mentioned that it is not always clear if and which regulations are relevant for a case. In this respect it is worth to mention that an overview of and guidance on how to apply existing legal judgements on products from waste (including cases in process) would be helpful. Sometimes, they are internally available, but a webportal is also provided by 'Rijkswaterstaat' (www.afvalcirculair.nl). Unfortunately, applications for processed waste materials in this database do not contain information on the composition of the waste material. Table 3.2 gives examples of legal judgements on new applications.

Table 3.2 Examples of legal judgments on products from waste processing by? different organisations.

Organisation	**Legal judgement (material/substance) ('Rechtsoordeel')**	**Outcome**
ODNZK	Handsoap and unopened personal care products	continued use
ODNZK	Wet lecithine from soybeans for fermentation	by-product
DCMR	Cut grass → fodder	continued use
DCMR	Zinkcatalyst → zinkproductie	end-of-waste
DCMR	Vegetal and animal oil → input for pre-processing for Hydrotreated Vegetable Oil (HVO)	Lack of data of individual flows
DCMR	worn linen from elderly home → cleaning cloth	continued use
DCMR	wooden pallet→ kindlings for locomotief	continued use
DCMR	Inoculum sludge → starting wastewater treatment	by-product
DCMR	Coffee grounds → growing soil for oyster mushrooms	continued use
DCMR	Pretreated vegetal an animal oil → gresoyurce for production of Hydrotreated Vegetable Oil (HVO)	end-of-waste request
DCMR	mineral waste oils → fuel	end-of-waste request
DCMR	gum (phospholipids) from vegetable oil processing → food	by-product/end-of-waste request
OD-Twente	Capturing and applying CO2	end-of-waste
OD-Twente	Many organic residual flows for co-fermentation with manure	end-of-waste

When judging a new application, existing legislation is leading. Any technology should comply with legal waste and product criteria, for instance for the presence of SoC. Existing legal judgments or permits can be used to assess new applications. In situations where hazards can be present, but for which no safety criteria exist, RIVM is frequently asked for assistance. Interviewed persons also mentioned that in some cases a comparison with the quality of virgin materials is made. It was also mentioned that the hazardous potential calculation method (HP14

'Ecotoxic' of Waste Framework Directive, 2008/98/EC[7]) is used to determine for an EURAL code if it concerns hazardous waste. The environmental permits determine if the process itself and the emissions are safe. Many NEN criteria are available to assess the quality of products, just as European regulations. It is not easy to get an overview of these criteria.

The 'guidance on waste and product' (Leidraad afval en product, in Dutch)(IenW 2021) is an important document for starting to assess materials coming out of a recycling process. This guidance helps determining the legal status of any waste material (waste, byproduct, continued use as product or end-of-waste). Rijkswaterstaat stated that for advice on the safety for man and environment it is important to have a better fit between legal criteria for waste and products and the risk-based approach, like in SSML. The risk-based approach is important when legal criteria are missing. An interesting remark focused on the relevance of existing criteria: 'without legal criteria, applications cannot be refused'. TNO mentioned the development of some frameworks for sustainability safety assessment they have available: MVO Sustainability hotspot scan[8] and the PRISM-model (Plastic Recycling Impact Scenario Model)[9].

When assessing the safety of new technologies, information on the composition of mixed/complex waste flows is mostly required, especially information on hazardous compounds for which no criteria exist. Secondly, a clear view on relevant legal frameworks is needed, not only with respect to processing waste materials, but also with respect to the final products. Another issue mentioned in the interviews was related to the recycling technology. Does this technology result in new hazards (e.g. other substances produced during pyrolysis)? Or does a technology result in the release of substances immobilized in the earlier use (e.g. during shredding)?
Once it is known if a hazard is present, the risk (hazard x exposure) for humans and the environment can be calculated. There is no standard method for calculating the risk. Currently risk assessment of is often limited to checking existing criteria. In some situations a relative risk assessment is done by comparing the technology using waste material with a technology using virgin materials. However, many/most? authorities prefer to work with an assessment of the absolute actual risks.

In all situations, the stakeholders require an easy to interpret result from the risk assessment. Preferably the outcome should be a yes or a no. This also applies for the sustainability assessment; any tool outcome must show that a technology's result should at least meet the minimal standard of the LAP3.

In case of a lack of sufficient information, authorities contact organisations like RIVM and Rijkswaterstaat, but also consultancies for more information. Sometimes authorities have organized informal

[7] Council Regulation (EU) 2017/997 amending Annex III to Directive 2008/98/EC
[8] http://www.biobasedeconomy.nl/wp-content/uploads/2017/11/SHS-Leaflet-CoP.pdf
[9] https://www.tno.nl/en/focus-areas/circular-economy-environment/roadmaps/circular-economy/plastics/the-prism-model/

working groups for information exchange like the 'national working group waste management' (WAB). In other situations, authorities act pragmatically. Waste material that is used for the same purpose can be allowed, even when criteria are not available. And authorities keep in mind that companies do not take too large (economical) risks.

Sustainability aspects are judged by using best reference techniques ('BBT'), the LAP3 and 'Wet Milieubeheer'. Emissions and energy use are recognised for getting an idea of a technology's contribution to sustainability. Sustainability and safety are currently not balanced. It is mentioned that balancing both aspects might have a stimulating effect on recycling. When considering sustainability aspects, it is not always clear within which boundaries (local/national/global) calculations should be made.

3.2.4 *A central, regular meeting (3)*

Interviewed persons informed us that a regular, central meeting would be appreciated in which specific cases or general issues on safety and sustainability of material flows (waste and or products) could be discussed. Meetings already take place at various levels (e.g., WAB, mentioned before), but a meeting on national level would be helpful, because recycling processes not always take place in one, local facility. Such meetings can be used for the exchange of experiences with case studies, and for exchange of interpretations of rules and legislation. The results of the meetings can be stored in a central database. Some persons indicate that theoretical cases, or cases from other countries could also be a topic during a central meeting.

During the workshop, it was suggested to:

1. Organise a meeting about a recycling initiative with the recycler and the competent authority. In this meeting a provisional plan is discussed, and the information needed for the complete plan can be discussed.
2. Only after this first meeting the recycler makes a complete plan. This plan can be discussed in a regional platform of different competent authorities with external legislative of experts with different background.

Potential participants of the meeting could be regional Environmental Agencies (in Dutch ODs), RIVM, Werkgroep Afval Beheer (of ODs) and specialists/experts, trade associations, companies, 'versnellingshuis', Vereniging van Afvalbedrijven, Renewi/Suez. Participation from companies or trade associations is welcome, especially at an early stage of (recycling) technology development. Participation of private parties could help to develop new safe and sustainable technologies for recycling waste materials, to stimulate the development of new safe and sustainable production technologies.

It was suggested to organise a meeting with a frequency of four times a year; the umbrella organisation of regional environmental agencies (the Omgevingsdienst-NL) or The Human Environment and Transport Inspectorate (ILT) could organize the meeting. Some concern was raised with respect to finance.

3.3 Conclusions

Based on the stakeholder consultations during the workshop and the interviews we can draw the following conclusions on the needs and demands concerning the assessment of recycling of waste streams.

First, there is a strong need for a central/national database containing information on composition of waste flows, including substances of concern (SoC), on relevant rules and legislation and on earlier legal judgements on case studies.

Secondly there is a need for a tool or tools to assess cases based on legal criteria for waste handling and product criteria (when available) and to identify and estimate risks of additional hazards. Databases on the composition of waste streams will have to be developed further and data on the composition of products with SVHC is being developed (SCIP-database). It should also be easier to find product criteria. Attention needs to be paid to the link between legal standards and a risk-based approach for the assessment of an initiative for recycling of waste streams. The outcome should preferably be simple: risk or no risk ormore information required).
Next to risk assessment, there is a need for tools to assess the contribution to circularity and sustainability. These tools should help to identify important innovative initiatives and hotspots that need attention.

Thirdly there is a strong need for a national platform for exchanging information, discussing specific cases and more general legal issues or safety aspects. The umbrella organisation of the regional Environmental agencies (Omgevingsdienst NL) or 'The Human Environment and Transport Inspectorate' (ILT) are identified to take the initiative for that.

4 Radiation module and case study building materials

4.1 Radioactive substances in a circular economy

4.1.1 Relevance of the module

The first version of SSML (Quik, Lijzen et al. 2019) included modules for several substances of concern. However, the assessment of the risks due to the presence of radioactive substances was not yet included. There are several substances and residues known to contain small amounts of radioactivity. Some of these low-active-substances or low-active-residues containing natural radioactivity are already recycled, but most of low-active-substances containing natural or artificial (=man-made) radioactivity are in practice labelled as radioactive waste and safely stored for eventual disposal, even though the radiological risk might be considered 'trivial' in some situations. In other words, the current management practice of radioactive residues and wastes is often based on a linear instead of a circular approach, lacking a proper risk assessment. Therefore it is useful to include a radioactive residues module for both natural and artificial radioactivity.

Policy and legislation for radioactive waste management in the Netherlands was developed separately from the general waste and sustainability regulations and policy in the Netherlands. Furthermore, legal provisions on radioactive substances have legal precedence over general waste requirements. Consequently, the management of radioactive residues and radioactive waste in practice became a niche, with little interaction with general waste and sustainability policy. Combined with a societal fear for radiation, it led to the situation that the concept of circularity for radioactive substances is relatively underdeveloped until now. Including a radiation module in SSML is a first step towards incorporating radioactive residues in a safe and sustainable use of materials.

The radiation module is, like other modules, made up of different tiers. Tier 0 is about the selection of the relevant modules. The main question is if the presence of radioactive substances in residues is likely or not. In Tier 1 a first, relatively quick and easy screening of the risk of recycling a material, based on the material properties is done. For Tier 2 more expertise and information is required. It considers optimization, preventing uncontrolled spreading of radioactivity and finally, if needed, a thorough quantitative risk assessment.

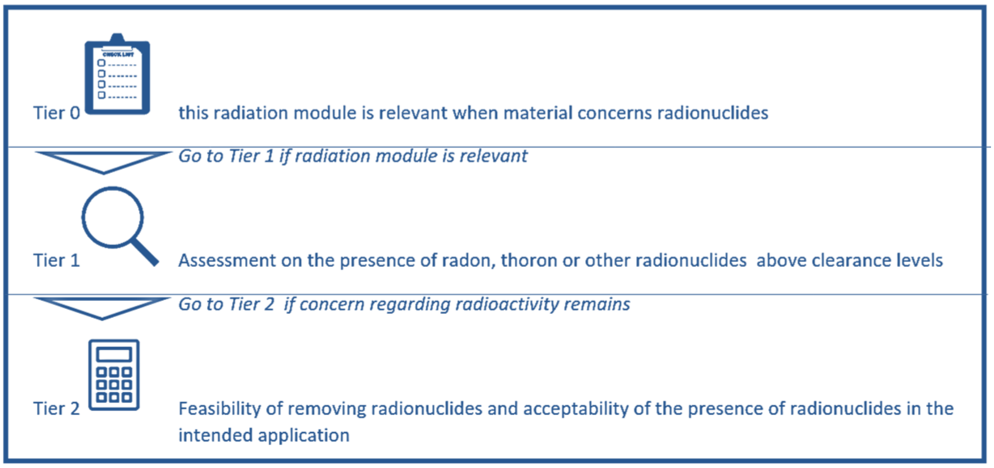

Figure 4.1 Schematic overview of tiered workflow in radiation module.

4.1.2 *Legislative and regulatory framework for radioactive substances*

Although the radiation module primary follows a risk-based approach, a short introduction into the Dutch legal and regulatory framework for radioactive substances is useful to understand how it is designed.
The basis of the legal framework is laid down in the Dutch Nuclear Energy Act (1963)(in Dutch: Kernenergiewet, referred to as Kew). There are various decrees (Algemene Maatregel van Bestuur, AMvB) relating to the Nuclear Energy Act imposing rules regarding more specific situations. The Decree on Basic Safety Standards for Radiation Protection (IenM 2017)(In Dutch: Besluit basisveiligheidsnormen stralingsbescherming, referred to as Bbs) is of most relevance for this report. In the Ministerial ordinance on Basic Safety Standards for Radiation Protection (Regeling basisveiligheidsnormen stralingsbescherming (IenW 2018), hereinafter referred to as Rbs) and the ANVS-regulation (ANVS 2018), some aspects are elaborated in even more detail, or requirements are included for more specific situations. In the Netherlands, the European Directive 2013/59/Euratom (Euratom 2013) laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation, is implemented in the Bbs, Rbs and Vbs.

A few aspects of the Dutch regulatory framework for radiation protection will be highlighted, as these are relevant for the radiation module presented here. Within the Dutch legislation a difference was made between the policy for man-made radioactivity (artificial) versus the policy for radioactivity from natural origin. For artificial radioactivity, criteria are risk-based. For naturally-occurring radioactivity, the criteria were determined on the basis of consideration of the worldwide distribution of activity concentrations for these radionuclides. It should be noted that these values are not based on risk.

For the management of radioactive residues or radioactive waste, the concept of ‘clearance’ applies. Clearance means the decision to release any type of material arising from any radiological practice from regulatory control. Clearance levels are nuclide-specific values in kBq/kg.

Since clearance levels for artificial nuclides are risk-based, the risk-criteria for artificial radioactivity (in µSv/a) had to be translated into the above mentioned- nuclide-specific - operational (measurable) clearance levels (in kBq/kg). As this translation was carried out in a very conservative way, covering almost all realistic scenarios, the values can be used to substantiate a clearance decision without posing any additional conditions.
Together with the clearance levels for naturally-occurring radioactivity (also in kBq/kg) these values serve as the operational basis for clearance and are referred to as 'generic clearance levels'. These generic clearance levels can be found in the Dutch Bbs (Bijlage 3, onderdeel B, tabel A) and Rbs (Bijlage 3.2, tabel A).

For specific materials stemming from specific practices or for small amounts of material, higher clearance levels may be justified, provided that the associated risk in the specific situation remains trivial. So, for the purpose of clearance, where amounts of radioactive substances do not comply with the general clearance values, an assessment shall be made where the exposure for members of the public shall not exceed accepted dose criteria. For recycling material containing artificial nuclides, the specific clearance level is based on the dose criterion of 10 µSv per year. For the derivation of specific clearance levels for radioactivity of natural origin, a dose criterion of 300 µSv per year was established.

Often a mixture of radionuclides occurs in a material, for which clearance is desired. For mixtures of artificial radionuclides present in the same matrix, a weighted sum shall be calculated of nuclide-specific activity concentrations divided by the corresponding clearance levels. In order to comply with the exemption and clearance criteria, this (dimensionless) weighted sum shall be equal to or less than one. For comparison with the generic clearance levels for natural radioactivity, calculation of a weighted sum is not necessary, according to the Dutch regulations as the general clearance levels are not based on dose (risk) criteria.

Finally, it is worth mentioning the three general principles of radiation protection. In the words of ICRP publication nr. 103 (Valentin 2007):

1. *"The Principle of Justification: Any decision that alters the radiation exposure situation should do more good than harm.*
2. *The Principle of Optimisation of Protection: The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors.*
3. *The Principle of Application of Dose Limits: The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the Commission."*

While deciding if a radioactive material can be recycled, these three principles should be considered. For justification, the benefit of recycling a radioactive material should outweigh the radiation detriment. The optimization requirement is fulfilled by removing radionuclides from residues if reasonably feasible, by putting in effort to keep inhalation of radon (Rn-222), thoron (Rn-220) and radioactive decay products as low as reasonably achievable and by considering clearance to make the best use of regulatory resources. Dose limits for individual members of the public and workers are the constraints in the final Tier.

4.2 About the radiation module

The module as presented below is based on the risks accepted in the Euratom directive and similarly implemented in the Dutch Bbs (Euratom 2013, IenM 2017). Meaning, a dose criterium per year of 10 μSv for artificial radionuclides and 300 μSv for naturally-occurring radionuclides. It should be emphasised that the clearance levels for naturally-occurring radionuclides referred to in this module are not the general clearance levels mentioned in de Dutch regulations but are taken from RP 122 part II. Clearance levels in kBq/kg from RP122 part II are based on the effective dose of 300 μSv per year. Unfortunately, RP122 did not include possible consequences of exhalation of radon or thoron. Therefore, in this module exhalation of radon and thoron are addressed separately from the clearance levels. If this module would be used as a check if the intended recycling of a material is allowed according to the Dutch regulations, the exemption and clearance limits from the Bbs should be used in Tier 1 or the presented dose criteria could be used to apply for specific clearance as regulated in article 3.19 and 3.21 of the Bbs in Tier 2.

In case this module is relevant it is assumed that data on the origin of the residue as well as data on the radionuclide content of the material are known. The latter will be necessary already for Tier 1. If data on radionuclides and their activity concentrations are not available, measurements should be performed. Furthermore, for Tier 2 additional data is needed like information on the feasibility to remove radionuclides from the material and on radon and thoron exhalation.

All clearance levels mentioned in this module apply to any solid, dry material, not to liquids or gases.

4.2.1 Tier 0

The aim of Tier 0 is to identify whether the radiation module is relevant for a specific material or waste stream (Figure 2). Based on very general information like the origin and the intended use of the material, it is decided if the presence of radionuclides can be expected and if so, might be of concern.

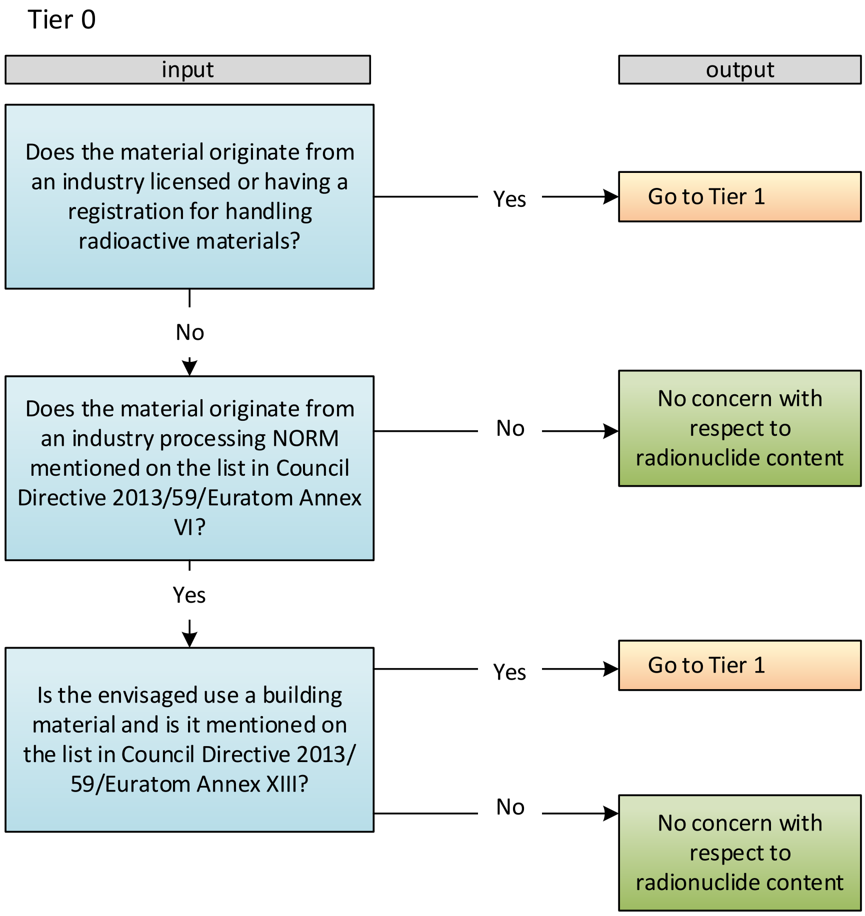

Figure 4.2 Tier 0 of the radiation module.

The initial check to perform, is to find out if the disposer is licensed or has a registration for the handling of radioactive materials. Handling or disposal of artificial nuclides above clearance levels should be authorised. However, for naturally occurring radioactive material (NORM), this is not always the case.

Therefore, for materials that might contain naturally occurring radionuclides, additional checks are needed. This should be done firstly by checking if the industry of origin is mentioned on the list of industrial sectors involving naturally occurring radioactive material (Euratom directive ANNEX VI). In The Netherlands an extended list of industrial sectors is available in the Rbs (IenW 2018) (Bijlage 3.1, onderdeel A).

And finally by checking, if the residue material is mentioned on the indicative list of types of building materials considered regarding their emitted gamma radiation (Euratom directive ANNEX XIII). In the Netherlands an extended list of building materials is available in the Bbs Bijlage 9.

In case all questions can be answered with “No”, no concern with respect to radionuclide content can be expected. And in that case, the radionuclide module is not relevant. In case one of the questions in answered with “Yes”, the situation gives rise to a Tier 1 assessment.

4.2.2 *Tier 1*

Tier 1 (Figure 4.3) provides the user with a first straightforward screening of the material for which limited knowledge of radiation protection is needed. This screening is purely based on material properties and does not yet take the intended application into account. The steps taken in this tier are, apart from the extra attention to exhalation of radon and thoron, very similar to the general clearance procedure in the Dutch regulatory framework. However, instead of using clearance levels according to the Dutch regulatory framework, clearance levels proposed in the IAEA SRS-44 and the EC RP-122 part II are used. The clearance levels mentioned in this module are, in contrast to the Dutch clearance levels, all based on risk assessments. Below the clearance levels and with exclusion of radon- or thoron exhalation, any materials can be released from regulatory control with acceptable risk, from a radiation protection point of view.

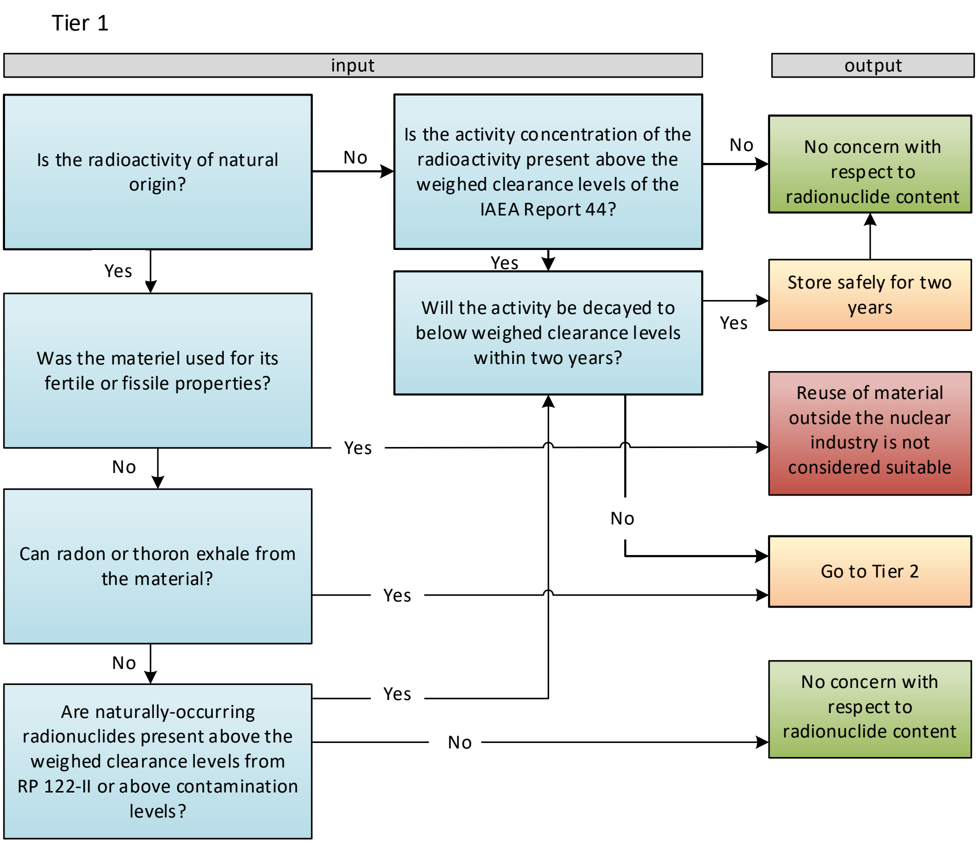

Figure 4.3 Tier 1 of the radiation module.

In the first block the origin of the radionuclide content is checked. If the nuclides are manmade (artificial) then only two questions are left to know if there is a concern with respect to the radioactive content. The first question is whether the activity concentration is below the clearance level given in the IAEA Safety Reports Series No. 44 (IAEA 2005). In this IAEA report explanation is given on how the limits presented in the Euratom directive 2013/59 are related to the dose criterium of 10 μSv for artificial radionuclides. The report considers various scenarios of material reuse, including for example an application of the material in building materials for dwellings. So, if these clearance levels are not exceeded, it can reasonably be assumed that the residual material concerned can be safely reused (will not lead to doses exceeding 10 μSv per year) regardless of the intended application. If this is not the case, then the second question is if the activity concentration will be below clearance levels within two years. Due to short half-lives a radionuclide might decay within two years to activity concentrations below clearance levels. Within the Netherlands it is allowed to safely store residues for two years on-site. If, after two years of storing, activity concentrations are still above clearance levels, a Tier 2 analysis should be conducted.

As mentioned earlier, if the user of the module prefers to comply with Dutch regulations, one should check different clearance levels instead of those used in this document. The clearance levels for regulatory purposes can be found in the Bbs Bijlage 3, Onderdeel B, Tabel A Deel 1 and Rbs Bijlage 3.2, Onderdeel B, Tabel A Deel 1.

If the radionuclide is of natural origin, the first step is to check if these were not used for their fertile or fissile properties. Residues from the nuclear industries are not generally re-used outside the nuclear industry and are out of scope for this module. If naturally occurring radionuclides were not used for fissile of fertile properties, then the risk of radon- or thoron exhalation is very likely and this is a point of attention. In RP 122-part II radon concentrations below 200 Bq/m^3 were not taken into account as this was regarded as an intended design level for construction after 1990 (90/143/Euratom). This concept of a design level of 200 Bq/m^3 was abandoned later on. For thoron exhalation, although risks can be relatively high, there is no legislation yet. Within the Dutch regulations, the radon reference concentration level is 100 Bq/m^3. Current radon concentrations in Dutch buildings are six times lower on average, but re-using building materials with elevated levels of natural radioactivity may lead to substantial increases of radon (and thoron) concentrations in dwellings. In the potential case where radon and thoron are not exhaling from the material with natural nuclides it should be checked if the activity concentration in the residues is above general clearance limits proposed in the EC RP-122 part II. The RP-report of the European Commission presents clearance limits that are related to a dose criterium of 300 μSv per year, using scenarios of material reuse for naturally-occurring radionuclides. The radionuclide-specific clearance levels are defined using the most restrictive case from the different exposure pathways within the different scenarios. However, below an exposure of 300 μSv per year it was recommended that building materials would be exempted from any restrictions.

As mentioned in paragraph 4.1.2, the legal clearance levels in Dutch legislation and in the Euratom directive, for radionuclides of natural origin are not risk based and differ from the clearance levels given in RP122-II. If the user of the module prefers to comply with the Dutch regulations, he or she should check clearance levels noted in Bbs Bijlage 3, Onderdeel B, Tabel A Deel 2. Mind that risks from thoron daughters are not considered in the Dutch legislation.

Materials from which radon/thoron cannot exhale and with activity concentrations below the exemption values or radioactive contamination below legal levels lead to a green block in the flowchart (Tier 1) above. Legal contamination levels are 4 Bq/cm2 for beta or gamma emitters and 0,4 Bq/cm2 for alpha emitters. In case of a green block in de flowchart of Tier 1, the radiological risks to individuals caused by the practice are sufficiently low, as to be of no regulatory concern, independent of the application.

Artificial radioactivity or radioactivity of natural origin that has not been used for its fertile or fissile properties, but exhale radon or thoron or have concentration levels above the clearance levels given in IAEA SRS-44 or EC RP-122 part II, even after two years of safe storage, are probably a concern regarding exposure to radiation. They lead to an orange block in the flowchart, indicating that further analysis or assessment of the intended application is needed in Tier 2. Due to specific situations and assumptions, it is thinkable that the intended reuse does stay below risk-levels on which these clearance levels are based. Also, if general clearance levels are taken from the Dutch regulations instead of the IAEA or EC reports, it is thinkable that, the envisaged reuse of the material leads to effective dose risks below 10 or 300 µSv per year for artificial respectively natural nuclides.

4.2.3 Tier 2

Both Tier 0 and Tier 1 are valuable for screening out materials where human risk from ionising radiation is such that the materials can be exempted from further control. Where it is not possible to state that the risk is below concern, the assessment should proceed to Tier 2. Tier 2 (Figure 4.4) provides an assessment of the intended use of the material. To carry out the Tier 2 assessment expert-level knowledge on radiation protection is needed.

The first block focuses on the optimization principle by removing the radionuclides from the material matrix if feasible. This is not merely a technical question but also a practical, social and financial one. If removing is feasible then the material matrix should be checked again by going through this module from Tier 1 onwards. The radioactive residue should be analysed to check whether there might be a concern when it is reused or recycled.
If removing radionuclides from the material matrix is not feasible or unnecessary, the next question to pose is if nuclides are likely to disperse from the material. These risks should be avoided as much as reasonably achievable, both in the near and in the far future, regardless of the (next) application of the same material. If there is any concern for uncontrolled spreading, except for exhalation of radon (or thoron), the radioactive material should not be reused. Especially not in a circular economy, in which every material should be re-used several or even an endless number of times.

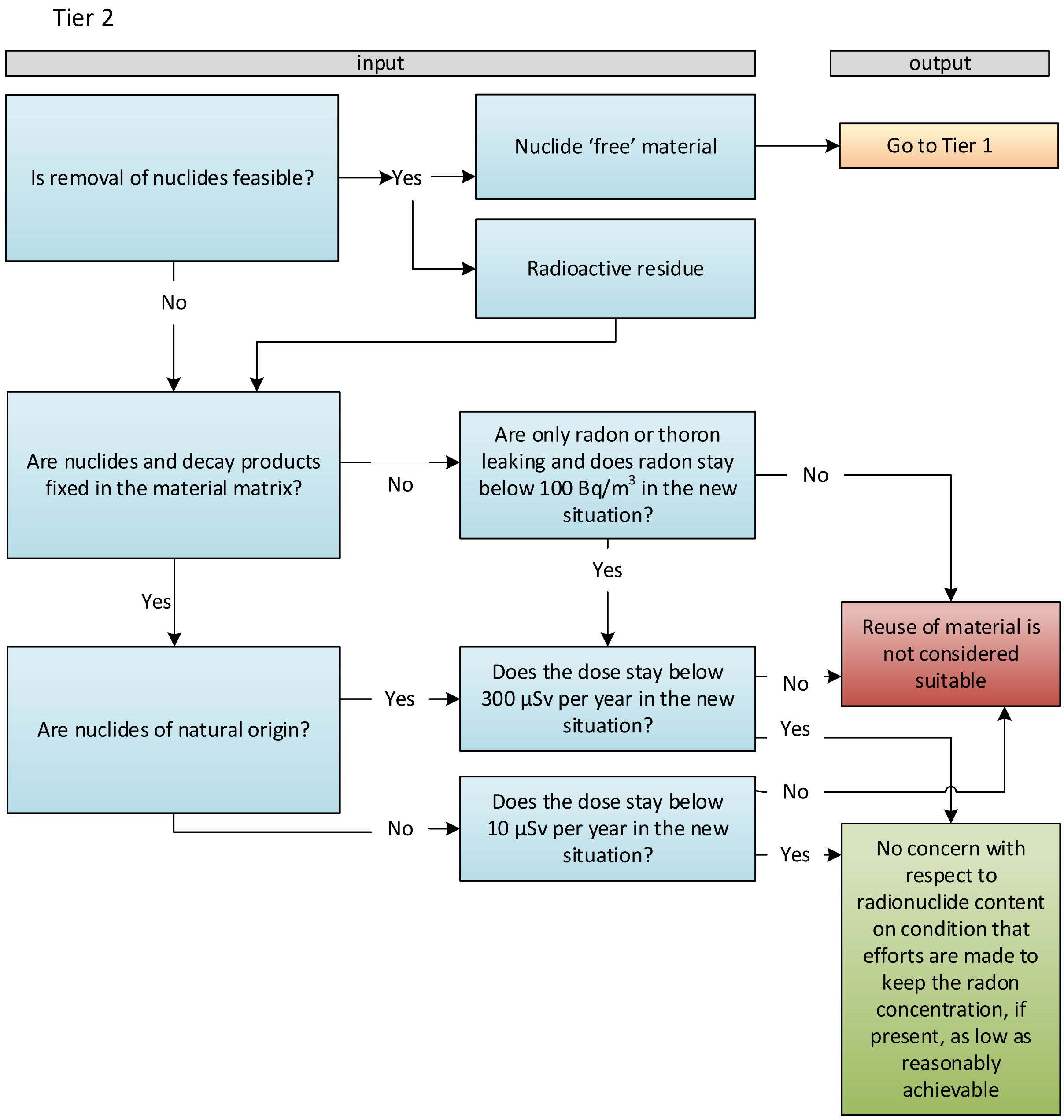

Figure 4.4 Tier 2 of the radiation module.

Outdoors in the Netherlands, radon- and thoron concentrations are low and do not cause a problem (Smetsers and Bekhuis 2021). Indoors radon concentrations might reach up to much higher values. When due to exhalation from building material, the indoor radon air concentration stays below 100 Bq/m^3, the effective dose for the scenario should be calculated, including all different pathways, before deciding if reuse is of any concern. The level of 100 Bq/m^3 radon is equal to the reference level chosen in Dutch law. If levels of radon concentrations are found above 100 Bq/m3 no further calculation is needed. The material should not be reused. If the activity concentration stays below 100 Bq/m^3 and the effective dose stays below 300 µSv per year, effort should still be made to decrease the radon concentration. When thoron is present indoors, effective dose calculations have to be made. For thoron, just like radon, even when the effective dose stays below 300 μSv per year, effort should be made to keep lower the concentration. Ventilating the building may be an effective way of doing so.

If the nuclides are fixed in the material matrix, the effective dose within the envisaged use should be calculated. Below the dose constraint of 10 μSv per year for reuse of residues containing artificial radionuclides, there is no concern. For reuse of residues containing radionuclides of natural origin, the constraint effective dose value of 300 μSv per year should not be exceeded. Tier 2 will lead the user to a definitive outcome of the module (or to a former block for re-evaluation).

Dose calculations for scenarios are likely to be complex and unique. It is therefore not possible to provide highly specific guidance on how the assessment should be conducted. These calculations should be performed by a radiation protection expert.

4.2.4 Recommendations and discussion
The radiation module as presented above is a way to assess the risks of a recycling option of materials containing radionuclides. The other modules of SSML may be used to integrate the assessment of other risks and benefits.

In particular for residues that contain low concentrations of radioactivity, and originate from authorised practices, legislation offers various options for reuse and recycling of these substances.
However, due to societal fear for radiation, complex procedures and lack of tuning with general waste legislation, recycling of residues originating from practices with ionising radiation remains a rare phenomenon.

The module presented here is risk-based and uses the dose criteria as presented in the Dutch regulatory system. However, it is decided not to follow the exemption and clearance limits for naturally-occurring radionuclides from the Dutch regulatory system as these are not directly related to risk. There are several arguments for following the local regulations (or not). The practical use of SSML will be improved by following regulations. In that way it can function as a kind of flow scheme to meet the legislative and regulatory framework. However, the added value will be limited. Also, it will not be based on a risk or science-based framework as regulations are partly based on political choices and feasibility. Additionally, it will result in a national framework that cannot be used in other countries.

Within this module, the assumption is made that radionuclides are homogeneously spread throughout the material matrix. Often this is not the case. By taking several samples to estimate the radionuclide content, a mean concentration can be derived. As constraints are always chosen on the conservative side, inhomogeneous distribution of nuclides does not directly lead to a higher risk. An exception to this is the situation where there are hot spots of radioactivity within the matrix. This situation is not treated in this module.

4.3 Case description artificial radioactivity in building materials

Decommissioning of cyclotron vaults creates a waste stream of -amongst others- concrete containing radioactive material. This concrete is used as shielding material for the radiation coming from the cyclotron. The concrete is steel-reinforced but this case deals with the concrete material only, all metal parts are not considered.
Besides the natural radionuclides present, there are artificial radionuclides created through activation (neutron capture reactions). The natural radionuclides are far below criteria considered to cause any harm and are not further considered. For the artificial radionuclides present in the concrete, instead of using information from stakeholders it was chosen to use an example based on the technical information from a publication. Activation products in walls of a cyclotron vault and their activities after ten years operation are taken from (Kimura, T. Ishikawa et al. 1994). Kimura gives information on the activation of the inner concrete wall of the cyclotron vault at the University of Tohoku. This cyclotron has mainly accelerated 19 MeV protons and the residual long-lived radioactivity's are predominantly due to ^{46}Sc, ^{60}Co and ^{152}Eu from thermal neutron capture reactions (Table 4.1).

Table 4.1 Activation products in walls of a cyclotron vault and their maximum activity concentrations after ten years of operation ((Kimura, T. Ishikawa et al. 1994)).

	Half-life	**A (Bq/kg)**
Sc-46	83.8 d	130
Mn-54	312.5 d	36
Co-60	5.272 y	135
Zn-65	243.9 d	10
Cs-134	12.065 y	6
Eu-152	13.52 y	105

In this example the cyclotron is housed in a vault room of dimensions 5.8 m x 5.8 m x 3.5 m (Figure 4.5). The vault room walls are 2 m thick laterally and 1.9 m at the top and made of concrete (with a density of 2350 kg/m^3). When this vault will be decommissioned in total, 1393 tons concrete will be released.

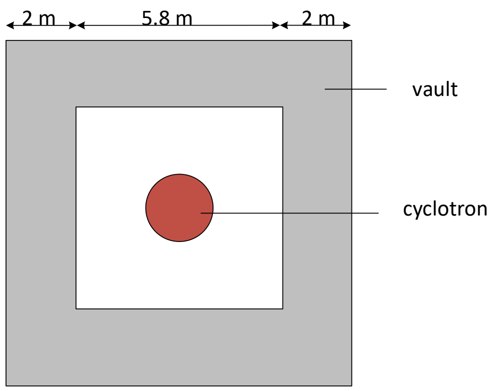

Figure 4.5 Top view of cyclotron vault with dimensions.

The highest neutron-induced activities are at a depth of 5 to 10 cm. Beyond a depth of approximately 30 cm within wall concrete, the neutron induced activity decreases exponentially. And beyond a depth of 40 cm activities are far below clearance levels (Kimura, T. Ishikawa et al. 1994)). For this reason, the 40 cm layer of inside concrete walls are taken as residue. For the vault dimensions described here the residue equals 163 tons (163485 kg) with activity concentrations ranging from 6 to 135 Bq/kg of respectively Cs-134 and Co-60 (Table 4.1). When taking the highest activities for the whole inner 40 cm a conservative estimation will be given.
When it is not possible to only remove the inner 40 cm of the vault, and the vault will be decommissioned as a whole, all the concrete should be taken into account. In this case study both options will be considered.

Option 1: Only the 40 cm layer of the inner vault will be removed. For this situation 163 tons of concrete with amongst other 135 Bq/kg ^{60}Co and 105 Bq/kg ^{152}Eu will be taken for recycling suitability assessments. In Table 4.2all radionuclides present and their maximum activity concentrations within the inner layer are given.

Option 2: All concrete from the vault will be decommissioned. The inner layer of 40 cm will contain artificial nuclides with similar activity concentrations as taken in option 1. However, this concrete will be homogeneously mixed with the rest of the concrete from the vault that is free from activation products. The activation concentrations will therefore be reduced by a factor 0.12 (which is the mass ratio from the inner layer relative to the total mass of concrete). In option 2, 1393 tons of concrete with mean concentrations of amongst other 16 Bq/kg ^{60}Co and 12 Bq/kg ^{152}Eu will be taken for recycling suitability assessments. In Table 4.4all radionuclides present in the complete vault and their activity concentrations are given.

4.4 Application of relevant modules

Three modules will be used to assess 1) the circularity, 2) the environmental impact and 3) the risk, concerning the recycling of concrete of the cyclotron vault. The general modules on sustainability and circularity are described in the SSML report (Quik, Lijzen et al. 2019). For the risk assessment, the radiation module is used (see chapter 4.1).

4.4.1 Circularity

Circularity - Tier 0

Tier 0:

- Will the intended application of the residual material or waste stream be higher, equal or lower on the LAP-3 waste hierarchy compared to the current application?

In the current application concrete is used as construction material with the additional purpose of shielding the radiation from the cyclotron. In the new application the recovered concrete is granulated and used as a substitute for sand and gravel in the production of new concrete. In principle a downcycling takes place from concrete to granulated concrete, which corresponds to a lower position on the LAP 3 waste hierarchy.

Circularity - Tier 1
Tier 1:
- Does the material under consideration contain any of the EU critical raw materials?
- Supply check: Is there a concern for material supply due to a significant increase in demand for the source material?

Concrete is not considered to be a critical raw material (CRM) as defined by the European Union. Furthermore, it is not expected that in the near future the supply of concrete will significantly decrease or that alternative materials will be used to capture radiation in cyclotrons.

Circularity - Tier 2
Tier 2:
- Recovery efficiency: The resource fraction recovered from the total material flow, corrected for auxiliary material use.
- Contribution to the market: Contribution of the recovered resource fraction towards total resource use in an application or material cycle.
- Recyclability: The resource fraction available for recovery or reuse after the use phase of the intended application.

Recovery efficiency
The scope considered for this indicator is the demolishing and granulating of radioactive concrete structures. During the demolition phase some minimal losses are expected due to the formation of dust and small-sized residues. However, for the calculation it is assumed that the structures are completely recovered into concrete granulate. The recovery efficiency is therefore 1.

Contribution
For the calculation of this indicator the application of radioactive concrete granulate in new concrete production is considered. The cyclotron in the case study yields 1371 ton of concrete granulate which can be used to replace up to 20% of the river sand and gravel used in new concrete production. The total amount of new concrete produced per year is approximately 13-14 million cubic meters[10] of which 1839 kg/m3 is river sand and -gravel (Bijleveld, Bergsma et al. 2013).The contribution for this cyclotron is therefore 2,8E-07. The total amount of recovered radioactive concrete recoverable from current cyclotrons in the Netherlands equals 3000 ton maximum (Schaaf, Bekhuis et al. 2022), which corresponds to a contribution factor of 6,04E-4.

Recyclability
The scope for this indicator includes the applied radioactive concrete granulate in new concrete and the subsequent recycling thereof back into concrete granulate. Again, it is assumed that recycling into granulate occurs without losses (Rret=1), and that 20% of river sand and gravel can be replaced with concrete granulate in the production of

[10] https://betonhuis.nl/cement/betonmarkt-nederland

new concrete (Rta = 0,16). As concrete granulate is considered a downcycling into a similar application a quality factor (Qr) of 0,5 is applied in accordance with SSML. This yields a score of 0,078 for the recyclability indicator.

Overview circularity

Indicator	Score
Recovery efficiency	1
Contribution	$2{,}8*10^{-7}$
Recyclability	0,078

The application of gravel from cyclotron into new concrete can be done with an efficiency. This is because the gravel from the old cyclotron can be directly used as gravel for new concrete. The contribution to the market is close to zero as the amount of available gravel from cyclotrons is very limited compared to the required amount of gravel for concrete in the Netherlands. The recyclability is relatively low as not all required gravel for concrete can be replaced by recycled gravel from old concrete. For all three circularity indicators they are higher than the immobilisation alternative as there the circularity is 0.

4.4.2 *Environmental impact – CO_2 footprint*

The environmental impact module from SSML is used to assess the environmental impact of recycling concrete from a cyclotron vault. The environmental impact assessment module is always relevant, as there is always a difference in required energy for either the recycling process or the replaced product.

Tier 1

No tier 1 assessment is available within SSML.

Tier 2

To assess the environmental impact, SSML environmental impact module tier 2 is used.

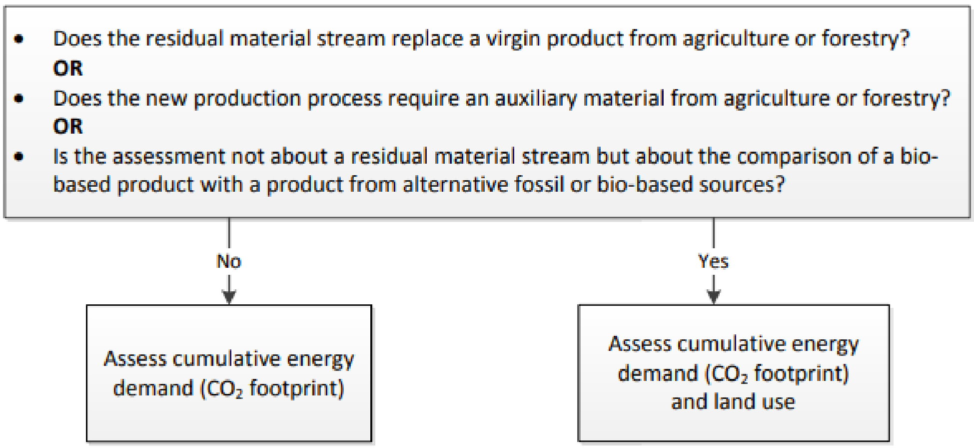

Figure 4.6 Diagram to identify whether land use should be assessed in addition to cumulative energy demand or CO2 footprint (from(Quik, Lijzen et al. 2019)).

The general SSML environmental impact assessment module tier 2 consists of two comparative assessments:

1. comparative assessment of CO2 footprint (or energy demand),
2. comparative assessment of land use.

An assessment of the land use is relevant only when one of the processes uses materials from biological origin (Figure 4.6). This case study is dealing with recycling concrete residue of a cyclotron vault. Concrete, nor recycled concrete are of biological origin thus land use is not included. Relevant for this case study is the environmental impact assessment for the greenhouse gas emissions. This comparison is a simplified LCA, based on the life cycle stages that are expected to contribute most to the CO2 emission and that differ between the baseline scenario and the circular scenario.

Scoping
The environmental impact assessment is limited to two scenario's, a baseline scenario and a circular scenario. In the baseline scenario the concrete from the cyclotron is granulated and immobilized. In the circular scenario, the granulated concrete is used as a replacement for gravel in new concrete. About 20% of the gravel in new concrete can be replaced with granulate from old concrete (TNO 2017), this corresponds with about 16% of the new concrete that can be made from old concrete. This means that in the circular scenario there is less gravel needed for the construction of new concrete. Figure 4.7 displays the scope of the analysis. As a functional unit 1 kton of (new) concrete is used.

For both scenarios also a comparison between CO2 emission from transport is taken into account, even though there are uncertainties about the transport distance. For the baseline scenario (disposal of radioactive concrete from the cyclotron vault), there is only one storage facility in the Netherlands. This facility is situated in Zeeland in the municipality of Nieuwdorp. As an average distance to the waste storage facility, we use the distance between Utrecht and Nieuwdorp (169km). For the circular scenario, there are multiple places where concrete is produced. The average distance to a concrete production facility would be around 50km. We assume a transport distance of 50km as this is the lump sum value from the 'Bepalingsmethode Milieuprestatie gebouwen' (NMD 2020).

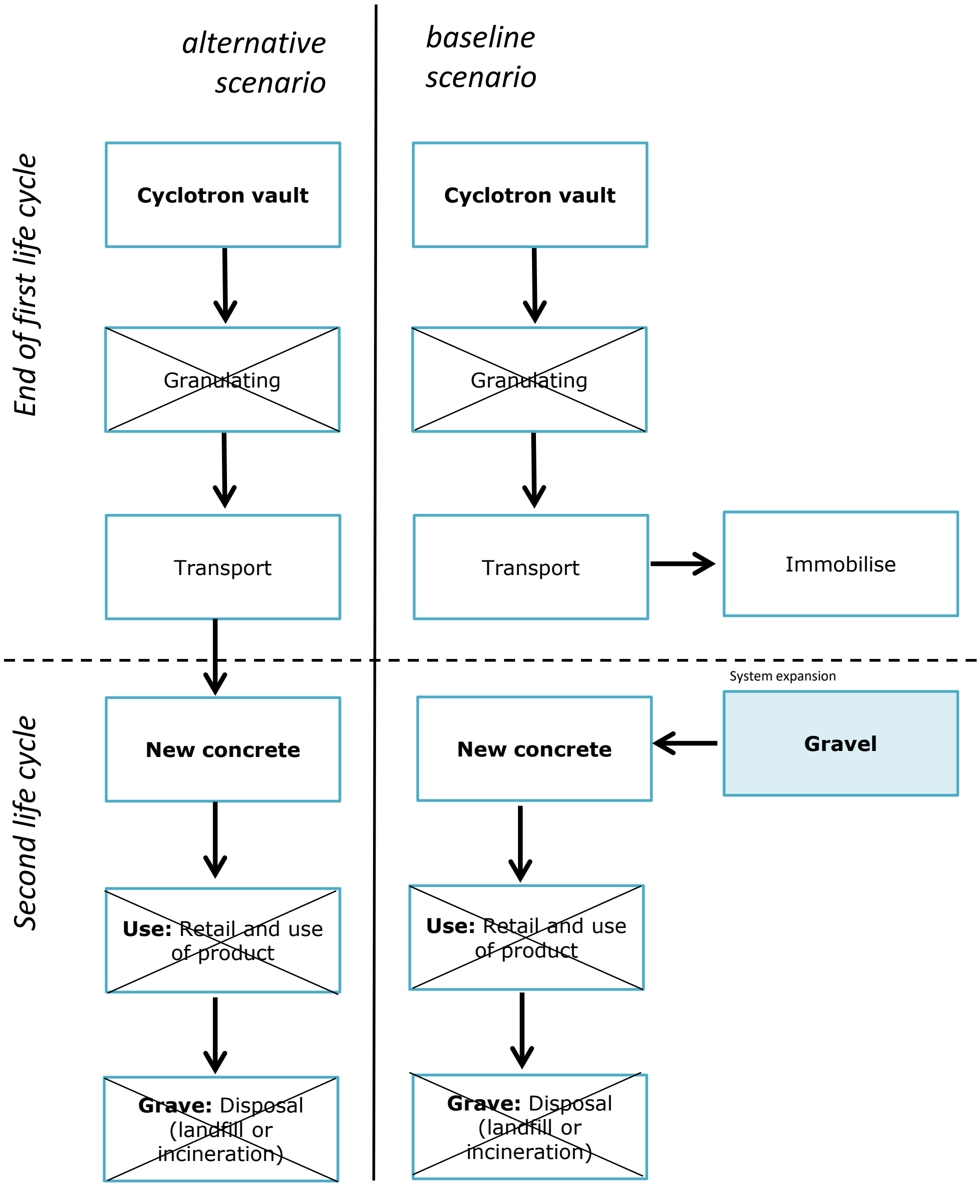

Figure 4.7 Schematic overview of the alternative and baseline scenario for the use of granulated concrete as a replacement for gravel in new concrete

Results
Two life cycle stages are incorporated in the analysis: transport of (old) concrete and the creation of new concrete.

When the old concrete is transported by trucks, with a capacity of >20 ton, a CO2-eq of 0,105 kg is emitted for each kilometerton. This number is taken from the national environmental database (NMD 20207). Transporting a kton of activated concrete to the storage in Nieuwdorp (169 km) would then result in the emission of 0,018 tonCO2-eq. Transporting it to a nearby concrete facility (50km) would result in 0,005 ton CO2-eq. In other words, transport can have a major impact on the greenhouse gas emissions.

When concrete from the cyclotron is recycled into new concrete, fewer virgin materials are needed to produce new concrete. Replacing 20% of the gravel and river sand with granulate results in a reduction of greenhouse gas emissions. A general number of 1,09 ton of CO_2-eq reduction is the result per kton of newly created concrete (TNO, 2017). When compared to the standard CO2 emission discharged with the production of concrete, a percentage of 0,13% reduction of the total CO_2 emissions can be realized with the production of concrete.

For concrete coming from the inner 40 cm of a cyclotron vault (option 1 as described in chapter 4.3) a mass of 0,16 kton old-concrete is residue. This leads to 1 kton new-concrete, and to a reduction of nearly 1,12 tons of CO2. In addition to this is the transport to the waste facility compared to the transport to the concrete production plant. From differences in distance a reduction of 2 ton CO2-eq is estimated. The total CO2 reduction when comparing the baseline scenario to the circular scenario for 0,16 kton activated old-concrete from a used cyclotron vault, is 3,1 ton CO2-eq.

With option 2, as described in chapter 4.3, the residue equals 1,39 kton old-concrete. However, as seen from the risk assessment, mean concentrations of radionuclides in the residue are below clearance levels. This means that it is no longer radioactive from a regulatory point of view. Therefor the baseline scenario (storage at the waste facility in Nieuwdorp) no longer applies. The baseline scenario now is construction with new virgin concrete. When comparing the circular scenario with a baseline where new concrete is used for construction, the CO2 reduction can still be assessed. As recycling the old-concrete into new-concrete still yields to a reduction of 9,7 ton CO2-eq.
CO2 reduction from different transport routes, is not relevant for the residue without radionuclides, described as option-2-residue.

Discussion
SSML tier 2 environmental impact assessment module is a simplification of reality, thus various steps in the recycling and immobilisation scenario are not included. One example of this is that granulating of cyclotron concrete cannot take place in the same way as non-activated concrete. When concrete is granulated, dust is created and released in the air. This dust is not a problem coming from regular concrete, but from activated concrete it is. Additional steps needed to limit the creation of dust were not included in the analysis, since they are expected to be similar in the recycling as the immobilisation scenario.

About two thirds of the emissions that can be avoided are associated with the reduction of transport distance. In the Netherlands there is a single depot where activated concrete can be stored, whereas there are multiple locations where old concrete can be recycled into new concrete. As average distance from the storage depot the distance from a central place in the Netherlands is taken (Utrecht). In practice, the distance to this depot is more uncertain, as is the distance to the nearest recycling site. In a specific case, the distance to a recycling facility or storage depot can be made more exact.

4.4.3 Radiation module, a safety assessment

Tier 0
Does the material originate from an industry licensed or having a registration for handling radioactive materials?
Yes, cyclotron requires a license. Go to TIER 1

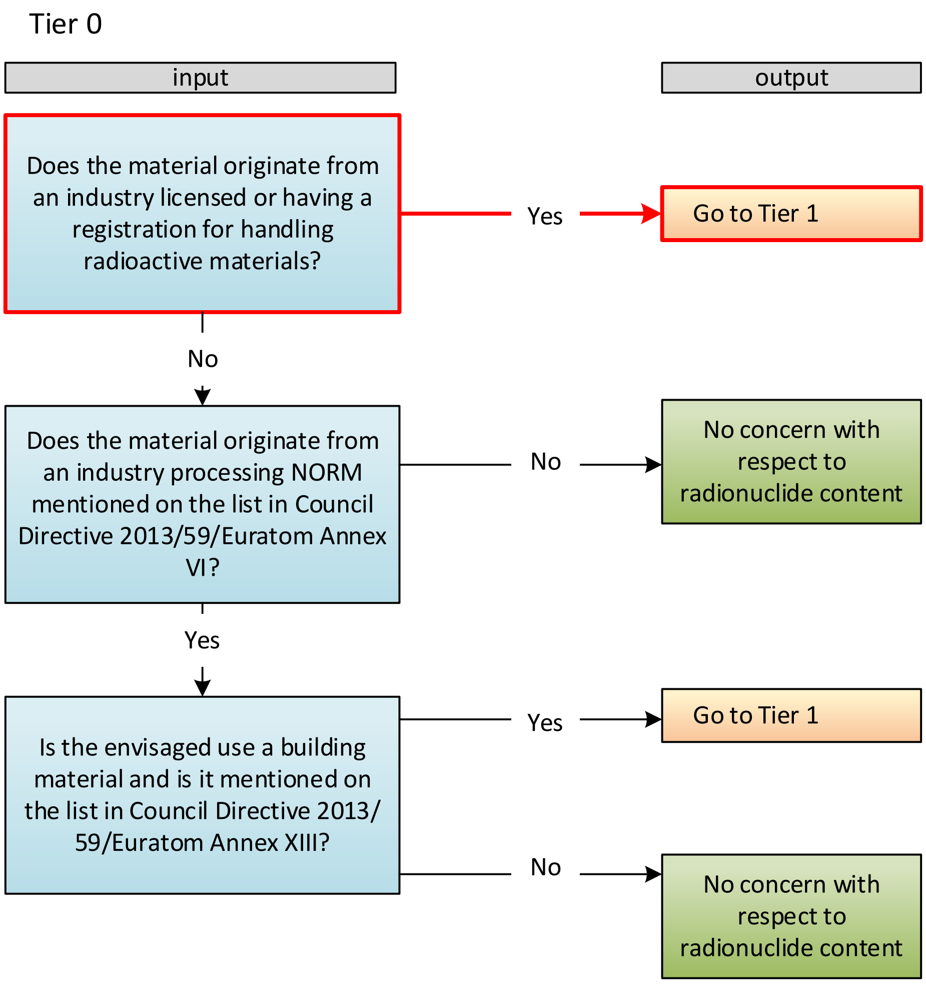

Figure 4.8 Tier 0

Tier 1
Is the radioactivity of natural origin?
No, it is artificial as it is manmade.

Is the activity concentration above clearance levels?
From this point onwards the different options mentioned earlier, have different outcomes. This assessment will firstly be done for option 1.
In case of option 1 the activity concentrations in de concrete residue are shown in Table 4.2.

Table 4.2 Activity concentrations in concrete residue (option 1)

	Half-life	**Activity concentration (Bq/kg)**	**Clearance level (Bq/kg)**[11]	**Above clearance level?**
Sc-46	83.8 d	**130**	100	yes
Mn-54	312.5 d	36	100	no
Co-60	5.272 y	**135**	100	yes
Zn-65	243.9 d	10	100	no
Cs-134	12.065 y	6	100	no
Eu-152	13.52 y	**105**	100	yes

Yes, this residue contains activities above clearance levels. For mixtures of radionuclides present in the same matrix, a weighted sum shall be calculated of nuclide-specific activity concentrations divided by the corresponding clearance levels. In order to comply with the clearance criteria, this (dimensionless) weighted sum shall be equal to or less than one. However, in this case, three nuclides alone are already exceeding the clearance levels, therefore calculating a weighed sum is no longer necessary.
The nuclides Sc-46, Co-60 and Eu-152 are above clearance levels.

Will the activity be decayed to below clearance levels within two years?
For calculations of the activity concentrations after a two year decay period, the following formula is used:

$$A_t = A_0 \cdot (0{,}5)^{t/T½}$$

- At activity concentration at time t
- A0 activity concentration present
- T½ half-life (in years)
- t time (2 years later)

- The activity concentrations of the different radionuclides after a two year period are shown in Table 4.3

Table 4.3 Activity concentrations in the concrete residue after a decay period of two years.

	Half-life	**Activity concentration (Bq/kg)***	**Activity after 2 years (Bq/kg)**	**Above clearance level?**
Sc-46	83.8 d	130	0,3	no
Mn-54	312.5 d	36	7,1	no
Co-60	5.272 y	135	**104**	yes
Zn-65	243.9 d	10	1,3	no
Cs-134	12.065 y	6	5,3	no
Eu-152	13.52 y	105	95	no

[11] (IAEA), I. A. E. A. (2005). Derivation of activity concentration values for exclusion, exemption and clearance. S. 44. Vienna. **44**.

The activity is not decayed to values below clearance levels within 2 years. Co-60 is still present with an activity concentration above clearance level. Therefore, a weighted sum of nuclide-specific activity concentrations divided by the corresponding clearance levels will surely be more than one.

Go to TIER 2
In Figure 4.9 the overview of tier 1 for this scenario is given.

Tier 1

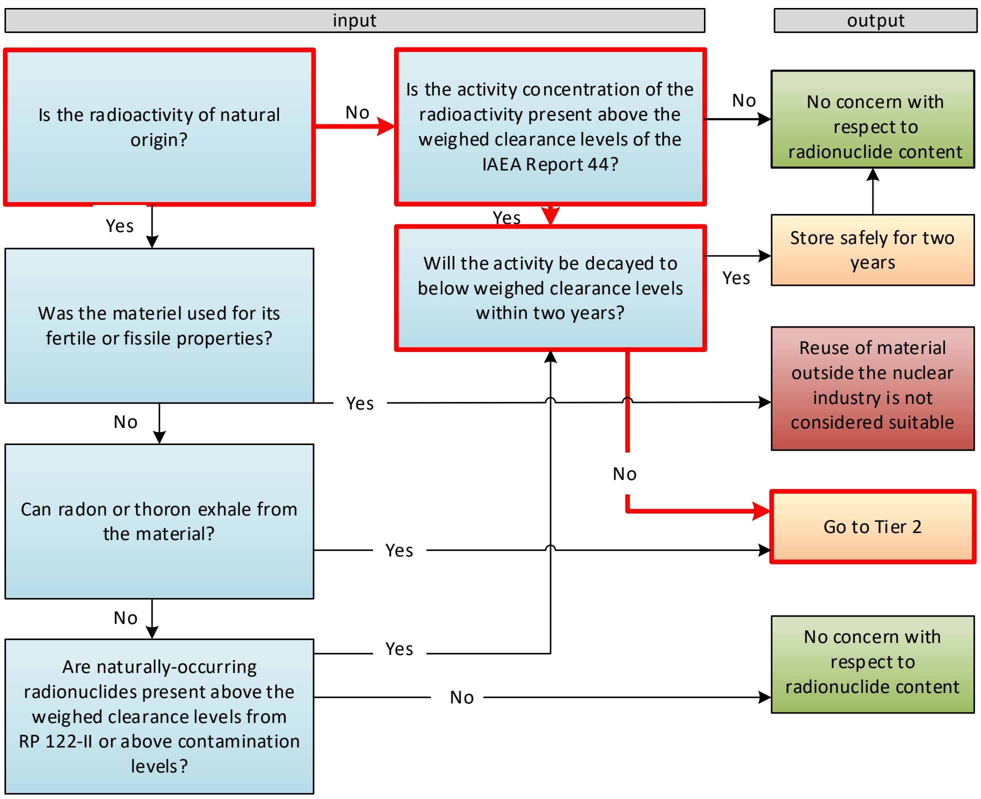

Figure 4.9 Tier 1 considering option 1

Tier 2
Is removal of radionuclides feasible?
No, there is no method that would separate the nuclides or only Co-60 from the concrete.

Are nuclides and decay products fixed in the material matrix?
Yes, the nuclides will not leak outside the material and decay product are not gaseous.

Are nuclides of natural origin?
No

Does the dose stay below 10 μSv/year in the new situation?
To calculate a dose, the new situation (scenario) must be known. The residue can be re-used as replacement of gravel in new concrete. To do so, the residue concrete first must be grinded to gravel. A percentage of 9 % of the new concrete can be replaced by residual concrete gravel. The nuclides in the residue have decayed for 2 years before re-using,

meaning the activities are 104 Bq/kg and 95 Bq/kg of resp. Co-60 and Eu-152. Even though only C0-60 has an activity concentration above clearance levels, all artificial nuclides present should be taken into account when calculating the dose. However, the contribution of the dose due to the presence of the nuclides Sc-46, Mn-54, Zn-65 and Cs-134, is neglectable compared to the dose caused by Co-60 and Eu-152. Therefore, the effective dose is based on the presence of Co-60 and Eu-152 in the new scenario.
The scenario chosen is to construct a building of contaminated material (concrete containing residuals). The exposure geometry chosen is a room of 3 m × 4 m with a height of 2.5 m. The calculations are based on two walls and a ceiling that are 20 cm thick. It is assumed that windows and doors account for the other two walls and that the floor is made of other material. This choice is made in analogy with a scenario described in IAEA report 44. Doses are calculated for a geometry in the middle of the room at a height of 1.25 m.
By mixing 9% of the residue with new concrete the activity concentrations within the new walls will be 9,4 Bq/kg Co-60 and 8,6 Bq/kg Eu-152, assuming homogeneous dispersion of the nuclides within the new concrete.
A final assumption is to set an exposure time of 5110 hours per year, meaning a person would stay 14 hours per day during a whole year inside this room. This assumption is different from the continuous exposure time given in (IAEA 2005) report but still very conservative. Would the person in this room receive an effective dose below 10 μSv a year?
This is where the radiation expert needs to do the calculation. Dose calculations have been done using Mathematica with a 3D-point kernel integration of gamma dose, including shielding and buildup. Ambient dose equivalent conversion coefficients were 0.36 μSv/h per MBq/m^2 for Co-60 (Keverling Buisman 2015) and 0.189 μSv/h per MBq/m^2 for Eu-152 (RPD, 2014). The Berger formula [B(r) = 1 + aμrebμr] is used to address the buildup factor of gamma-rays, taking for Co-60 the term a as 1.1355 and b as 0.0478. For Eu-152 the a-term is 1.3995 and the b-term 0,1074 (Trubey 1966) The linear attenuation coefficient (μ) for Co-60 gamma's in concrete (density 2,35 g/cm^3) is 0.1342 cm^{-1} and for Eu-152 μ is 0.1786 cm^{-1} (Bos, Draaisma et al. 2007).
Within this room the ambient dose is 10.4 nSv per hour. A person staying 5110 hours per year in the middle of the room will receive a dose of 53 μSv.

The answer to the question 'Does the dose stay below 10 μSv/year in the defined scenario?' is 'no' because these nuclides are classified as artificial and the dose of 53 μSv/year exceeds the criteria of 10 μSv a year. It is therefore not allowed to re-use the vault residue in construction material for dwellings as described in this scenario. The residue should, within our law system, be seen as radioactive waste and will be safely stored at an isolated at a controlled facility. Figure 4.10 shows an overview of tier 2 for the scenario with the residue as described as option 1. Another scenario might result in another outcome.

NOTE: if these nuclides were classified as 'natural' this scenario was allowed because then a dose up to 300 μSv/year would be allowed. This *division in origin of the nuclides is written within our legal framework. When considering risks only, our body does not differentiate between radiation from natural or artificial nuclides. The question is what risk/dose do we accept? The answer to this question is not addressed in this report.*

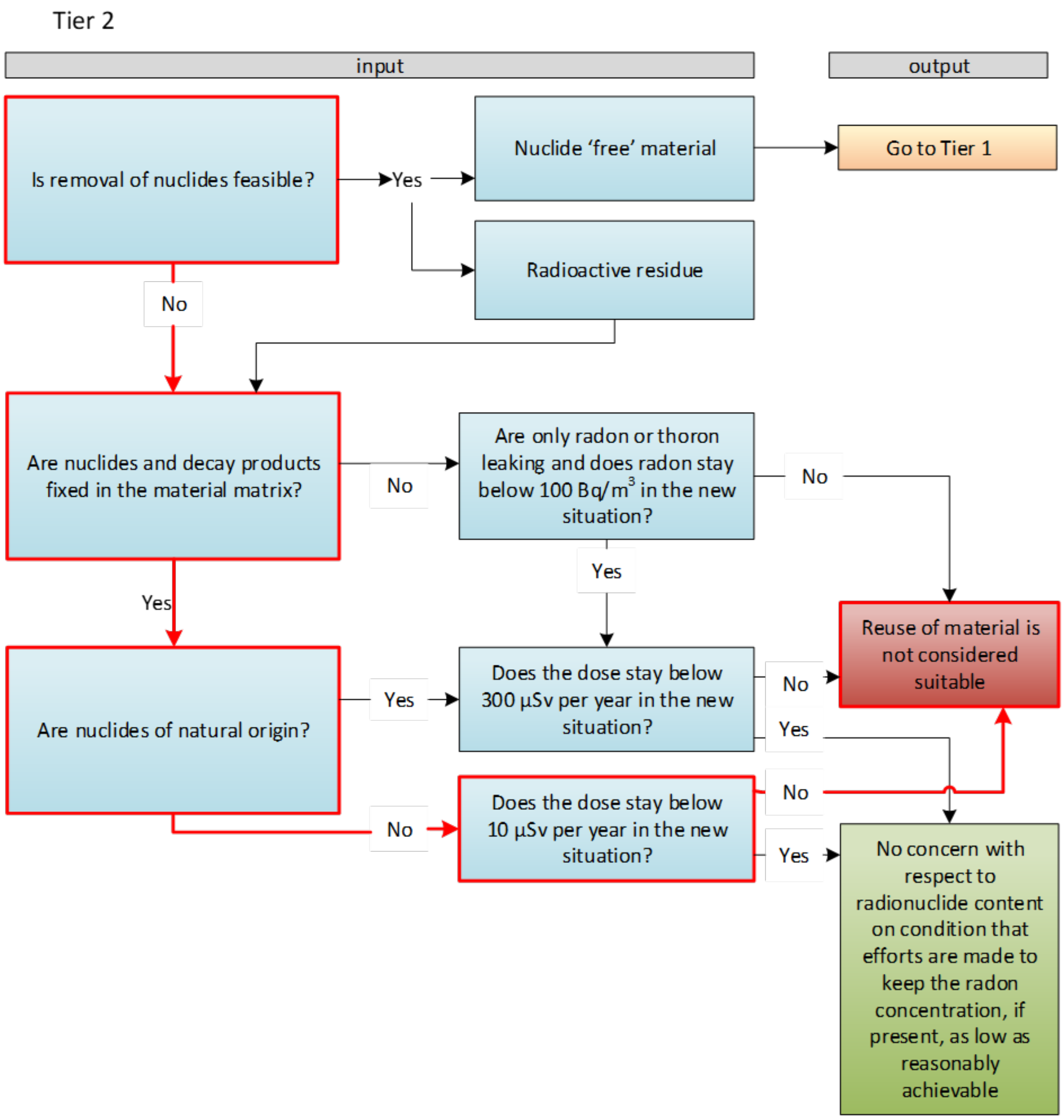

Figure 4.10. Tier 2 when considering option 1

Option 2 assessment.
The residue described as option 2 is not only taken from the 40 cm layer of inner concrete walls but instead all the concrete from this vault was taken and mixed homogeneously.
Tier 0 is similar for the residue from both option 1 and 2 since the residue is still coming from the same cyclotron vault, therefore the assessment of option 2 is started from Tier 1.

Tier 1
Is the radioactivity of natural origin?
No, it is artificial as it is manmade.

Is the activity concentration above clearance levels?
In case of option 2 the activity concentrations in de concrete residue are shown in Table 4.4. These activation concentrations are, compared to concentration taken in option 1, reduced by a factor 0,12 due to homogeneously mixing the activated inner layer of concrete with the rest of the not-activated concrete.

Table 4.4 Activity concentrations in concrete residue (option 2)

	Half-life	**Activity concentration Bq/kg)**	**Clearance level (Bq/kg)**	**Above clearance level?**
Sc-46	83.8 d	15	100	no
Mn-54	312.5 d	4,2	100	no
Co-60	5.272 y	16	100	no
Zn-65	243.9 d	1,2	100	no
Cs-134	12.065 y	0,7	100	no
Eu-152	13.52 y	12	100	no

When taken per nuclide, none of the radionuclides in the residue contains an activity concentration above the clearance level. However, for mixtures of radionuclides present in the same matrix, a weighted sum shall be calculated of all nuclide-specific activity concentrations divided by the corresponding clearance levels. In order to comply with the clearance criteria, this (dimensionless) weighted sum shall be equal to or less than one.
The weighed for this situation is:
$$\left(\frac{15}{100}+\frac{4.2}{100}+\frac{16}{100}+\frac{1.2}{100}+\frac{0.7}{100}+\frac{12}{100}\right)=0.5$$
and 0.5 < 1
Since the weighed sum is below one, the clearance levels are not exceeded.
Activity concentrations below the clearance values lead to a green block in the flowchart (Figure 4.9). So, when recycling residue from the cyclotron vault as described in option 2, there will be no concern with respect to the radionuclide content.

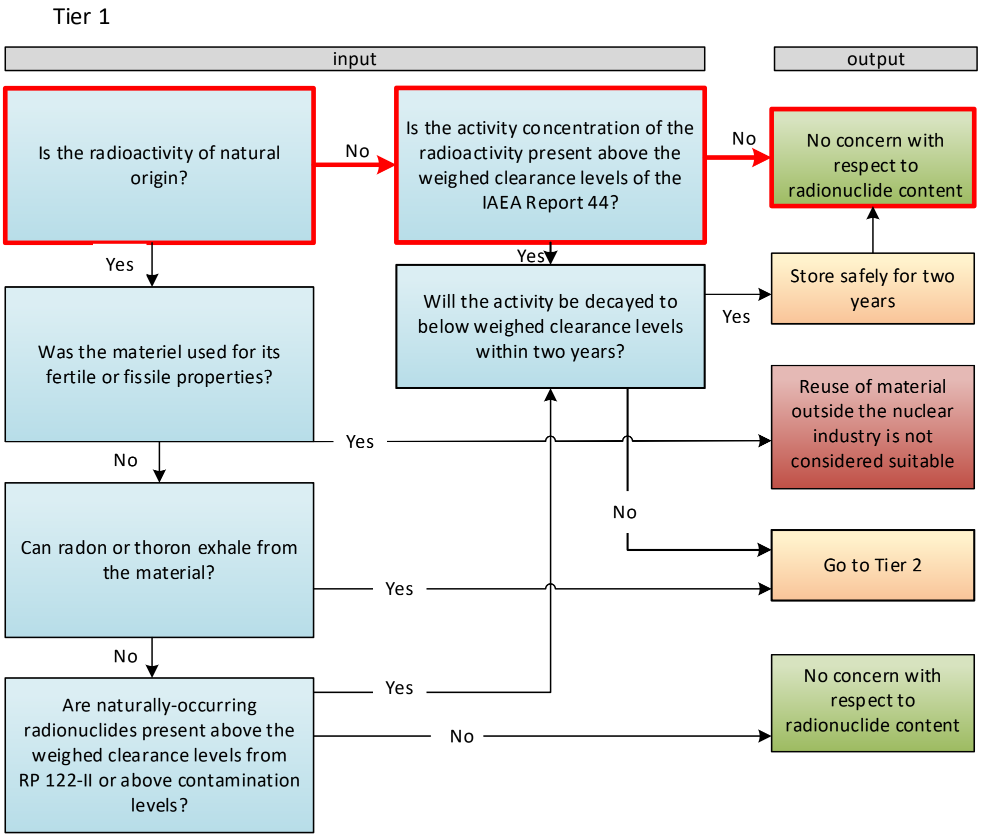

Figure 4.11 Tier 2 when considering option 2

The green block saying that there is no concern with respect to the radionuclide content is just part of the total assessment. Besides risk assessment, also an environmental impact assessment and a circularity assessment should be taken into account when considering the re-use of a radioactive contaminated residue.

4.5 Discussion of case study

When dealing with radiation, three general principles of radiation protection (Valentin 2007) are of main importance.

1. *"The Principle of Justification: Any decision that alters the radiation exposure situation should do more good than harm.*
2. *The Principle of Optimisation of Protection: The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, considering economic and societal factors.*
3. *The Principle of Application of Dose Limits: The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits specified by the Commission."*

For justification, the benefit of recycling a radioactive material should outweigh the radiation detriment. Currently, the principle of justification is mainly used when deciding if radioactivity can be introduced deliberately in medical, industrial or nuclear domains. The introduction of radioactive sources should lead to benefits for patients, workers,

members of the public or the environment. For disposal of low-radioactive waste (material with radionuclides above clearance levels) the question of justification is not yet considered. The residue exists and there is a need to get rid of it. Today, the only consideration in regulation, is to protect the people against the risks of radiation. Therefore, all residues above clearance levels, are immobilized and stored. Since this is a one way track we need to enlarge the capacity of storage on a regular basis and in some cases even consider long-term storage in a deep geological repository.
Within the circular economy we should ask ourselves again if it is justified to recycle low-radioactive residues. The difference with the disposal-scenario (baseline scenario) is that we should not only take radiation risks into account but also societal and environmental factors. In this case-study, a first step is made by assessing in addition to radiation-risks, the CO_2-reduction and the level of circularity. Risks from recycling are compared to accepted risks in current international regulations, whereas CO_2 reduction from recycling is compared to CO_2 reduction from a disposal scenario. Recycling low-radioactive residues is without any doubt more circular then immobilising and storing. When within the circular scenario, risks are acceptable and CO_2 reduction is high, recycling is obviously the better option. This is the case with the concrete residue from the cyclotron vault described as option-2. However, when there are conflicting interests, weighing the different factors will be a challenge. The latter counts for the concrete residue described as option 1. Assessment of option-1-residue leads to radiation risks just above accepted levels, but the circular scenario also leads to a substantial reduction of CO_2.

4.6 Lessons learned from the case study

4.6.1 Observations

Pioneering idea: The policy and regulation for radioactive waste management in the Netherlands was developed separately from the general waste and sustainability regulations and policy in the Netherlands. Furthermore, legal provisions on radioactive substances have legal precedence over general waste requirements. As a consequence, the management of radioactive residues and radioactive waste in practice became a niche, with little interaction with general waste and sustainability policy. A main lesson is to see radioactive residues in a broader perspective. Introducing possible benefits to the environment by assessing the CO_2 reduction of recycling low-radioactive residues is a pioneering idea, when dealing with radioactive residues.
Technical improvement: The module for radiation assumes a homogeneous spreading of radionuclides throughout the material. This is rarely the case in practice. Therefore, the maximum activation concentration has been taken as a mean value for assessment. This might lead to very conservative risk estimates.
Governance: for this case-study activity values from a publication haven been taken. Due to the presence of information from international literature, no stakeholder information was taken into account.
Regulations/science: The radiation module used is risk-based, therefore is does not follow the clearance levels for naturally-occurring radionuclides from the Dutch regulatory system. However, for artificial nuclides, clearance levels within the Dutch legislation are based on the

same risk level as taken in the module. This means that for artificial nuclides, the module can also be used as a flow scheme to meet the legislative and regulatory Dutch framework.

4.6.2 *Recommendations*

Pioneering data: it is recommended to view radioactive residues in a broader perspective. Introducing possible benefits to the environment by assessing the CO_2 reduction of recycling low-radioactive residues is not only a pioneering idea but it is necessary, when dealing with radioactive residues.
Technical improvement: The conservative risk estimates resulting from taking the maximum activity concentration found within the concrete as the point of departure should be downgraded to realistic values. Even though there is an inhomogeneity of activity values within the concrete wall, it is also known that the long-lived activities (Sc-46: 84 d, Co-60: 5,3 y, Eu-152: 13,5 y) are highest at a depth of 5 to 10 cm and then decrease exponentially to a low level at a depth of about 40 cm (inner layer)(Kimura, T. Ishikawa et al. 1994). When granulating the concrete, it is recommended to calculate the mean activity concentrationof the inner layer instead of the maximum activity concentration to obtain more realistic activity values.
Governance: Recently cyclotrons haven been decommissioned in the Netherland. This case-study was set as an example based on information from literature. However, with Dutch information available, it is recommended to go through the radiation module again using stakeholder information from a Dutch decommissioned cyclotron vault.
Regulations/science: since the radiation module is risk based it does not work as a flow scheme for waste with radionuclides from natural origin. It is recommended to compare the outcomes of the Dutch regulation system with the radiation module for natural radionuclides like radioactive scale from a decommissioned coal-fired power station. The comparison can give information on the feasibility of using the module for specific clearance within the Dutch regulation.

5 Case study on recovery of cellulose from waste water

5.1 Case description

In the Netherlands, waste water is treated in Waste Water Treatment Plants (WWTPs) and effluent is discharged mainly on surface waters. The remaining material is separated as sludge, sometimes fermented, and then dried and incinerated. Sludge is a major waste stream, because of its large volume and mass (Zweers 2021). Because sludge is a water-rich fraction, its energetic efficiency is limited. Therefore, sludge incineration generally results in an approximately neutral energy balance.

Besides organic matter and other substances/components, sludge from WWTPs also contains cellulose, mostly from toilet paper (Remy, Conzelmann et al. 2020). Cellulose is considered as a valuable resource. It is most well known as paper fibres, but it is also used in a variety of other products such as asphalt, paint, drywall, diapers and cosmetics. Cellulose is extracted from woody biomass (primary source) or recycled from paper (secondary source). Currently, several ways to recover cellulose from waste water (tertiary source) have been developed and are now being tested on pilot or semi-commercial scale. Tertiary cellulose is already used in construction and infrastructure and more applications such as biobased chemicals are being developed.

In this chapter, the recovery of cellulose from waste water by Recell Group B.V. (using the Cellvation® process) is assessed as a case study for testing SSML. This case study is done in collaboration with another project at RIVM that is commissioned by the Ministry of Infrastructure and Water Management. Rijkswaterstaat has received questions on an application for an end of waste status for tertiary cellulose from waste water. In order to get this status, the resource needs to meet certain requirements. The aim of this other RIVM project is to assess the safety for human health and the environment, using the safety modules of SSML. Based on Tier 0 of SSML, the modules ZZS, pharmaceutical residues, pathogens and antimicrobial resistance were used. In addition, also the pesticides module was used to test the module and check the assumption that this module is indeed not relevant for this case study based on tier 0. To complete the analysis using SSML, this case study assesses the circularity and environmental impact modules.

The assessments of the safety modules were still ongoing when writing this chapter. Therefore, only the circularity and environmental impact modules are described here. For the lessons learned from this case study, also the preliminary assessments of the safety modules -including the process- were taken into account.

5.2 Application of circularity and environmental impact modules

5.2.1 Circularity

For the circularity and environmental impact assessment, we use the following scope: recovery of cellulose from domestic waste water using the Cellvation process by Recell Group B.V. and Cirtec B.V.. Cellulose can also be recovered using other processes, but here we focus only on the Cellvation process as this is currently the only production technology that produces a proven standardised marketable product (Recell®). The source of cellulose is the recovery from domestic waste water by fine-sieving, dewatering and further valorisation. (Remy, Conzelmann et al. 2020) describe the details of this process. It considers a domestic waste water treatment plant in Geestmerambacht (in the Netherlands). The recovered cellulose (Recell®) is used as a functional additive in asphalt, as this is the first market that is developed by Recell Group B.V..

Where applicable, the comparison is made between cellulose recovered from waste water (tertiary cellulose) and cellulose from wood (primary cellulose). For primary cellulose the wood is stripped of lignin and hemicellulose, after which cellulose pulp remains for the production of, for example, paper. Recycled paper (secondary cellulose) is not considered here. Tertiary cellulose currently has a more limited range of applications than primary cellulose, because of a quality difference and limited public acceptance.

Circularity - Tier 0
Tier 0:
Will the intended application of the residual material or waste stream be higher, equal or lower on the LAP-3 waste hierarchy compared to the current application?

Higher. Using the waste hierarchy, the recovery of cellulose results in a higher classification compared to the conventional way of waste water treatment, which results in sludge and effluent with no particular use of cellulose in sludge in the Netherlands. Sludge is generally dried and co-incinerated with little energy recovery, because of the large amount of water still present in sludge. This clearly shows that an increase in circularity is likely, so we continue on to Tier 1.

Circularity - Tier 1
Tier 1:
1. Does the material under consideration contain any of the EU critical raw materials?
2. Supply check: Is there a concern for material supply due to a significant increase in demand for the source material?

1. Cellulose is not identified as a critical raw material (CRM) by the EU. (Also no CRMs are used in the Cellvation process.)
2. Supply check: most of the domestic waste water is still treated in the conventional way, with no recovery of resources from the waste water and little energy recovery from co-incineration or sometimes a combination of fermentation (with biogas generation) and incineration. So no supply problems are currently foreseen on the scale of a WWTP. However, in the Netherlands there are several pilots on the recovery of resources contained in domestic waste water, such as struvite, alginate (Kaumera) or the bioplastic PHBV. Even though the pilot studies focus on the extraction of different resources from waste water, they all use the same source material (waste water and sludge) to extract it from. From this point of view, it would be good to investigate

which resource extraction methods can be combined and in which cases it will lead to a competition for the same source material or a production loss if several resources are extracted from waste water.

For further assessment of the material circularity, a Tier 2 should be conducted.

Circularity - Tier 2

Tier 2:

1. Recovery efficiency: The resource fraction recovered from the total material flow, corrected for auxiliary material use.
2. Contribution: Contribution of the recovered resource fraction towards total resource use in an application or material cycle.
3. Recyclability: The resource fraction available for recovery or reuse after the use phase of the intended application.

Recovery efficiency

The amount of cellulose that is recovered from domestic waste water varies. According to data from Remy *et al.* (2020) the recovered resource (Rx) varies between 29 and 100 g dry matter (DM) per m^3 influent (Remy, Conzelmann et al. 2020). For our calculations we use the average value of 72 g DM/m^3. Also, the amount of cellulose that is present in domestic waste water is fluctuating. The total amount of suspended solids in waste water influent is 290 g/m^3, but this only partly consists of cellulose. Estimations range from 27% according to Remy *et al. (2020)* and 35% to 51% of cellulose in total suspended solids according to STOWA (STOWA 2020). The average value of both references (35%) was used for the calculations of the total resource in source (Rtm), leading to a value of 101,5 g DM cellulose/m^3. No auxiliary materials are used in the Cellvation process. This leads to a recovery efficiency score of 0.71.

Contribution

This indicator quantifies the degree to which recovered cellulose can fulfil the demand within a defined geographical market (in this case we chose the national level). Currently, the Cellvation process is only applied on pilot scale at WWTP Geestmerambacht, resulting in an estimated production amount of 500 ton/year of recovered cellulose (Rx) (Remy, Conzelmann et al. 2020). This recovered cellulose (Recell®) is assumed to be applied completely as a functional additive in asphalt. Only a small fraction of the total amount of cellulose needed for asphalt production in the Netherlands (between 5,400 and 10,000 ton/year (STOWA 2017), leading to an average of 7,700 ton/year) is currently assumed to be covered by Recell, leading to a contribution of 0.06. But if the production of Recell is to be extrapolated to the theoretical potential of applying the Cellvation process on all domestic WWTPs in the Netherlands (with a total amount of 120 000 ton cellulose/year in domestic waste water (Postma and van der Oost 2018), this would lead to contribution of 11.05. This would be more than 10 times the annual requirement for cellulose in asphalt production This is just a theoretical calculation, since this type of additive is just one of many applications and it is not realistic that Recell Group B.V. will recover all cellulose from waste water. Recell can also be extracted from different sources and can be used for different applications, making the contribution a rather arbitrary indicator for this case study.

Recyclability
In this case study recovered cellulose is applied as a functional additive in asphalt. Although asphalt can be recycled to new asphalt, the cellulose fraction in asphalt cannot be recovered. Therefore, the recyclability score is 0. However, cellulose by itself is a natural bio-based fiber that can be used in a large range of applications. For a different application, recyclability can be larger (up to 1). This shows that recyclability is less relevant as an indicator for this case study. Recell Group B.V. recovers tertiary cellulose as a resource for different applications. This indicator could become relevant when choices have to be made which product of Recell® is more circular, but generally a resource supplier just sells the resource to a product manufacturer. Choices on the application of the resource and on the recyclability of the product are made by the product manufacturer (not by the resource supplier).

Overview circularity

Indicator	**Score**
Recovery efficiency	0.71
Contribution	0.06
Recyclability	0

The three indicators for the circularity of recovered cellulose (Recell®) used as a functional additive in asphalt are 0.71 for recovery efficiency, 0.06 for market contribution and 0 for recyclability. The results are given as a fraction (a value between 0 and 1). Generally, a higher number represents a better outcome.
However, it should be noted that these indicators for circularity posed some challenges when applying them to this case study, as they are meant to be used for the recycling of a product to a new product. In this case study we are looking at the recovery of a resource from a waste stream that is currently still at pilot scale. Because of the pilot scale and broad application range potential of cellulose, the indicators contribution and recyclability are less relevant for this case study.

5.2.2 Environmental Impact – CO2 footprint and Land use

For the environmental impact module two indicators are available: energy or CO_2 footprint, and land use. The use of the indicator energy or CO_2 footprint mainly depends on the availability of data. The use of the indicator land use depends on its relevance for the case study. In this case CO_2 footprint and land use are applied as indicators for environmental impact, as data on greenhouse gas emissions were available and virgin cellulose is produced from a biotic source that uses a lot of land. The outcome of this assessment shows how much of a reduction of environmental impact, e.g. less CO_2 emission and land use are obtained when recovering cellulose compared to a baseline scenario.

Definition of scope and baseline scenario:
1. What material flows and resulting products are assessed?
2. What is the reference product that is replaced by the new application of the non-virgin material?

3. What are the system boundaries?

In this case study, cellulose is recovered from domestic waste water. Waste water is fine-sieved with suitable mesh size (~ 158-350 μm) and this sieved material is then used in the Cellvation® production process. In the Cellvation process cellulosic sludge is dewatered on the basis of residual heat and further valorised to tertiary cellulose (Recell®).
The reference product is cellulose from primary sources, in this case woody biomass from forestry.
The alternative and baseline scenario consider a waste water treatment plant in Geestmerambacht (in the Netherlands) (Remy, Conzelmann et al. 2020). The LCA report is based on a WWTP with a capacity of 200,000 inhabitant equivalents annually and an associated annual production of 1260 tons of Recell® (average value). The current pilot scale facility only has an annual production of 500 tons of Recell®, but for the LCA it was assumed that production would be at full capacity for this WWTP. The material flows that are different in the WWTP are considered from the influent up to the co-incineration of sludge and cellulose production in the alternative scenario. Sieving of waste water for the recovery of cellulose from the sewage treatment reduces the number of solids in waste water and therefore also the amount and composition of sludge. This saves CO_2 on aeration, thickening, dewatering, drying and transport of the sludge. On the other hand, the reduction of the sludge also results in a decrease in the energy yield from the sludge incineration. These are the cradle-to-gate life stages. The gate-to-grave stage is assumed to be the same for the two scenarios. This means that the use of cellulose as functional additive in asphalt (and recycling of asphalt) are not considered in both alternative and baseline scenario. However, the avoided use of primary cellulose (from wood from forestry) is included in the baseline scenario (see Figure 5.1).

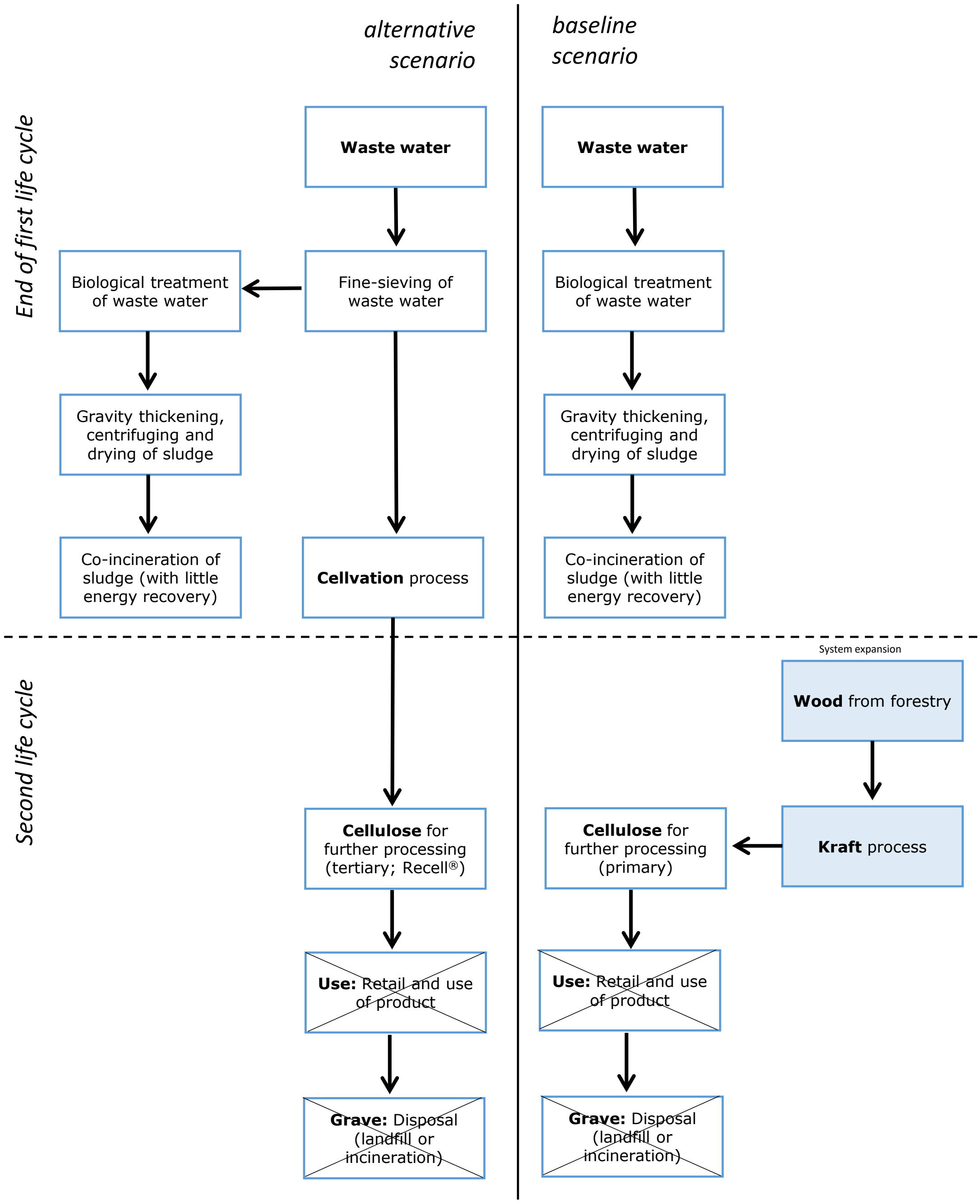

Figure 5.1 Schematic overview of the alternative and baseline scenario for the production of cellulose from waste water.

Tier 2:
1. Determine scope: is the functionality of the new product different from the product it replaces? Is there a difference in function, quality or durability?
2. Make a list of materials and energy required for each scenario.
3. Search for generic CED or CO_2 emission values and land use estimations for the materials and energy used.
4. Sum the CEDs, CO_2 eq. and land use per functional unit and compare different scenarios.

1. It is assumed that there is no difference in the functionality of tertiary cellulose from waste water compared to primary cellulose from wood. Therefore a cradle to gate perspective is used as scope. This means that the use and end of life stages are not considered. In practice there is a quality difference between primary and tertiary cellulose, and therefore tertiary cellulose has a more limited range of applications than primary cellulose. In this case study this is not taken into account for the following reasons:
   - There where tertiary cellulose is used, it replaces primary or secondary cellulose and is applied in a similar way.
   - It is assumed that the amount of secondary cellulose remains the same, so that cellulose obtained from waste water (tertiary cellulose) replaces the use of primary cellulose.
2. In the alternative scenario, the recovery of cellulose from domestic waste water using the Cellvation process is considered. This consists of 1) a fine-sieving step of the waste water, that also has an effect on aeration, thickening, centrifuging, drying, transport and energy yield from the co-incineration of the sludge, and 2) drying and further valorisation of the cellulose product, using electrical energy (0,556 kg CO_2/kWh (CO2emissiefactoren 2021) and low-grade residual heat from waste incineration (Remy, Conzelmann et al. 2020).
   In the baseline scenario waste water treatment without cellulose recovery is considered, combined with primary cellulose production, using woody biomass from forestry and the Kraft process (see Figure 5.1). Land use for the production of woody biomass for primary cellulose is also considered.
3. Data for waste water and sludge treatment and the Cellvation process were taken from an existing LCA study in which CO_2 emissions for both scenarios are described (Remy, Conzelmann et al. 2020). For comparison with primary cellulose, data from the Ecoinvent database v3.6 were used for CO_2 emissions in the Kraft process (primary cellulose production process) and for CO_2 emissions of forestry, thereby assuming a mass allocation of 43% of wood biomass being used for paper- and cardboard industry (Sustainable forest management, EcoInvent v3.6). The differences in CO_2 emissions are given in Table 5.1.
   Land use estimations for wood production used for primary cellulose are estimated using the Ecoinvent database v3.6. These estimations are given in Table 5.2.
4. The relative CO_2 footprint and land use of cellulose production from waste water (tertiary cellulose) compared to baseline waste water treatment and cellulose production from wood (primary cellulose) is summarized in Table 5.3. Land use values were converted to represent the production of 1 ton of cellulose.

Table 5.1 (Relative) CO2 emission of different process steps of the recovery of cellulose from waste water (alternative scenario) and the baseline scenario.

ton CO_2/ton cellulose	**Alternative scenario**	**Baseline scenario**
Waste water and sludge treatment		
Reduction in energy needed for aeration of waste water and thickening, dewatering, drying and transport of sludge	-2.41	
Reduction of energy yield from co-incineration of sludge	1.71	
Cellvation process	0.58	
Subtotal end of first life cycle	*-0.12*	
Cellulose production		
Kraft process		0.65
Forestry		1.54
Subtotal second life cycle		*2.19*
Total	**-0.12**	**2.19**

Table 5.2 Land use for wood production (forestry) for the production of primary cellulose based on the market average composition.

Process	**% of total**	**Land use** (m^2year/kg cellulose)	**Source**
Mechanical & semi-chemical pulp	26.7	0.26	EcoInvent v3.6
Sulphate pulp production (bleached)	4.4	1.11	EcoInvent v3.6
Sulphate pulp production (totally chlorine free bleached) (kraft)	68.9	2.03	EcoInvent v3.6
Total	100	**1.53**	

Table 5.3 Overview of relative CO_2 footprint and land use of cellulose production from waste water (tertiary cellulose) compared to baseline waste water treatment and cellulose production from wood (primary cellulose).

Process	**CO_2 footprint** (ton CO_2 eq / ton cellulose)	**Land use** (hectare*year / ton cellulose)
Waste water treatment	-0.70	
Cellvation process (tertiary cellulose)	0.58	
Kraft process (primary cellulose)	-0.65	
Forestry (baseline scenario)	-1.54	-15.3
Total	**-2.31**	**-15.3**

Conclusion

The outcomes clearly show that the application of the Cellvation process for recovery of tertiary cellulose from waste water has a lower CO_2 footprint and lower land use compared to primary cellulose production from wood. The application of the Cellvation process itself already shows a reduction in CO_2 footprint of waste water treatment. This reduction of 0.12 ton CO_2 eq /ton cellulose compared to the baseline waste water treatment is due to a more efficient waste water treatment process because of a reduced amount of solid particles due to fine-sieving of waste water. For cellulose production the Kraft process (for primary cellulose) and the Cellvation process (for tertiary cellulose) have a similar CO_2 footprint, but for primary cellulose the CO_2 footprint and land use are mostly dependent on the woody biomass production from forestry. This is taken out entirely in the case of tertiary cellulose. So, there is a positive environmental impact of the Cellvation process for recovery of tertiary cellulose, both on the waste water treatment process as well as on the cellulose production process. A more detailed analysis could be conducted as part of tier 3.

5.3 Lessons learned from the case study

5.3.1 Experiences on suitability and user friendliness of SSML

This case study was performed by RIVM in collaboration and with data collected by Recell Group B.V. Our contact person at Recell Group B.V. was very proactive and already familiar with LCA studies, so he could already do a first calculation on the environmental impact module based on the existing LCA study and other sources by himself.

Environmental impact module

The contact person's experience with the environmental impact module of SSML was positive. The module was perceived as usable and easy to do, but this was also because there already was an LCA report available. It took several years to compose the LCA report, because of data intensity. The module also matched well with market demand. He stressed the importance of scoping and setting the system boundaries together, also to get clarity on the data needed. Also the data sources that can be used are of importance for the outcomes. Own data and data from databases such as EcoInvent can be very different. The schematic overview of the alternative and baseline scenarios (Figure 5.1) was very important and helpful. This immediately clarified the process and was of great added value for gathering the right data.

Circularity module

This module was perceived as useful. It was clear how it works. For the recovery efficiency indicator, auxiliary materials are now included in the calculations. This does not match the calculations when you make a raw material. (This is not relevant for this case, because no auxiliary materials are used.) The contribution and recyclability indicators were not so relevant for this case study.

5.3.2 General remarks

Importance of scoping

Scoping of the case study is an essential part of the case study. The choices made in this scoping are based on estimations and assumptions, but they can have a major influence on the outcomes of SSML and also on the representativeness of the results. Taking time to discuss and find the appropriate scoping for the case study is therefore very important. Usually, when describing the case study, only the final scoping is described. We recommend to also describe the scoping options and arguments for the choices that have been made. These scoping choices can even vary between different modules for the same case study.

For the cellulose case study some of the scoping considerations, assumptions and/or choices were:

- There are several methods available for recovering cellulose from waste water. For the circularity and environmental impact modules described in this report, only the Cellvation process of the Recell Group B.V. was taken into consideration. For the safety modules a broader approach was taken and also other methods were considered.
- Recovered cellulose is a valuable resource that can be used for many different applications. For the safety modules it can make a difference for what kind of application the cellulose is used. For example when it is used for food packaging there are higher safety requirements than when it is used as functional additive in asphalt. Also for circularity calculations, the application of the cellulose resource is important. In the circularity and environmental impact modules of this case study we have limited the scope to the application of cellulose as functional additive in asphalt.
- Recovered (tertiary) cellulose is of a different quality than primary cellulose. It has a lower perceived quality and has a shorter fibre length and more contamination than primary cellulose. In addition, it is recovered from waste water that is considered as a waste stream, and thus subjected to waste legislation. These aspects currently limit the application range of tertiary cellulose compared to primary cellulose, even though it is technically possible to improve cellulose quality of tertiary cellulose. This limited application range is currently not taken into account in the circularity and environmental impact modules of this case study.

List of required data
The current SSML framework does not contain a list of data needed for executing the different modules. It also doesn't contain any quality requirements for those data. Users may therefore have difficulty finding the data or knowing how to calculate or measure them. A list of which data is required for the calculations per tier would have an added value, because companies/stakeholders would then know in advance what data they need to collect to be able to use SSML. The list of which data are required should also follow the tiered approach, because it is not always necessary to do all tiers of a module.

5.3.3 Circularity module

From waste to resource
SSMLwas originally developed for the recycling of products to products. In this case study we have looked at the recovery of a resource from a waste stream. Especially the circularity module does not exactly fit to the context. The three indicators that are calculated in tier 2 are not equally relevant to the case study and some relevant indicators are missing.

Something that is missing when looking at circularity of a recovered resource from a waste stream is the quality of the recovered resource. Tertiary cellulose is of a lower quality than primary cellulose. This is currently not taken into account when calculating circularity and can be seen as a shortage of the current circularity calculations.
The quality difference of tertiary cellulose (compared to primary cellulose) makes the range of possible applications smaller. Where tertiary cellulose is applied, it replaces primary cellulose one on one. Comparable to rainwater vs drinking water used to flush the toilet: it is of lower quality, but for this application it can be replaced one on one. This is not appropriately included in the circularity module at the moment. It is partly covered in the contribution indicator, but then this should be calculated for each application. A range could then be given, but this is not a very efficient approach.

Another observation is that a different application of tertiary cellulose largely affects the outcome of the indicators ‘contribution’ and ‘recyclability’. In this case study the application of cellulose as a functional additive was chosen, rather arbitrarily. It would have been more accurate to have calculated the circularity for several applications. To get a representative picture of the potential of recovered cellulose, you would have to recalculate contribution and recyclability for each of the entire range of application. In the case of cellulose recovery, cellulose can also be extracted from a different source (for example diapers instead of waste water). This would then especially influence the recovery efficiency indicator, with the possible range applications staying similar.

Accuracy of data
To collect the data for calculating circularity we depended on data that were already collected by Recell Group B.V. in a different context or data and estimations that were extracted from reports and/or personal communications. Therefore, there is a lot of variation and uncertainty in the data that was used to calculate circularity. For example, for the amount of cellulose in total suspended solids in waste water estimations range from 27% (Remy, Conzelmann et al. 2020) and 35 to 51% (STOWA 2020). This value has a large influence on the outcome of the calculation of the recovery efficiency of cellulose. We used the average value of both reports. Recommendation: indicating a range of uncertainty in the results of the circularity calculations can be of added value. For the calculations of the recovery efficiency and contribution of this case study the uncertainty of the outcomes when looking at a favourable and unfavourable scenario are given in Table 5.2.

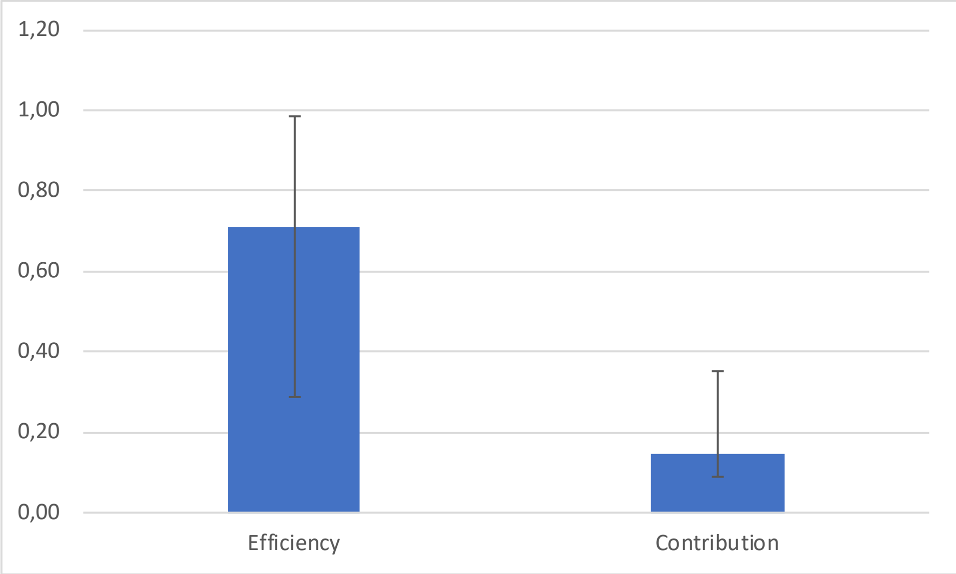

Figure 5.2 Outcomes of calculations of average recovery efficiency and contribution of tertiary cellulose, with uncertainty margins based on favourable and unfavourable recovery scenarios (Remy, Conzelmann et al. 2020)).

Recovery efficiency
The recovery efficiency is the resource fraction recovered from the total material flow, corrected for auxiliary material use. It is the first of the three circularity indicators in SSML. In this case study we have interpreted this indicator as the fraction of cellulose that is recovered from the total amount of cellulose in the waste water. However, depending on your reference point, there are several interpretations possible.
When sludge from waste water is taken as a reference point, as being the waste stream that can be reduced by recovering cellulose, the recovery efficiency could be interpreted as the reduction in the amount of sludge (the fraction of resource (cellulose) recovered from sludge). When looking at circularity this is also relevant information. According to Remy *et al.* (2020) the sludge production to disposal (DM amount) is reduced by 20% (on average) when cellulose is recovered.

Contribution
The contribution is the contribution of the recovered resource fraction towards total resource use in an application or material cycle. This is the second circularity indicator in SSML. As a first remark, it can be noted that this indicator is difficult to interpret as it can be seen as the fraction of recycled resource used in the market share or as the fraction of recycled resource used in the product. Secondly, it can be discussed what would be a good value for this indicator. Is a contribution close to 1 the best? When the contribution is low (0.06 in this case study), there is potential for growth. When the contribution is high (larger than 1, as is the case when looking at the potential for recovering cellulose from waste water), it exceeds the current market, and there is potential to investigate other applications.

Contribution is not a very good indicator for this case study, for several reasons:

- This case study is done at pilot scale, so the contribution is currently very low, but in potential much higher.
- In this case study of the recovery of a resource from a waste stream that can be used for many different applications, the contribution of the resource to the market share of one application does not give a representative picture. To get a more representative picture, also other sources and other applications of tertiary cellulose should be taken into account. The indicator is very dependent on the number of sources and applications taken into account.

Recyclability
The recyclability is the resource fraction available for recovery or reuse after the use phase of the intended application. In this case study the recyclability is calculated to be 0, because cellulose can’t be recovered from asphalt and reused. However, asphalt itself is being recycled and cellulose does not hinder this process.
For this case study (for the recovery of a resource from a waste stream), the recyclability of cellulose in a specific application is outside the scope. The recyclability indicator only says something about one specific application, but you actually would like to say something about the use of the resource or the future recyclability of the entire range of applications. Therefore, it would make more sense to look at the structure or composition of the resource itself. (in this case cellulose that in itself is a bio-based resource that is compostable and biodegradable). How valuable and safe (part of a non-toxic environment) is this resource in a circular economy? Also when a product is biodegradable, it is ‘recycled by nature’. Does this have the same value for a circular economy?

Conclusion
When looking at circularity of the recovery of a resource, the only relevant indicator currently present in the module is recovery efficiency. The other two indicators don’t fit the context. Something that is missing when looking at circularity of a recovered resource from a waste stream is the quality of the recovered resource compared to virgin resource.

5.3.4 Environmental impact module
Data intensity and robustness
This module is very data intensive. Collecting data is the most important and by far most of the work for this module. In this case study data from an existing full LCA were available and could be used for this module. The added value of this module, compared to the existing LCA report, is that we make a comparison with a baseline scenario (in this case with primary cellulose). We had no LCA data for this and made use of the Ecoinvent database.

When using data from the Ecoinvent database proxies (generalized data of processes that are comparable) are used instead of directly measured data from the specific process. This introduces a certain degree of uncertainty into the calculations. In LCA, a contribution analysis of the different processes can be performed. This allows for insight in which processes are most decisive for the results and gives some insight in the robustness of the results. Such contribution analysis is not performed in SSML.

Data from specific processes (in this case study taken from the existing LCA report) can also be variable due to measurement uncertainties or performance bandwidths. For this SSML module (tier 2) only average data were used, but in the LCA report also minimum and maximum performance data for the cellulose recovery unit and impact on waste water treatment were included (Remy, Conzelmann et al. 2020). Showing this bandwidth could have an added value for SSML, especially when two processes are compared as it gives some feeling about the variation in the recovery process. In Table 5.3 the minimum and maximum performance data that resulted in a positive CO_2 footprint of 0.12 ton CO_2/ton cellulose can also result in a negative CO_2 footprint of 0.30 ton CO_2/ton cellulose when taking the minimum performance scenario.

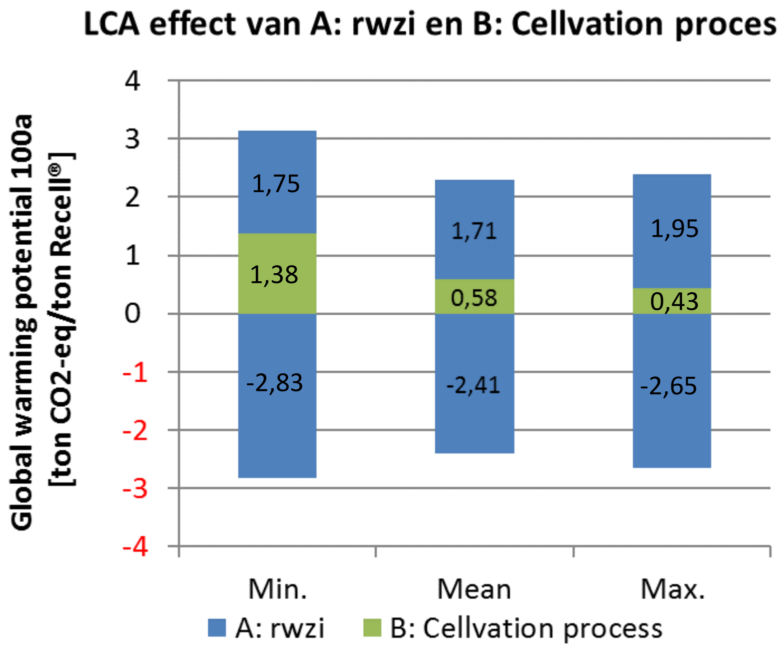

Figure 5.3 Summary of LCA results on the effect on waste water treatment (A: blue) and Cellvation process (B: green), including min and max performance scenarios of Cellvation process. Source (Remy, Conzelmann et al. 2020)

Impact on waste water treatment
Fine-sieving waste water for cellulose recovery also influences the waste water treatment process. The effects of these changes on CO_2 footprint are taken into account in this module. Whether this fine-sieving affects the quality of the effluent (treated waste water) on surface water is not considered in this module.

6 Case study on chemical recycling of PET

6.1 Case description

Nowadays, a lot of effort is invested in recycling of plastics. Different types of plastics, or actually the monomers of these plastics, have different recycling possibilities. Also for PET, the type of plastic investigated in this case study, different technologies are available for recycling (A.M.Al-Sabagha 2016). In this case the recycling takes place by a chemical process in which the PET is dissolved: solvolysis by glycol (Kárpáti, Fogarassy et al. 2019), developed as the CuRe technology. In this process the plastic PET bottles are, after pre-treatment, dissolved in a glycol solution. In this solution the PET depolymerizes to short chains, oligomers. Oligomers consist typically of about 5 to 10 monomers. From the oligomers the contaminants are removed. The clean oligomers are the starting material for a new polymerization process to make PET again. The recycled PET is noted as rPET. This process is schematically shown in Figure 6.1.

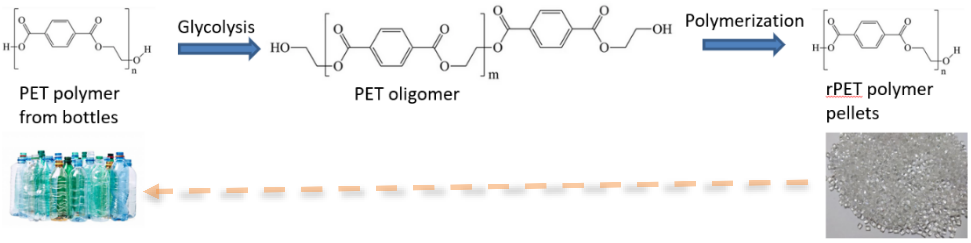

Figure 6.1 Simplified process overview of the partial glycolysis of PET.

The solvolysis technology can also be applied to break down the PET chains to monomers, as for example done by the company Ioniqa[12]. This would be a 'complete' solvolysis, whereas breaking down the polymer to oligomers could be called 'partial' solvolysis. From the repolymerized, and thus recycled, PET pellets all sort of products can be made. Including new PET bottles, but also food-trays or clothing. The process as shown in Figure 6.1 is simplified. Steps like washing, shredding, smelting and filtering are also included in the process.
The integrated analysis using SSMLfor this case considers the recycling of PET from bottles to rPET which is used to make bottles again. This is compared to the linear use of PET: producing PET bottles from petroleum and incinerating these after use, with energy recovery.
In this chapter, the chemical recycling of PET using the CuRe technology is assessed as a case study for testing SSML. Based on Tier 0 of SSML, the safety module ZZS is used and so are the modules about material circularity and environmental impact.

6.2 Application of relevant modules

6.2.1 *Circularity*

The scope is defined as: using PET bottles to make PET bottles again (with the CuRe© process as recycling method). The source of the PET is

[12] Bron: https://ioniqa.com/

from PET bottles collected in the deposit system. The functional unit is defined as: 1 ton pellets (r)PET.

Circularity - Tier 0

Tier 0:
Will the intended application of the residual material or waste stream be higher, equal or lower on the LAP-3 waste hierarchy compared to the current application?

Equal. Using the waste hierarchy diagram the chemical recycling of PET with CuRe results in an equal classification compared to conventional mechanical recycling. Compared with incineration with energy recovery, recycling of PET with CuRe scores higher. Mechanical recycling of PET is a developed technology and seen as complimentary to chemical recycling. Mechanical recycling is lower in energy; however material quality can only be kept up for about 7 cycles. For chemical recycling the amount of cycles is in theory almost infinite.

Circularity - Tier 1

Tier 1:
1. Does the material under consideration contain any of the EU critical raw materials?
2. Supply check: Is there a concern for material supply due to a significant increase in demand for the source material?

1. CRM check: In PET about 250 ppm of antimony is present. Antimony is an EU critical material and used as catalyst in the process. The PET as source contains about 250 ppm and the rPET an equal amount, thus the net amount of antimony used is quite small.
2. Supply check: The demand for recycled plastics, including PET, is increasing, mainly due to policies setting percentages of recycled materials producers should use (IenM 2014)[13]. For example, PET originating from bottles can also be used as material for clothing after recycling. PET in clothing is much harder to recycle than PET from bottles (heterogeneous versus homogeneous material flow). Potentially this effect could decrease the amount of rPET available for producing bottles. However, when specifically looked at the scale and market of the CuRe technology this would not have a significant increase in demand for the source material.
For further assessment of material circularity, a Tier 2 should be conducted.

Circularity - Tier 2

Tier 2:
1. Recovery efficiency: The resource fraction recovered from the total material flow, corrected for auxiliary material use.
2. Contribution: Contribution of the recovered resource fraction towards total resource use in an application or material cycle.
3. Recyclability: The resource fraction available for recovery or reuse after the use phase of the intended application.

[13] wetten.nl - Regeling - Besluit beheer verpakkingen 2014 - BWBR0035711 (overheid.nl)

Recovery efficiency
The amount of rPET that is recovered from PET is high, due to the very homogeneous source material and low auxiliary material use (e.g. almost all (99%) of the glycol is extracted and regenerated). Though, every recycling process suffers from losses. From experience the CuRe process recovers about 980 kg/ton PET. This leads to a recovery efficiency of 0.98.

Contribution
In potential almost all PET bottles can be used in the CuRe technology for rPET, with only a fraction of newly added material to compensate for losses. However, for economic reasons this would not be a realistic scenario. Mechanical recycling of PET is economically preferred, with chemical recycling as additional technology to keep up the quality of the material. No exact balance of rPET from these two techniques in e.g. a bottle is determined. In literature the 'virgin to recyclate ratio' for PET bottles is often mentioned as 70/30 by weight (Schyns 2020). Taking this ratio the contribution of CuRe for the rPET fraction in the PET material cycle is 0.3.

Recyclability
Bottles with rPET are commonly recycled to bottles again, with numerous loops possible. The returned resource to be reused is estimated at 98%. All PET from bottles can be used to make bottles again, making the level of application for this 'tertiary material' up to 100%. The quality factor is set at 1, because the regained PET is at almost the same functional level as the original PET. Note, this is when the PET is considered to become a bottle again. If the rPET ends up in textiles the quality factor decreases (with current technologies). The overall recyclability scores 0.98.

Overview circularity

Indicator	**Score**
Recovery efficiency	0.98
Contribution	0.3
Recyclability	0.98

The indicators shown in the table provides insight in circularity using a three-dimensional assessment. A few remarks on these numbers are that for the contribution there is not a single technology providing the most efficient recycling of all the material (So scoring 1 here is impossible?). And secondly, that for the recyclability the material in which the rPET molecule ends-up (e.g. bottle or clothing) is more dependent on market mechanisms than on the available technologies.

6.2.2 Environmental impact – CO2 footprint
The applied indicator for energy use is CO_2-equivalents per ton (r)PET. Land use is not considered to be a relevant indicator in this case study, and therefore neglected (material is not from agriculture or forestry). The outcome of this assessment shows how much the environmental impact has been reduced, e.g. less energy demand or CO_2-emissions when using the CuRe technology compared with a baseline scenario.

Definition of scope and baseline scenario:
1. What material flows and resulting products are assessed?
2. What is the reference product that is replaced by the new application of the non-virgin material?
3. What are the system boundaries?

This case study considers the recycling of PET from bottles to rPET which is used to make bottles again. With this chemical recycling technique PET that doesn't meet the quality criteria for mechanical recycling can still be recycled for multiple cycles. This is compared to the linear use of PET: producing PET bottles from petroleum and incinerate these after use, with energy recovery.
The scope is defined as: using PET bottles to make PET bottles again (with the CuRe© process as recycling method). The source of the PET is from PET bottles collected in the deposit system. The functional unit is defined as: 1 ton pellets (r)PET. See Figure 6.2 for a more detailed view of the baseline and recycling scenarios.

Tier 2:
1. Determine scope: is the functionality of the new product different from the product it replaces? Is there a difference in function, quality or durability?
2. Make a list of materials and energy required for each scenario.
3. Search for generic CED or CO2 emission values and land use estimations for the materials and energy used.
4. Sum the CEDs, CO2 eq. and land use per functional unit and compare different scenarios.

1. Determine the scope. It is assumed that there is no difference in the functionality of virgin or recycled PET (using CuRe). Therefore a cradle-to-gate perspective can be used as the scope. This means that the difference in the scenarios will lie in accounting for recycled material and polymerization.
2. Materials required in the CuRe process are MEG ('glycol'), activated carbon, nitrogen, water and air. And for the catalysis a small amount of antimony is used. The amount of energy used is sensitive information since it is a direct indicator for the economics of the process and, hence, the competitive position. Therefore details are not easily shared.

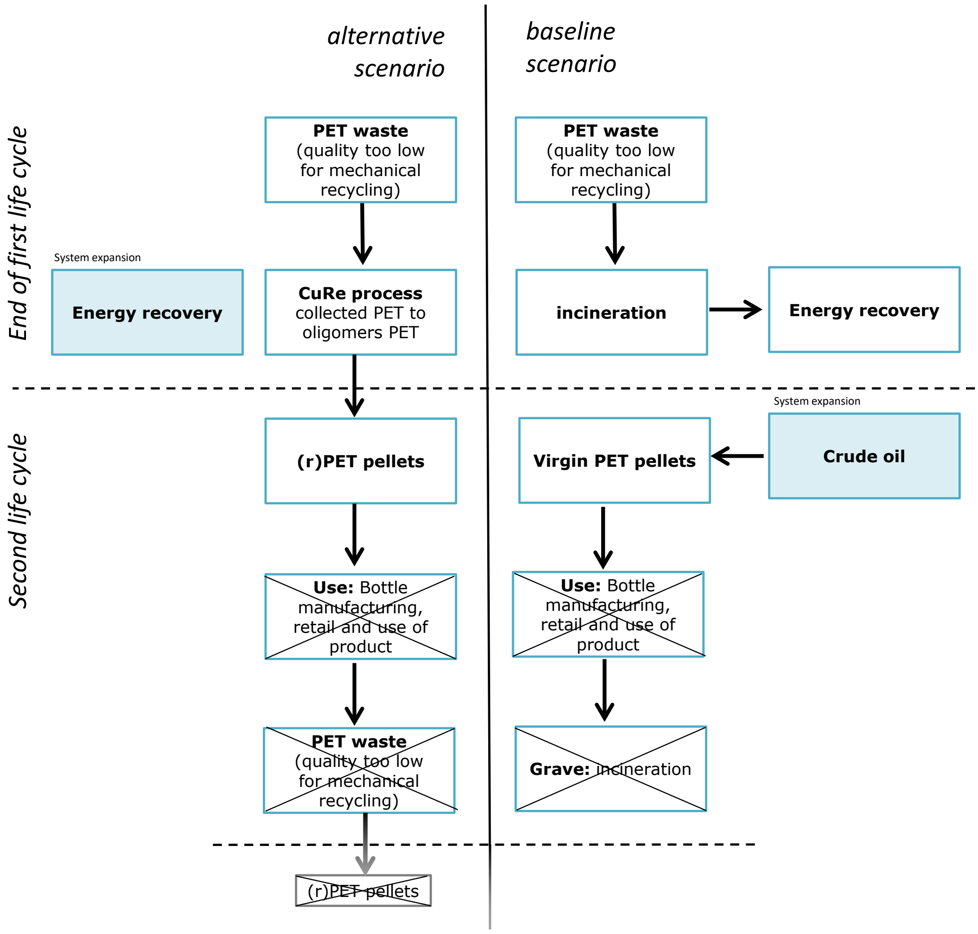

Figure 6.2 Schematic overview of the alternative and baseline scenarios for the production of PET . Two scenarios are assessed: 1) using virgin PET (baseline scenario), 2) using recycled PET with the CuRe technology (alternative scenario)

3. The company has done a scan-LCA of their process (via CE Delft) providing CO_2 emissions for the relevant activities (see Figure 6.4). Therefore more generic emission values are not looked at. The baseline scenario is estimated using LCA work, also done by CE Delft, as shown in Figure 6.3.
4. The Figure 6.4 shows the carbon footprint of the CuRe process with ton CO_2-equivalents / ton PET as functional unit.

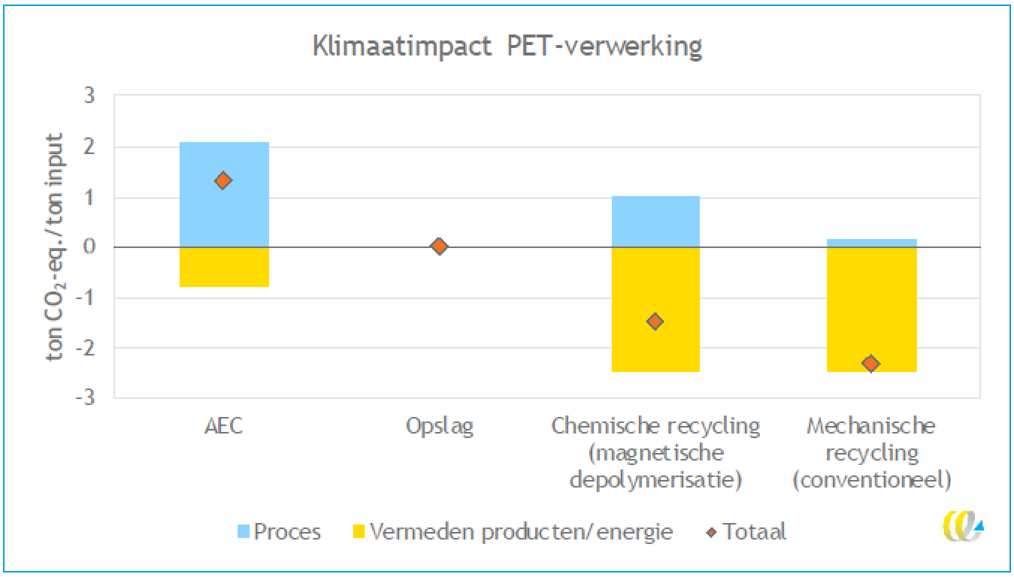

Figure 6.3 (in Dutch only): The impact of different options for treatment of PET, by carbon footprint (AEC: incineration with energy recovery; storage, chemical recycling, mechanical recycling). The results are based on PET trays (comparable to bottles) from: [(CEDelft 2019)][14]

Figure 1 - Carbon footprint of the production of one tonne PET with CuRe Technology, t CO_2-eq./t PET

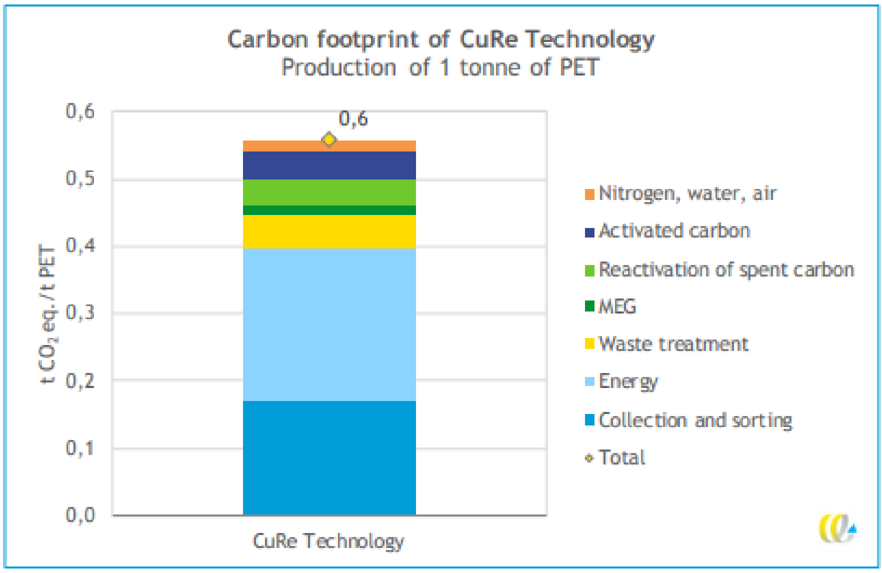

Figure 6.4 Carbon footprint of the production of one ton PET with CuRe Technology

The difference with CuRe and the chemical recycling technology assessed in Figure 6.3 is in the process part, with the CuRe technology having a slightly lower carbon footprint (0,6 vs. 1.0). The avoided emissions are the same. So, the carbon footprint of the CuRe technology is significantly lower compared to the baseline scenario, AEC ('waste energy plant').

[14] Verkenning chemische recycling. Update 2019 - CE Delft

Conclusion
Fortunately, data was available in the form of a scan-LCA of the process. This made a good estimation of the CuRe technology with the baseline scenario possible. It clearly shows the environmental impact gain from the CuRe technology compared to the baseline scenario. Investigation in full detail is not performed as the purpose of this case is on learning from applying the framework.

6.2.3 ZZS
PET from bottles is a food contact material and, therefore, substances of high concern are not expected to be present. During the recycling treatment the ZZS acetaldehyde could be formed in quantities < 1 ppm. With the post-condensation this substance is removed from the material.

Tier 0

Tier 0:
Are there ZZS present in the material flow?

Based on the information of the process a ZZS is identified in the material flow. In Tier 1 this is further assessed.

Tier 1:
1. Are POPs present above the concentration limit as included in Annex IV of the POP regulation?
2. Are individual ZZS present above 0.1% in the waste stream?
3. Could exposure of humans and the environment be considered as more critical for the intended application compared with the material in its original application?

If the answers to one or more of these questions is ‘yes’, a Tier 2 assessment should be performed. The answers to these questions are based on information obtained by interviewing an affiliate of the CuRe process.

1. No. POPs are not present.
2. No. The ZZS acetaldehyde is present in <1 ppm, as it is a byproduct of the process. This is below the 0.1%. Acetaldehyde is a degradation product of the PET monomer and removed afterwards by after-condensation. Next to that, in the process a heat transfer liquid is used (Therminol 66), which is a ZZS. Since this does not come in contact with the material, it is not taken into account.
3. No. The application is the same (PET bottles) and therefore no difference in exposure.

Therefore, a more detailed risk analysis of the ZZS is not necessary.

Conclusion
The module shows that a ZZS is temporarily present in the material, but since the concentration is far below 0.1% (w/w) and it is removed during the process, it is not of concern.

6.3 Lessons learned from the case study

6.3.1 General remarks

The assessed CuRe technology is in the development phase (pilot plant). Therefore, not all data are accurate or available for large scale operations. Besides that, it was found that quite some interpretations of SSMLare possible if assessed by the developer. When the steps are carried out and discussed with a RIVM specialist, the assessment is considered as doable. The developing company of the CuRe process was willing to cooperate. because they benefit from a clear and independent tool for comparing of the different chemical recycling technologies (for policy makers). A last general remark is on the scenario’s that are compared. It is found to be important to define these as precise as possible before the start of the assessment. For example, if a PET bottle ends up being used in the textile industry after recycling, different circularity and environmental impacts are found compared to a PET bottle becoming a PET bottle again. Therefore, the functional unit and the scope should be determined early in the process.

6.3.2 Circularity module

The existence of an EU list of critical raw materials was not known by the representative doing the assessment. A CRM is present in this process, as catalyst (antimony) which stays for a small portion (250 ppm) in the material. This is however not used during the life cycle, as it stays in the polymer matrix and with the specific chemical recycling process it is regained and reused. For the contribution it is noted that it is most efficient to use a combination of technologies for recycling of PET bottles. For the recyclability, the outcome depends on the scenario where the recycled PET ends up (e.g. bottles or textiles). This is mostly depending on market demand (and not on the technology used).

6.3.3 Environmental impacts.

As mentioned above, the scope and functional unit are largely determining for a proper comparison. In this case the RIVM expert set the scope and functional unit. The question remains if this is also doable for all users of the framework.
The carbon footprint is in this case sensitive information as energy use is a direct indicator for the economic feasibility of the technology. It is unclear whether the use of green energy is taken in account. Information on environmental impacts is more readily available when the process/technology is more mature (higher Technology Readiness Level (TRL)). In this case study on the CuRe process, a scan-LCA was already available, providing a good enough insight (and data) for this specific case.

6.3.4 ZZS

The module is only about ZZS in the material flow. ZZS used in the process are not assessed, this could be a shortcoming. The secondary resource flow is variable for this process. That makes that unwanted substances, like substances of concern, could be introduced. For example, flame retardants from curtains (which could contain polyesters). For the CuRe process this is problematic since unwanted substances could negatively influence the de- and repolymerization. This issue falls within the larger discussion of having a ‘bill of materials’ (materials and chemical substances). Further, this module was experienced as doable by the stakeholder.

7 Lessons learned from case studies

Combining the assessment of risks and sustainability in waste handling or recycling is a pioneering approach. The SSML framework was aiming its users to identify these risks and the consequences for sustainability when recycling but sofar wasn't tested by its intended users. It starts with the identification of possible hazards in tier 0, followed by a qualitative assessment in tier 1 and by a more quantitative assessment in the higher tiers. Its potential users, like recyclers and licensing authorities, should at least be able to handle tier 0 and 1.
In this study, two case studies have been done to test the user-friendliness of SSML and to identify improvements of the framework. People involved in previous case studies at the RIVM have also been interviewed about their experiences with SSML. Based on the interviews and our experiences with the two case studies, we describe the user friendliness and (technical) points for improvement of SSML.

7.1 Previous case studies

The past years, SSML was applied in several case studies. We included the experiences with the following case studies.
HBCDD (Janssen, Spijker et al. 2016): The HBCDD report focuses on a few cases where hazardous substances have been incorporated into potentially recyclable material: the flame- retardant hexabromocyclododecane (HBCDD) in Styrofoam (extruded polystyrene), and the plasticiser DEHP, cadmium and lead in polyvinyl chloride (PVC). The report outlines the technical background to the recycling of these materials, current practice and the complex legislation on recycling.
Rubber granulates (Oomen and de Groot 2016), (Groot, Oomen et al. 2017, Verschoor 2018): In this case RIVM determined the substances in rubber granulate from 100 sports fields that are representative of the synthetic turf fields in the Netherlands. The institute performed tests to examine human exposure and determined the release of substances from the granulate into the environment. An additional study focused on the environmental exposure.
Diapers and incontinence material (Lijzen, van der Grinten et al. 2019): To reduce the amount of diaper waste, materials can be recycled and new products can be made. It is important that these new products and materials are safe for people and the environment. To assess that, RIVM has developed a step-by-step plan that allows recyclers of these materials to collect the necessary data to perform a risk assessment.
Struvite (Grinten and Spijker 2018): Struvite from waste water is labelled as 'waste'. This classification as waste makes it difficult for sewage treatment plant managers to utilise struvite as a raw material for introducing new products to the market. To remove the waste label, this struvite must comply with certain safety criteria. RIVM looked for indicators to assess if the utilization of struvite can lead to increased risks for public health or the environment.
Railway sleepers (Quik, Dekker et al. 2020): RIVM has compared six different types of sleepers to sleepers made of cement concrete. The six sleeper types are made from copper-treated wood, untreated wood,

recycled steel-reinforced plastic (PE), virgin steel-reinforced plastic (PE), glass-fibre-reinforced plastic (virgin PU) and Sulphur-based concrete (instead of cement-based concrete). The comparison of the various sleepers was based on the aspects that are important for sustainability and safety of used substances for the environment.
Mattresses (Faber, Heens et al. 2021): RIVM has investigated the risks of recycling used mattresses, that may contain hazardous substances. It investigated the risks for workers and for users of products made from used mattresses, in particular paying attention to substances that were permitted in the past, but that are now more regulated. Another aspect examined was that mattresses can become contaminated by microorganisms, such as moulds and bacteria, during use.
Construction (Schut E 2015): The construction sector wishes, together with the government, to develop a vision on the high-quality use and reuse of materials in a circular economy. It is important to consider during the design and reuse how elements of a building can be reused in multiple cycles. In the Netherlands, a large proportion of all construction and demolition waste is recycled into foundation material for roads, new residential areas and industrial estates. However, buildings are hardly ever made from recycled products. The challenge is to design buildings in such a way that all used materials re suitable for high-quality reuse. In the Netherlands, the environmental performance of a building is already measured as standard over a single cycle.

In Table 7.1 the relevant SSML modules per case study are given. Lessons learned per module are given in the next paragraphs.

Table 7.1 Case studies (earlier and of this study) and the relevant modules

Case	**Module on circularity and environmental impact**	**Module ZZS**	**Module on pharmace u-ticals**	**Module on pathogens and AMR**	**Module on pesticides**
HBCDD	X	X			
Rubber granules in soccer fields	X	X			
Recycling of diapers	X	X	X	X	
Struvite from waste water	X		X	X	
Use of Railway sleepers	X	X			X
Recycling of Mattresses				X	
Recycling in construction	X				
Cs1: Cyclotron	X	X			
Cs2: Plastics	X	X			
Cs3: Cellulose	X		X	X	

7.2 General lessons learned and recommendation from case studies

1. User friendliness

SSML is found to be a clear and independent tool for analysing risks and benefits of recycling technologies. The framework allows for the analysis of a single technology or product. And, with some adaptation of the scope (e.g. 50 years of use), it can also be used for comparing different products, like was done in the railway sleeper case study.
The tiered approach of SSML should help users with different backgrounds and level of knowledge to assess the risks and sustainability of a recycling process. When identifying risks, SSML users from outside the RIVM should be able to perform tier 0 and tier 1. From former and current case studies, it turned out that SSML is considered as doable for these first tiers, although discussions with an RIVM specialist may be needed to avoid misinterpretations.

2. Required data

The current SSML framework does not contain a list of data needed for executing the different modules. It also doesn't contain any quality requirements for those data. Users may therefore have difficulty finding the data or knowing how to calculate or measure them. Adding a list of required data for the calculations would have an added value, because users then know in advance what data they need to collect to be able to use SSML. As SSML uses a tiered approach, the list of required data should follow this tiered approach. In addition, validated or prescribed analytical methods and criteria should be (made) available.

3. Scope definition

Scoping is an essential part of any case study. The choices made during this scoping, based on estimations and assumptions, can have a major influence on the outcomes of SSML and on the representativeness of the results. Therefore, the definition of the scope and scenario description are essential for a clear overall judgement. A defined final product (or functional unit) and a fully described recycling method, including emissions, should be included in the scope. The arguments for defining the scope should be reported.

4. Uniformity in approach of the modules

In the sustainability module a comparison between scenarios is made. The outcome of the sustainability modules is based on a comparison to a baseline scenario. For example: the sustainability of recovering cellulose from waste water is compared to the sustainability of cellulose from woody biomass. In the safety modules this comparison isn't made; only the alternative scenario is considered. For example, in the rubber granulate case study, only the safety of rubber granulate as infill in artificial grass fields is taken into account. The safety of other infill options is not considered.
A relative approach might also be helpful for the risk modules for situations where the environmental or human exposure routes are unclear or absolute criteria are missing, and at the same time there are data available of situations where the environment or humans are exposed to the identified hazard from other sources. In the struvite case for example the risk of (human) exposure to a pathogen is compared to the risk of (human) exposure to the same pathogen in manure. This

could be a way to interprete the significance of the identified risk. However, comparing with the current practice is no guarantee for prevention of risks. It is important not to create new problems, so absolute safety and for example the risk of accumulation in recycled products should always be taken into account.
Another point where the modules differ is the relation of risks with legislation. SSML is in principle risk-based, but starts in the first tiers with legal limits when possible. However, this differs per module. For example, the ZZS module limit values are the starting point of the asesement (being policy driven). It was mentioned in the HBCDD case study that the European Commission proposed to change the limit value. As a consequence, the safety assessment changes, independly of hazards being higher or lower. In the newly developed radiation module the risk based approach is the starting point for waste with radionuclides from natural and artificial origin. The legal levels based on background levels are less critical than the risk based approach, leading to different conclusions in the module. We recommend to include both the legal limit levels (relevant for legislative requirements of a recycling initiative) and to include a risk based approach in the safety modules of SSML, where possible. It should be indicated where this risk based approach differs from the Dutch regulatory system.

5. Integrated assessment
In the current SSML framework, risks and benefits are analysed and calculated, but not weighed. In future it would be very useful to work on a method to quantitively (or qualitatively) integrate the outcomes of the different modules. How to scale the advantages and disadvantages of recycling options is complex and to a certain extend policy related and based on societal values. These questions should be addressed in future work.

7.3 Lessons and recommendations from the circularity module

The most important improvements that can be made to the SSML circularity module are mentioned here.

1. Overall circularity score.
SSML has been developed to analyse the circularity of recycling processes. The analysis uses three indicators: efficiency, contribution (to the market) and recyclability. However it is not clear how to determine an overall score for the circularity module. When different scenarios score different on the three indicators (for example: Quik, 2020) it becomes difficult to pinpoint the preferred scenario.

Recommendation

- The circular economy has multiple goals and circularity can be split into different indicators as is done in SSML. Aggregation of these different indicators into one would undermine the heterogeneity of the circularity score. For now we do not recommend creating a possible aggregation of the three indicators. We do recommend a more thorough explanation what the indicators represent.

2. Applicability of indicators

SSML has been used to assess the circularity of end-of-life scenario's and of individual products. The three indicators *recyclability, contribution and efficiency* are not always applicable and for some cases they are not sufficient to determine the circularity. For example in the case study of recovering cellulose from waste water the indicators for *contribution* and *recyclability* are not relevant because the resource cellulose can be applied in different products. The outcome of the indicators *contribution* and *recyclability* differ for the different products.
Cellulose is available from a primary source (wood), from secondary material (used paper) or from waste water. However, the quality of cellulose from these sources is different. This is not taken into account in the three circularity indicators.
It is therefore recommended to add a guideline to the circularity module of SSML for when a specific indicator is relevant in a specific case. When assessing a product instead of waste (for example Quik, 2020) the material circularity indicator (MCI)[15] might be a valuable additional indicator to SSML circularity indicators, whereas efficiency might not be as relevant. When assessing an end-of-life scenario from waste to resource the added value of the contribution to market is debatable as it is outside the sphere of influence of the waste processor.

Recommendations

- Suggest new circularity indicators to cover the blind spots in cases where the efficiency, recyclability and contribution are insufficient.
- We recommend including a parameter for the quality (loss) of the recovered material compared to its quality from the virgin primary source in the calculation of the contribution.
- Include a definition of the scope that you want to assess with the circularity module; by default this should include the processing of waste, the second use phase and the second recycling up to the third use phase.

3. Guidance and data on circularity indicators

One of the goals of SSML is that a tier 2 assessment can be performed by professionals outside of the RIVM. However, SSML remains unclear or ambiguous on some parts. Ambiguity remains in the indicator 'contribution': this can be interpreted as 'contribution to market' of an existing products or materials, or as 'contribution to a new product'. In the case studies where SSML has been applied contribution has been interpreted as 'contribution to market'. In these cases it is sometimes difficult to determine what *the market* is exactly. The market can be the market for the recovered resource or as the market for the original product; especially when different recycling scenarios feed different markets, the contribution to market becomes vague (pyrolysis). The result from the 'contribution to market' should be seen as an additional parameter to identify the product chain. It is even possible to have a contribution greater than 1 (pyrolysis; construction) for a new product or new applications of a material.

[15] https://ellenmacarthurfoundation.org/material-circularity-indicator#:~:text=The%20Material%20Circularity%20Indicator%20(MCI,material%20price%20volatility%20and%20material

The indicator ‘efficiency’ can be interpretated as the efficiency in recovering a single resource from a waste stream or as the efficiency of recycling the entire waste stream.

Recommendations

- A tier 2 decision tree could possibly help with the selection of indicators. A possible starting question for this decision tree could be: ‘is it about a product, resource or recycling process?’
- Develop a list of required data with sources to quantify each indicator would be helpful.
- Make a guidance to determine the scope for the circularity module: This is valuable for the efficiency (of recycling) as well as the contribution (of the recovered material to the market).
- We recommend to define ‘efficiency’ as the fraction various components that is recovered from the original waste?
- Give more explanation with the ‘contribution’ indicator and how it can be used as additional information.
- It is recommended to include an indicator for quality of the recyclate compared to the source.

4. Scope of recyclability

The indicator recyclability deals with the next life cycle and assesses to what extent the resources from the new product can be recovered again. When the scope of the SSML assessment focusses on a recycling process, the result of the recycling process does not need to be a new product, it can be a secondary resource for various end products. For example, cellulose from waste water can be used as a road construction material (recyclability: 0), but also in furniture where it might have a next lifecycle (recyclability: > 0). Selecting a possible end product for the recovered resource on forehand is sometimes difficult. A loss of quality during recycling affects the future recyclability of a product from recycled materials. Recycled cellulose can only replace certain quality types of cellulose. So, in some situations, recycled cellulose highly contributes to the replacement of virgin cellulose whereas in other cases the quality of recycled cellulose might be too low to for secondary use.

Recommendation

- It is recommended to include the application of materials in a new product in the scope. When this is not possible or still unclear, it is recommended to leave out the recyclability indicator with an explanation or calculate the indicator for all applications.

5. Efficiency and quality

The efficiency indicator shows how efficient the recycling process is. Different recycling scenarios are compared leading to different recycling products (for example: Pyrolysis). The recycling efficiency does not account for quality differences in the recycled products.

Recommendation

- Add a (optional) quality indicator to the calculation of the efficiency. The new formula for the efficiency is shown in equation below, where Qrx is the quality of the recovered resource (between 0 and 1) compared to the resource in the source (waste) material.

$$Eff = \frac{Rx * Qrx}{Rtm} * \frac{Rx}{Qxa * Maux + Rx}$$

Eff = Recovery efficiency [-]; Rx = recovered resource x [kg]; Qrx= quality of recovered resource; Rtm = total resource in the (waste) material flow [kg]; Qxa= quality of raw materials; Maux = raw/virgin auxiliary materials used for production of resource [kg]

6. Higher R-strategies

SSML is aimed at recycling, other (higher) R-strategies are not part of the assessment. But end-of-life scenarios can differ in their R-strategy. When we want to compare these scenario's, SSML is not always readily applicable and it remains unclear how we can calculate the effects of reuse or reduce on the circularity indicators.

Recommendation

- SSML was developed with recycling scenarios as the main focus. This remains the focus for the time being. When the scope of SSML is broadened, the addition of higher R-strategies is one of the aspects that could be incorporated.

7.4 Lessons and recommendations for environmental impact

SSML uses a comparative LCA as basis for the environmental impact module tier 2. The most important recommendations are:

1. Required data and data sources

It is not always clear what data is required to make the LCA comparison and what data sources can be used. A clear scope would help to define which data is needed for the assessment, but the definition of a scope can be a difficult part of the assessment. Sometimes it remains unclear if a life cycle stage differs between scenarios and contributes a lot to the environmental impact or not. From the cellulose case, it became clear that help with the definition of the scope is one of the most valuable aspects that could be improved in SSML.

Recommendations

- Make a more (visual) guidance for the definition of the scope. The following questions should be included: 'What are the important life cycle stages and which ones have a significant effect on the environmental impact?'
- Compose and include a list of possible data sources for quantifying environmental impacts

2. Overall effect

In cases where organic resources are involved, the environmental impact is determined by two indicators, land use and either greenhouse gas emissions or cumulative energy demand. This results in the problem that results could become ambiguous. It would be helpful to come up with a method that combines the scores of the two indicators, but there are multiple ways of aggregating the effect in land use and greenhouse gas emissions. Additionally in some situations leaving out other dominant impact categories might be lead to misleading conclusions.

Recommendations

- Select a method for aggregating land use and greenhouse gas emissions

- Evaluate if the screening based on two impact categories is not leading to important omissions in comparisons and determine in what situations other impact categories might be added.

3. Tier 1

The environmental impact module starts with Tier 0 and jumps from Tier 0 to Tier 2. The module lacks a data friendly, easy to use, Tier 1. In order to make this module more user-friendly, including a qualitative Tier 1 is recommended. How this tier 1 assessment should be designed is up to debate. A suggestion for a tier 1 assessment is to compare for a waste stream the R-level of the application and for a product the presence of secondary resources (see Figure 1).

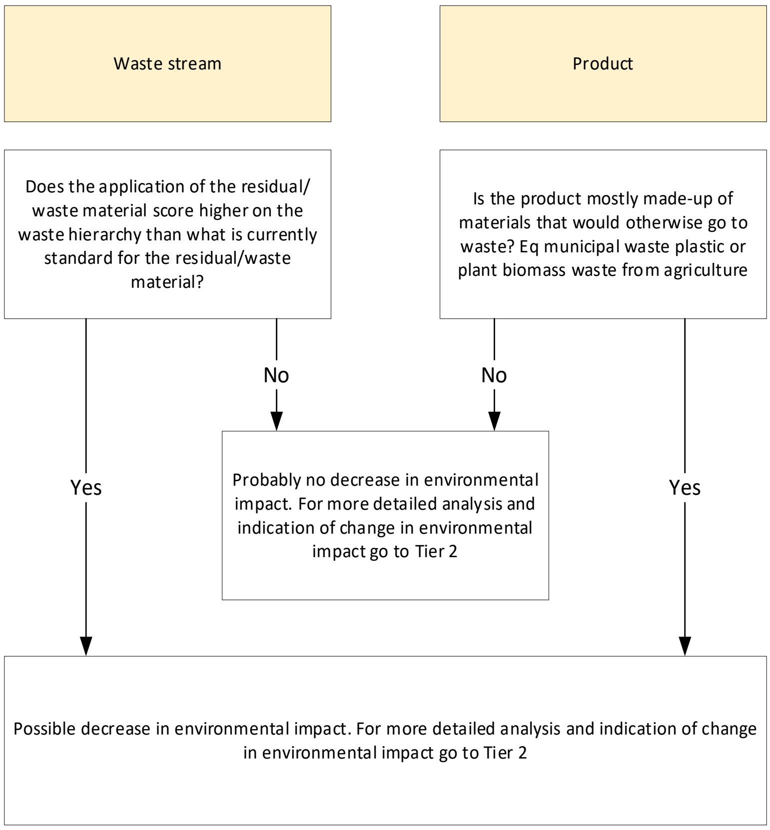

Figure 7.1 Tier 1 environmental impact assessment

7.5 Lessons and recommendations for module on ZZS

Two general recommendations can be made to make the module on ZZS more user friendly:

1. start with the scope: fully describe the recycling process, including auxiliary materials, new waste products and emissions.
2. write guidance in which SSML users can find information on:
   - Legal requirements[16];
   - What to do when legal criteria do not exist.
   - What to do when data are not or insufficiently available.
   - Definitions (e.g. 'critical')

[16] It is noted that due to REACH regulations a material must comply with product standards if it is not traded as waste.

1. Other substances of concern

The ZZS-module only regards the Dutch ZZS. From the rubber and diaper cases it became clear that also other substances of concern can hamper safe recycling. For example, heavy metals, like zinc, can cause soil contamination after leaching from rubber. Microplastics are not an ZZS, but can be considered as unwanted in the environment.

Recommendations

- Determine which substances-besides ZZS- should be considered; for example substances with a CLP classification, 'potential' ZZS or substances for which environmental quality standards are available. Based on the potential exposure routes of the new application of the material, the most relevant substances could be determined and substances can be priotorised based on e.g. persistence and toxicity. It is important to keep a good balance between being complete and the user friendliness of the module.
- As the ZZS-module is in line with regulation, it might not be suitable for other substances of concern. A separate module could be more useful.
- Working with a 'positive list' of safe substances could lead to less risks and workload. However, this leads to stricter rules for recycled materials than for virgin materials.

2. Quality standards

The ZZS-module contains many regulatory aspects and standards, including the 0.1% limit value for ZZS in waste streams. Standards are prone to change and are not always risk based, while SSML focusses on risks.

Recommendations

- Provide a guideline for using the ZZS-module when standards are not available (for a certain substance in an application)
- Clarify which standard should be used in which part of the ZZS-module and which standards could be useful (see (Zweers, Verhoeven et al. 2018)). It should be clear that, within the ZZS-module, standards for new products or applications are used to determine possible risks when recycling a waste stream[17]. This means that the ZZS-module does not safeguard all risks, ecause the ZZS-module does not include a complete compliance check of new product standards. . An overview of product regulations would strongly contribute to the assessment of new materials and products.
- We recommend to include risk assessment for specific (standardised) applications or products as a part of the higher tiers (even if this would lead to different conclusions compared to existing quality standards)

3. Data availability

Data availability on the occurrence and concentrations of ZZS in waste streams is limited. The first tier of the ZZS-module is always prescribed

[17] It is noted that due to REACH regulations a material must comply with product standards if it is not traded as waste.

when using SSML, so limited data might result in a high workload or discarding waste streams for recycling.

Recommendations

- Provide guidance on working with limited or uncertain data. This should include the options for a recycler, but also which information is required to affirm safe recycling. The use of guide (or indicator) substances or parameters might be included in the guidance. Experience with determining these parameters has been gained in some case studies.
- Check how the occurrence of ZZS is formulated in the module. Occurrence can only be ruled out below a certain threshold. The threshold should be chosen in line with LAP3 and be suitable for SSML.

4. Scope of the scenario

The scope of the scenario strongly influences the outcomes of the module. At the moment it is not clearly described how the scope should be taken and which parts of the module focus on which streams (incoming waste stream and/or outgoing product stream).

Recommendations

- Define how the scope should be taken in collaboration with the other modules (see next paragraph)
- Clarify which parts of the module focus on incoming streams and on outgoing streams.
- Include a question on the waste streams resulting from the recycling process. This can also refer to relevant regulations, such as the Industrial emission directive.
- Include ZZS that are used in or originate from the recycling process.

5. Alignment with other modules

The ZZS-module is one of the safety modules in SSML considering the risks in the next application. The sustainability and circularity modules also consider other scenarios (e.g. baseline scenario).
Practical implications of the module are not taken into account. For example: a waste recycling technology turns out to be unsafe, incineration is the only way to deal with the waste. What if the processing capacity of incineration plants is insufficient, or what if the cost aspect of removal of ZZS is too high for economically efficient recycling.

Recommendations

- Determine together with the other modules which applications are reviewed and what is defined as the baseline scenario. A workable functional unit for all modules should be defined.
- For the ZZS-module it is important to include both the legally binding aspects (resulting from LAP) and the aspects giving room for a broader (risk) assessment. The outcomes of a broader (risk)assessment can be more, but also less strict. It also might be integrated with the outcomes of other modules and with practical implications.

6. Question on more critical applications
In tier 1 it needs to be determined whether the next application is more critical. This appears to be a difficult task as there is no clear definition of 'critical'. The ambition is that tier 1 should be 'easily' doable for users.

Recommendations
- Change the focus of the question from critical to the change or degree of potential exposure of humans or the environment.
- Provide guidance on how to answer this question. It can include emissions, the recovered material and closed loop recycling.

7.6 Lessons and recommendations for Pharmaceuticals
1. Indicator compounds
For each case indicator compounds have to be selected in Tier 1, because the large amount of active ingredients in pharmaceuticals. In one case the stakeholder selected the compounds based on relevant criteria in another case the RIVM was asked to select indicator compounds. This resulted in partly different indicator compounds.

Recommendations
- To promote a consistent and transparent approach for future cases, it is proposed to have a longlist of human pharmaceuticals for the Netherlands and to apply a set of criteria to select indicator compounds for the specific case .
- The longlist should be made for any matrix, for any type of waste, e.g. waste water, incontinence/diaper materials or hospital waste water (see Moermond *et al*., 2020 for measurement concentrations).
- Indicator criteria could be: good measurements in water or a material matrix (minimal recovery efficiency of analysis), expected presence in residual flow or product (taking into account the use, metabolism in the human body, fate/degradation during recycling) and environmental fate (distribution water-sludge, degradation). The recycler should stay responsible for the selected compounds.
- It is also important to explainwhat the function of the indicator criteria is (e.g. human toxicological or ecotoxicological endpoint). In principle all selected compounds should be within the criteria.
- Veterinary medicinal products should be added to the module and a separate long list could be selected from when relevant.
- The list of indicator compounds should stay flexible allowing state-of the-art testing.

2. Trigger values
In tier 1 of the module measured or estimated concentrations can be assessed with trigger values. It is not clear for all users how to apply the available trigger values for water, soil, sludge and materials, if it is obligatory to perform an assessment with trigger values in tier 1, and if trigger values apply for the incoming or outgoing flows.

Recommendations
- Trigger values or generic quality standards are important for tier 1. It should be made clear that assessment with trigger values

only should be done when no other quality standards are available.
- It should be made clear in which situations and for what compartments the trigger values are available and for which they apply (water, soil, sludge).
- A trigger value preferably should first be applied on the (undiluted) incoming waste flows (worst case) and secondly on the outgoing material flows (depending on the application).
- Hormones and endocrine disrupters could have separate trigger values, just like cytostatics and anti-parasitica.

3. Harmonisation of modules

The assessment of pharmaceuticals is applied for the assessment of struvite coming from waste water and the recycling of materials from incontinence materials and diapers (Grinten and Spijker 2018) (Lijzen, van der Grinten et al. 2019). For struvite a less conservative scenario seems to be followed than for diapers recycling, with differences due to simultaneous development in these case studies.

Recommendations
- It is recommended to evaluate the assessment of the human toxicity of pharmaceuticals. Depending on new international knowledge on the human toxicity of pharmaceuticals (e.g. when assessing drinking water) the generic trigger of 1/10,000 of the lowest dose could be revised or detailed.
- New approaches described in the struvite and diaper report can be included in a revised model.
- The steps and tiers in the module need more transparency. Steps should not be iterative (going back from tier 2 to tier 1). When e.g. criteria are missing, side steps (within the same tier) could be included for deriving trigger values or quality standards. In principle it should be possible for a recycler/producer to perform a tier 1 assessment.
- Because not all environmental compartments are taken into account, it should be considered to add groundwater as an endpoint, next to the topsoil (being included in the struvite case). For persistent mobile compounds (PMT) this is important.

7.7 Lessons and recommendations for pathogens

1. The assessment of pathogens is applied for identifying risks linked to waste of biological origin. When SSML was used, it turned out that tier 1 of the module could be easily applied. However, the module was not 'activated' in Tier 0 in case of recycling mattresses which is now seen as an omission.

   Recommendation
   - Reconsider Tier 0, and also include biological contamination of non-biogenic materials

2. A full description of the recycling process would be helpful to identify pathogen risks linked to the process, products and emissions.

Recommendation
- Start the pathogen module with a full description of the recycling process, including new waste products and emissions and identify process steps where pathogens are reduced or fully eliminated.

3. When a recycling process results in a product that can be applied as a raw material, various legal requirements can become relevant, depending on the application of the recycled product.

   Recommendation
   - Write guidance in which SSML users can find information on legal requirements on pathogens in materials and products.

4. For pathogen contaminated recycled products that are not a consumer product, but that are used in, for instance, a production chain that leads to a consumer product (e.g. struvite used as a fertilizer of crops) it is not possible to determine an absolute human risk, as the identified hazard might already be present in soil and/or the identified hazard in a recycled product might grow in soil, leading to an increased human risk.

   Recommendation
   - A relative approach (e.g. compared to manure) when assessing the pathogen risk is recommended when other criteria are missing.

7.8 Lessons and recommendations for AMR, pesticides and other hazards

Antimicrobial resistance

The AMR module of SSML deals with risks linked to antimicrobial resistant organisms, to genes encoding for either antibiotics or enzymes involved in antimicrobial resistance and to antibiotics themselves. Risks linked to AMR are very similar to either pathogens (antimicrobial resistant organisms) or pharmaceuticals (antibiotics) (and some desinfactants and metals). Identifying risks linked to the presence of AMR genes is complex, but risk reducing strategies for AMR organisms do also apply to AMR genes.

Recommendation
- We suggest splitting the AMR module into two submodules, one for AMR organisms and genes, and one for antibiotics. The first submodule could be added to the pathogen module, the latter to the pharmaceutical module.

Pesticides

In the casus of railway sleepers an existing method for biocide assessment was used, that is not part of the SSML-module. Currently the pesticide module is used for assessing risks and benefits of the application of digestate with pesticides on soil and not for other scenarios.

Recommendation
- The module should be extended with the method or a reference to the method of biocide assessment.

Another observation is that the pesticide module is not activated for waste water, although it could be present in case of raining water run-off.

Radiation module
A radiation module was developed and is described in chapter 4 of this report. We recommend adding the radiation module to SSML.

Genetically modified organisms
Genetically modified organisms (GMOs) can be present in a (biotic) waste stream, for example in plant waste or biomass from a bioreactor, or can be used in the process of recycling biomass waste. Currently, there is no safety module for GMOs in SSML. Risks of GMOs can partly be covered by the pathogens and AMR (gene transfer) modules. However, we recommend investigating if all GMO-related risks are covered by the current SSML modules or whether the framework should be further extended to also cover these risks.

8 Overall conclusions and recommendations

The aim of this study was to test and improve the assessment framework SSML from the perspective of user-friendliness and suitability for analysing innovative recycling options for waste flows. We focused on:

1. The general needs and demands of stakeholders when assessing recycling initiatives and recycled materials. From the workshop, interviews and the cases we could derive lessons and recommendations that can be used for the further development and implementation of assessments tools like the Safe and Sustainable Material Loop framework.
2. Technical improvements of the presented framework, based on the cases we performed with stakeholders and the experiences of RIVM-experts. By developing an extra module on radiation we were also able to extend the tool.

In this chapter the main outcomes of the study are summarised and recommendations are formulated.

8.1 Stakeholder demands and general lessons

Stakeholder demands

During the stakeholder consultations (workshop and interviews) it became clear that the stakeholders have extensive experience with individual cases based on expert judgment. Based on the outcome of the consultations we have three main conclusions and recommendations on the needs and demands concerning recycling of waste streams:

1. Waste handling is subjected to legislation. There is a need for guidance on how to comply with this legislation and on how to act when legal or product safety criteria lack. It should be made more transparent in what situations a tool for hazard and risk assessment, like SSML, can be used. The outcome of such assessment should preferably be simple (Is it yes/no within legal criteria (or risk limits) or more information required).
    - We recommend paying attention to the link between legal standards and a hazard/risk based approach in the assessment of an initiative for recycling of residual flows.
    - Besides hazard/risk assessment stakeholders confirm they have a need for tools to assess the contribution to circularity and sustainability as it is present in the circularity and environmental impact module.
2. In addition to the need for guidance, stakeholders have a strong need for information on composition of waste flows, including substances of concern (SoC), on relevant legislation, and on an overview of previous legal judgements on case studies. Preferably this should be made available in a central/national database or linked databases. It should help stakeholders to use the relevant information sources.
    - We therefore recommend the National Government to build or further develop a database and to develop a guidance for its use.

3. There is a strong need for a national platform for exchanging information, discussing specific cases and more general legal issues or safety aspects. The umbrella association of the regional Environmental agencies (Omgevingsdienst NL) or The Human Environment and Transport Inspectorate (ILT) were mentioned by the stakeholders as partners to initiate that. The RIVM could be one of the organisations to provide knowledge and perform studies on specific subjects.

General lessons
SSML can be used to identify potential risks and to assess the sustainability impact linked to a recycling technology or its product. It is a modular framework, with modules focusing on various hazards and two aspects of sustainability: circularity and environmental impact (see Figure 8.1). In this section, general lessons, lessons not specifically related to the modules.

1. Defining the *scope* of the assessment needs more guidance. The assessment should include the safety of emissions to the environment during the process and the safety of recovered materials for humans and the environment. To be able to define the scope it is important to first make a description of the production chain or life cycle, including: the input material (waste stream), process (recycling method), emissions and use of resources during the process, the output material, and application in product(s). The scope should also include a reference scenario (being the current main practice).
   In the case studies we found that the scope definition can be different for impact assessment, circularity and safety modules. In principle, one scope should be defined for the whole assessment. The reasons for adjusting the scope for specific modules should be explained.
   Risks for workers are not included, but should preverably be added or included when considered relevant.
2. One ambition of this study was to come up with suggestions to make SSML a more *user-friendly tool* of which tier 0 and 1 can be performed by all stakeholders. Professionals on specific subjects should be able to perform tier 2; tier 3 describes a tailored approach that can be performed by (RIVM-)experts. We recommend to:
   - make a more user-friendly interface (e.g. a web based tool) and
   - write guidance in which SSML users can find information on:
     - Relevant legislation and legal requirements[18].
     - What to do when legal criteria do not exist.
     - Data requirements: what data are needed, where to get data from (for all modules) and what to do when data are not or insufficiently available.
     - Definitions of indicators and criteria (e.g. ‘critical’).
3. From the case studies it was found that in some modules the risk based approach is only partly harmonized with legislation. We

[18] It is noted that due to REACH regulations a material must comply with product standards if it is not treated as waste.

recommend including both the legal approach which is relevant for legislative requirements of a recycling initiative and to include a risk based approach in the safety modules of SSML, where possible. It should be indicated where this risk based approach differs from the (Dutch) legal criteria/legislation. Sometimes legal criteria are absent or change[19]. In such situations, the SSML tool is expected to help identifying hazards and/or risks. Validated or prescribed analytical methods and criteria should also be available.

4. In SSML risks and benefits are quantified, but the outcomes are not weighed leading to an integrated value. This can sometimes make it difficult to arrive at an overall decision. We recommend therefore to explore methods and possibilities to compare and weigh different risks and benefits.

8.2 Main lessons and recommendations on modules on circularity and environmental impact

Instructions on circularity indicators. The circularity module has been developed to analyse the circularity of recycling processes. Three indicators are given: efficiency, contribution (to the market) and recyclability. Tier 2 of the circularity module gives a value for each of the three indicators. Although an overall score for the whole product chain could be interesting, separate indicators give more information on the different aspects of circularity.
We recommend giving more instruction on how to calculate them, including a list of required data to score each indicator. In particular the indicator contribution (to the market) needs a clear description to give insight in the potential effect on relevant product chains.

Additional indicators and parameters. We recommend to add the material circularity indicator (MCI)[20] as an indicator when assessing a product. We also recommend and to add a quality parameter of the recycled materials to the efficiency indicator, including an instruction on how to calculate them.

Data sources and scope of environmental impact. The environmental impact module uses an LCA-like approach in which a recycling process is compared to a reference process (baseline). Because the scope is very relevant for the results, it is recommended to give more (visual) guidance for the definition of the scope, including questions on the most relevant life cycle stages. An instruction on which data are required and on the (generic) data sources that can be used is recommended. Providing easily accessible data sources on environmental impact of processes is also recommended.

Aggregating score for environmental impact categories. The overall environmental impact of a recycling technology or product is the result of many factors. The environmental impact score in SSML is based on

[19] In several cases, it was notified that legal criteria change in time (e.g. thresholds for acceptable levels of flame retardents in products). As a consequence, the overall result of the assessment (e.g. safe or not) can also change, when SSML follows these legal criteria.
[20] https://ellenmacarthurfoundation.org/material-circularity-indicator#:~:text=The%20Material%20Circularity%20Indicator%20(MCI,material%20price%20volatility%20and%20material

two of these factors: land use and greenhouse gas emissions (or energy demand), as they are known to be also a first indication of other impacts. We recommend to evaluate this assumption and to think of using an additional factor when the assumption is invalid.
We recommend to develop a method for aggregating individual indicator (e.g. land use and greenhouse gas emissions) scores to come to an overall environmental impact score.

Tier 1. The environmental impact module directly jumps to a Tier 2 assessment, which is data intensive. To make this module more user-friendly, we recommend to explore if the addition of a Tier 1 assessment is possible.

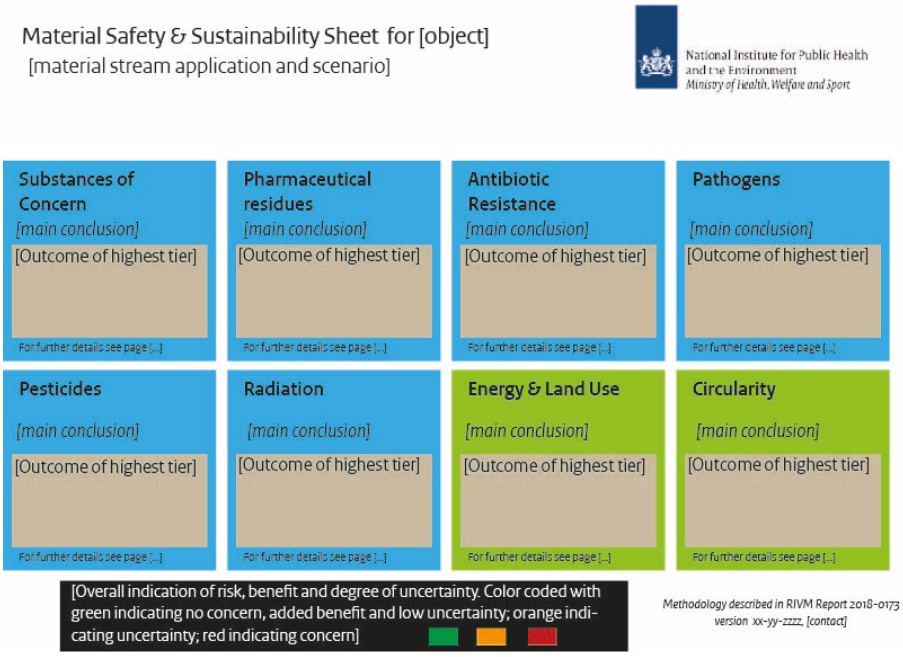

Figure 8.1 Modules of the framework Safe and Sustainable Materials loops in the generic data sheet to present the outcome of the SSML assessment. The radiation module was added.

8.3 Main lessons and recommendations on safety modules

Lacking criteria. When thresholds in environmental media or critical levels in materials are lacking, the assessment is hampered. We recommend to derive more robust assessment criteria for negligible risk. Risk assessment for standardised (exposure) scenario's or products in higher tiers would also make assessments easier. When a material is recovered that can be applied in many products, we recommend to assess the safety of the most critical application for different type of risks.

Tiered approach. It is recommended to harmonise the content of the tiers in all modules, including the tuning of legislation (see section 8.1) . The first tier should be qualitative (hazard assessment), in the second tier a qualitative exposure assessment should be added. If human or environmental exposure is not possible, a recycled product is safe, despite the presence of a hazard. If exposure is possible, quantification of the riskis required in tier 2, or in tier 3, when a tailored approach is needed and/or criteria are lacking.

Incoming waste flows and final products. SSML aims to identify several chemical hazards, like SoC or SVHC (Dutch policy is based on national guidance on substances, mainly ZZS), heavy metals, pharmaceuticals and pesticides. If present in the incoming waste flow, they can be present in the final product to form a risk. If such hazards are absent in the incoming flow, a risk can only occur if new hazards are formed or added during recycling. If concentrations in the incoming waste are below any legal safety criteria, they can only lead to risk if during the recycling process new hazards or hazardous substances are concentrated, added or formed. We recommend to clearly state if available criteria should be applied to incoming (waste flows) or outgoing materials orproducts).

Endpoints of risk analysis. Because current legal standards for ZZS are not always risk based, we recommend to extend the possibilities in SSML to perform a risk-based analysis (by including exposure pathways). Any risk is the result of the *severity of a hazard* x *level of exposure*. An important recommendation is to clearly describe the human and environmental endpoints including the exposure pathways that should be considered. We recommend to include in the higher tier risk assessment for standardised applications or products. For environmental risk this could be water (→ ground water and/or surface water), (top)soil quality, wildlife, vegetation, air quality. For human risks this could include food consumption, food contact materials, direct contact (adults/children), ingestion of soil/dust, inhalation (of materials/products and process emissions)for public and as well as workers.
For these endpoints we recommend to develop standard exposure scenarios for assessing potential human and environmental risks.

Reference scenario and relative risks assessments. Lack of exposure criteria hampers a risk assessment. In these situations it is possible to have an indication of the safety of recycling and new materials by comparing with the current situation (as is done in the sustainability modules). Therefore, it would be valuable to apply the safety modules also to the reference process (baseline). This also includes uncertainties or potential safety risks of the reference.

Substances of concern (SoC) (including ZZS). For the ZZS module and other risk modules it should be made clear what criteria should be used for the assessment of the (incoming) waste stream (e.g. 0.1% limit value for ZZS in waste streams) and which ones for the recovered material. We recommend to include a practical list of the substances (currently Dutch ZZS) and assessment in order to make the assessment user friendly. We recommend to also include other substances of concern, like metals or microplastics.

Radiation. An additional module was developed for the assessment of natural and artificial radiation. It was successfully tested on the recycling of concrete of a cyclotron vault based on literature data. We recommend to apply this module on waste streams with radiation from both artificial and natural origin.

Pharmaceuticals. In Tier 1 of the module indicator compounds need to be selected (for each case study). This is can be subjective. For more consistency we propose to make use of a longlist of pharmaceuticals, with selection criteria to come to a list of indicator compounds for a specific case. These indicators should also represent hormones and veterinary pharmaceuticals.
When no other quality standards are available for the assessment, trigger values can be used. We recommend to derive more trigger values (or generic quality standards) for environmental media/compartments. Based on trigger values, screening levels of the incoming residual stream (e.g. waste water) or in new materials could be derived to identify substances that can pose a risk.

Pathogens. Waste flows containing material of biological origin can harbour pathogens. For many products, hazard specific safety criteria for pathogens are missing. Yet, the potential presence of pathogens in a product that results from a recycling technology can present a risk. When safety criteria for pathogens are missing, we recommend to use a relative approach in which the new level of exposure is compared to the level to what the relevant endpoint (environment/human) already is exposed to by other sources.

Antimicrobial resistance (AMR). Risks linked to AMR are very similar to either pathogens (antimicrobial resistant organisms) or pharmaceuticals (antibiotics). Identifying risks linked to the presence of AMR genes is complex, but risk reducing strategies for AMR organisms do also apply to AMR genes. It is therefore suggested to split the AMR module into two submodules, one for AMR organisms and genes, and one for antibiotics. The first submodule could be added to the pathogen module, the latter to the pharmaceutical module. Also consider the inclusion of risks from genetically modified organisms (the organism itself and its genes) in SSML.

8.4 Concluding remarks

As stated in section 8.1 it is recommended to focus activities on availability of data, assessment tools and platforms for exchanging information. To further develop and build SSML a variety of adjustments summarised in the former paragraphs need to be implemented. The aforementioned general lessons in section 8.1 (3 and 4) need more scientific basis, while other lessons are more operational and need additional stakeholder consultation (1 and 2). As a follow up of this work we aim to develop the assessment method(s) tailored for specific applications together with its stakeholders. Such a method can contribute to transparency in the contribution of initiatives to environmental sustainability and to safe guarding human and environmental hazards. Part of the recommendations will be elaborated on in the next phase and should lead to easy to apply tools to assess recycling of waste flows.

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10 References

(1963). Kernenergiewet.
https://wetten.overheid.nl/BWBR0002402/2022-02-16.

(IAEA), I. A. E. A. (2005). Derivation of activity concentration values for exclusion, exemption and clearance. S. 44. Vienna. **44**.

A.M.Al-Sabagha, F. Z. Y., Gh.Eshaq,bA.M.Rabieb,A.E.ElMetwally (2016). "Greener routes for recycling of polyethylene terephthalate." *Egyptian Journal of Petroleum* **25**(1): 53-64.

ANVS (2018). ANVS-verordening basisveiligheidsnormen stralingsbescherming.

Bos, A. J. J., F. S. Draaisma and W. J. C. Okx (2007). *Inleiding tot de stralingshygiene*. Den Haag, Sdu Uitgevers.

CEDelft (2019). Verkenning chemische recycling. Update 2019. Delft.

CO2emissiefactoren. (2021). "CO2emissiefactoren.nl." 2021, from https://www.co2emissiefactoren.nl/.

De Poorter, L. R. M., L.C. van Leeuwen (2017). Zeer Zorgwekkende Stoffen: prioriteringsopties voor beleid, RIVM.

EC (2000). Directive no 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Off J Eur Communities: Legis**:** 1-72.

Euratom (2013). Euratom Directive 2013/59.

Faber, M., F. Heens, N. Spanbroek, J. Lijzen and A. van Drongelen (2021). Recycling van matrassen : analyse van risico's van verwerking en nieuwe toepassingen. *RIVM rapport 2021-0131*, RIVM.

Grinten, E. v. d. and J. Spijker (2018). Medicijnresten, pathogenen en antibioticaresistentie in struviet uit Nederlands huishoudelijk afvalwater. Bilthoven, RIVM.

Groot, G. d., A. Oomen and M. Mennen (2017). Evaluation of health risks of playing sports on synthetic turf pitches with rubber granulate : Scientific background document (in Dutch). Bilthoven, the Netherlands, Rijksinstituut voor Volksgezondheid en Milieu RIVM.

Herwijnen, R. v. (2013). Guideline 'identification of ZZS in the Netherlands' (in Dutch); Handreiking identificatie Nederlandse zeer zorgwekkende stoffen. *RIVM briefrapport 601357012/2013*. Bilthoven, RIVM.

IAEA (2005). Derivation of activity concentration values for exclusion, exemption and clearance. *Safety Report Series ISSN 1020-6450;* . Vienna, International Atomic Energy Agency. .

IenM, M. o. (2014). "Regeling - Besluit beheer verpakkingen 2014 - BWBR0035711 ", from https://wetten.overheid.nl/BWBR0035711/2021-07-01.

IenM, M. o. (2016). Government-wide programme for a Circular Economy: A Circular Economy in the Netherlands by 2050. T. M. o. I. a. t. Environment. The Hague, The Netherlands.

IenM, M. o. (2017). Besluit basisveiligheidsnormen stralingsbescherming. M. o. IenW.

IenW, M. o. (2018). Regeling basisveiligheidsnormen stralingsbescherming;Regeling van 9 januari 2018, nr. IENM/BSK-2017/291098, houdende vaststelling van nadere regels ter bescherming van personen tegen de gevaren van blootstelling aan ioniserende straling

IenW, M. o. (2020). the third National Waste Management Plan, called LAP3.

IenW, M. o. (2021). The 'guidance on waste and product' *Leidraad afval en product.*

IenW, M. o. (2021). Uitvoeringsprogramma Circulaire Economie.

Janssen, M., J. Spijker, J. Lijzen and L. Wesselink (2016). Plastics that contain hazardous substances: recycle or incinerate? *RIVM letter report 2016-0025.*

Kárpáti, L., F. Fogarassy, D. Kovácsik and V. Vargha (2019). "One-Pot Depolymerization and Polycondensation of PET Based Random Oligo- and Polyesters." *Journal of Polymers and the Environment* **27**(10): 2167-2181.

Keverling Buisman, A. S. (2015). *Handboek Radionucliden*, Uitgeverij Nucleus.

Kimura, K., T. Ishikawa, M. Kinno, A. Yamadera and T. Nakamura (1994). "Long-lived radioactivity in a cyclotron vault." *Health Physics,* **67**(number 6).

Lijzen, J., E. van der Grinten and A. M. van Drongelen, CTA Venhuis, B (2019). Beoordeling hergebruik van luier- en incontinentiemateriaal : Stappenplan en risicobeoordelingskader voor de mogelijke risico's van stoffen en pathogenen in producten. *RIVM letter report 019-0111*.

NMD (2020). Bepalingsmethode Milieuprestatie Bouwwerken. Rijswijk, Stichting Nationale Milieudatabase.

Oomen, A. and G. de Groot (2016). Beoordeling gezondheidsrisico's door sporten op kunstgrasvelden met rubbergranulaat. *Evaluation of health risks of playing sports on synthetic turf fields with rubber granulate*, Rijksinstituut voor Volksgezondheid en Milieu RIVM.

Postma, J. and R. van der Oost (2018). Rubbergranulaat op kunstgrasvelden. *Verkenning milieueffecten voor het aquatisch ecosysteem*. S. T. O. Waterbeheer. **STOWA 2018-37**.

Quik, J., E. Dekker and M. Montforts (2020). Safety and sustainability analysis of railway sleeper alternatives : Application of the Safe and Sustainable Material Loops framework. *RIVM report 2020-0126*. Bilthoven, the Netherlands, RIVM.

Quik, J. T. K., J. P. A. Lijzen and J. Spijker (2019). Creating safe and sustainable material loops in a circular economy : Proposal for a tiered modular framework to assess options for material recycling. *RIVM report 2018-0173*. Bilthoven, The Netherlands., RIVM.

Remy, C., L. Conzelmann, N. R. Martinez and B. Benedetti (2020). SMART-Plant; Environmental Impact Report, incl. LCA (Life Cycle Assessment); Integration, valuation and validation. Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants. Berlin, Kompetenzzentrum Wasser Berlin.

Rijkswaterstaat (2018). A guidance on the risk analysis for ZZS in waste.

Rijkswaterstaat (2020). Third National Waste Management Plan, called LAP3.

Schaaf, M. v. d., P. D. B. M. Bekhuis and L. Boudewijns (2022). Radioactieve rest- en afvalstromen in Nederland; Een inventarisatie. Bilthoven, National Institute of Public Health and the Environment (RIVM).

Schut E, C. M., Mesman M (2015). Beleidsverkenning circulaire economie in de bouw : Een perspectief voor de markt en overheid. *RIVM rapport 2015-0197*.

Schyns, Z. O. G. S., Michael P. (2020). "Mechanical Recycling of Packaging Plastics: A Review." *Macromolecular Rapid Communications* **42**(3).

Smetsers, R. C. G. M. and P. D. B. M. Bekhuis (2021). Blootstelling aan natuurlijke bronnen van ioniserende straling. Bilthoven, Rijksinstituut voor Volksgezondheid en Milieu**:** 163.

STOWA (2017). Van zeefgoed naar asfalt, VANEZA - Ontwikkeling eerste product-markt-combinatie voor zeefgoedcellulose. *STOWA 2017-29*. Amersfoort, STOWA.

STOWA (2020). Monitoring cellu2pla: Het winnen van cellulose uit rioolwater voor de productie van een bioplastic. *STOWA rapport 2020-01*.

TNO (2017). Een verkenning van de milieu-impact van circulair bouwen in de woning- en utiliteitsbouw.

Traas, T. P., P.G.P.C. Zweers, J.T.K. Quik, S.L. Waaijers, J.P.A. Lijzen (2021). Towards sustainable recycling; Method for comparing safety and sustainability of the processing of residual flows. *RIVM Letter report 2020-0217*.

Trubey, D. K. (1966). A survey of empirical functions used to fit gamma-ray buildup factors. Tennessee, OAK RIDGE NATIONAL LABORATORY

Valentin, J. (2007). The 2007 Recommendations of the International Commission on Radiological Protection, ICRP. **103**.

Verschoor, A., C.W.M. Bodar, R.A. Baumann (2018). Verkenning milieueffecten rubbergranulaat bij kunstgrasvelden. *RIVM Briefrapport 2018-0072*.

Zweers, P. (2021). An inventory of innovation in recycling waste streams with substances of concern; Towards a safe circular economy. *RIVM Letter report 2021-0009*.

Zweers, P. G. P. C., J. K. Verhoeven, P. N. H. Wassenaar, J. Spijker, R. L. Luit, J. H. Ganzevles and M. P. M. Janssen (2018). Advies voor een handreiking met afwegingskader risicoanalyse ZZS in afval. *RIVM report 2017-0168*.

Annex 1 Opzet workshop en vragenlijst RENEW

Workshop 13 februari 2020 12-17 uur in S2M Utrecht

Vooraf

Onderstaande vragen zijn bij de uitnodiging per mail verstuurd om de context van de workshop te schetsen:

- Met welk type afvalstromen hebt u in uw dagelijkse praktijk te maken?
- Hoe beoordeelt u een aanvraag tot vergunning, aan welke voorwaarden toetst u?
- Op basis van welke informatie (bron?) neemt u een besluit tot wel of niet vergunnen?
- Tegen welke vragen loopt u aan bij de beoordeling?
- Wat doet u bij gebrek aan informatie?
- Hoe beoordeelt u veiligheid en duurzaamheid?
- Wilt u een ervaring uit eigen praktijk presenteren?

Doel van de workshop:

- Behoefte peilen bij vergunningverleners;
- Nagaan of tool Safe and sustainable Material Loops (SSML) een hulpmiddel kan zijn;
- Ideeën voor verbeterslagen SSML: bruikbaarheid/volledigheid, bv:
    - Welke stappen (tiers) kunnen de vergunningverleners zelf invullen?
    - Bij welke stappen is ondersteuning nodig?
    - Is het proces helder?
    - Bij volledigheid gaat het o.a. over de vraag of het alles dekt: nucleair/radiologisch; exoten etc.
    - Wat kan een gebruiker met het resultaat?

Programma van de workshop

13.00 Opening/welkom
13.15 Inleiding op project RENEW
13.30 Behoeftepeiling

- Brainwriting:
    - Eerste rondje met behoefte zonder op elkaar te reageren
    - Reageren op behoeften
    - Aanvullingen met nieuwe behoeften
- Selectie enkele behoeften en die plenair kort bespreken

14.15 Pauze
14.30 Tools

- Toelichting SSML en schets ideaalbeeld van de tool
- Bruikbaarheid/volledigheid/verbeteringen
    - We willen vooral het gesprek voeren met de groep
    - Eventueel/indien nodig prikkelen met vragen/stellingen

15:45 Afronding en wrap up
16.00 Sluiting

Vragenlijst interviews RENEW

November en december 2020

In de workshop van februari 2020 met omgevingsdiensten en Rijkswaterstaat kwam naar voren dat er behoefte is aan:

1. Een databas;
2. Een beoordelingstool;
3. Een regulier/centraal overleg;

In aanvullende interviews met RWS, DCMR, ODNZK, ODTwente, ODMWB, TNO and RHDHV) is via een vragenlijst ingegaan op deze drie onderwerpen. Daarnaast zijn ook specifieke vragen gesteld per organisatie.

Ad 1. Een database

- Welke databronnen gebruikt u nu het meest om toelaatbaarheid van stoffen risico's voor mens en milieu in te schatten?
- Welke informatie (bron?) is noodzakelijk voor het indienen van een vergunningsaanvraag?
- Welk type data is meeste behoefte aan?
- Waar worden data verzameld, bewaard en beheerd?
- Wie heeft toegang?

Ad 2. Een beoordelingstool

- Binnen welke beleidscontext moeten beoordelingen worden gedaan?
- Heb je inzicht in de afvalstromen waarvoor een afval-geen afval vraag is gesteld?
- Hoe beoordelen bedrijven de veiligheid en aan welke voorwaarden toetst u?
- Aan beoordeling van welk type risico of welke afwegingen is het meeste behoefte aan?
- Welke soort uitkomsten is gewenst? (een kwantitatieve inschatting per thema; geïntegreerde beoordeling; etc.)
- Tegen welke vragen/knelpunten loopt u aan bij een beoordeling?
- Wat doet u bij gebrek aan informatie?
- Beoordeelt u ook hoogwaardigheid/circulariteit/duurzaamheid van een initiatief (binnen welke beleidskader)?
- Worden risico's alleen in absolute zin beoordeeld of wordt ook wel een relatieve risicoschatting gemaakt (afzetten tegen bestaande situatie)

Ad 3. Een regulier overleg

- Is er behoefte aan meer afstemming en bespreking van casussen tussen bedrijven onderling, of tussen bedrijven en vergunningverleners.
- Welke zaken moeten in een overleg besproken worden?
- Wie moeten in een overleg betrokken worden?

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