Master's Thesis – Master Sustainable Business and Innovation

Mission-oriented Innovation System (MIS) analysis on transition towards circular personal protective equipment in Dutch academic hospitals

15/08/2022

Utrecht University

Author:	Hidde Bijlmer
Student number:	5980461
Student mail:	h.j.t.bijlmer@students.uu.nl
Supervisor Utrecht University:	Prof. dr. Ellen Moors
Word Count:	21.073

Acknowledgement

During this year, I have been working on my thesis to obtain my Master's degree in Sustainable Business & Innovation. Writing this thesis has been an excellent opportunity to apply the gained knowledge of the Master's degree to conduct an adequate academic study. However, it has also been one of the most challenging tasks in my academic career. Therefore, I would like to express my gratitude to several individuals who significantly contributed to this process.

First of all, I would like to thank my supervisor prof. dr. Ellen Moors. Her insightful comments, clear feedback and good communication ensured that the research process progressed smoothly. Furthermore, my sincere gratitude for always having the possibility to ask questions and advice.

Secondly, I really would like to thank the people who participated in the interviews. The healthcare sector is a busy industry where time is scarce. Therefore, I am extra grateful that I got to conduct interviews with 21 respondents who have made time for this cause. My special thanks to the six respondents who, in addition to the interview, took the time to validate my results.

Abstract

The Covid-19 pandemic has put a lot of pressure on the healthcare sector. In addition, the pandemic shed light on the enormous amount of waste production caused by the single-use of personal protective equipment (PPE) in hospitals. PPE is equipment that is used to prevent or minimize the healthcare worker and patient exposure to hazards and includes gloves, face masks, goggles, face shields and gowns. The extensive use of disposable PPE has led to a worldwide production of 8 million tons of plastic waste, with more than 25.000 tons ending up in the oceans. The transition from these disposable PPE to the use of circular alternatives would save tons of plastic waste production and significantly reduce the environmental impact. This transition would contribute to the circular mission of the Green Deal Duurzame Zorg 2.0 in the Netherlands. The mission-oriented innovation system (MIS) approach is an adequate approach to analyse the innovation system related to this mission, as this approach enables the analysis of the development and diffusion of multiple circular PPE innovations.

The MIS approach has been used to answer the following research question: "*What are the barriers for a transition from disposable personal protective equipment towards circular alternatives in Dutch academic hospitals".* In addition, the research will provide policy recommendations to overcome the identified barriers to the transition. The research question is examined according to five analytical steps of the MIS approach: problem-solution diagnosis, structural analysis, functional system analysis, systemic barrier analysis, and the identification of systemic instruments. These analytical steps allow the mapping of the circular PPE alternatives, the network of stakeholders and institutions, system strengths, system barriers and useful policy instruments.

The problem-solution diagnosis showed that there already are circular PPE alternatives available in the market. However, the alternatives are not yet implemented on a large scale in the Dutch academic hospitals. Based on the data analysis, four systemic barriers were identified. These include the strict infection prevention guidelines within hospitals, the lack of knowledge proving the environmental advantage of the circular PPE alternatives, the lack of stimulating financial institutions and regulations that incentivise the development and adoption of the circular PPE alternatives, and a lock-in of healthcare workers to using disposables. Currently, there are little to no governance actions and policy instruments in place in the Netherlands that effectively stimulate the transition to circular PPE alternatives within Dutch academic hospitals. In the final step of the MIS, several policy instruments and specific intervention strategies are presented to overcome the identified systemic barriers. The most important policy instruments include the provision of government funding for hospitals to cover the extra costs of the transition towards circular PPE alternatives and financially stimulating PPE manufacturers to develop these alternatives through pricing, standardising and subsidising. By implementing the recommended policy instruments and intervention strategies the circular PPE alternatives are able to develop and diffuse more efficiently which contributes to the circular mission of the Green Deal Duurzame Zorg 2.0.

Table of contents

List of abbreviations

AMC: Academisch Medisch Centrum

AZM: Academisch Centrum Maastricht

CE: Conformité Européenne

CO_2: Carbon dioxide

FFP: Filtering Facepiece Particle

Green Deal 2.0: Green Deal Duurzame Zorg 2.0

HCW: Healthcare worker

IP: Infection prevention

IS: Innovation system

LCA: Life cycle analysis

LCH: Landelijk Consortium Hulpmiddelen

LUMC: Leiden Universitair Medisch Centrum

Ministry of VWS: Ministry of Health, Welfare and Sport

MIS: Mission-oriented innovation system

MPZ: Milieu Platform Zorgsector

NEN: Stichting Koninklijk Nederlands Normalisatie Instituut

NFU: Nederlandse Federatie Universitair Medische Centra

NVB: Nederlandse Vereniging van Banken

NVZ: Nederlandse Vereniging van Ziekenhuizen

OR: Operating Room

PDZ: Programma Duurzame Zorg

PPE: Personal protective equipment

RIVM: Rijksinstituut voor Volksgezondheid en Milieu

SBIR: Small Business Innovation Research

TIS: Technological innovation system

UMC: Universitair Medisch Centrum

UMCG: Universitair Medisch Centrum Groningen

UK: United Kingdom

VDSMH: Vereniging van Deskundigen Steriele Medische Hulpmiddelen

VHIG: Vereniging voor Hygiëne en Infectiepreventie in de Gezondheidszorg

WHO: World Health Organisation

WIP: Working Party on Infection Prevention

YLD: Years lived with a disability

YLL: Years of life lost

ZN: Zorgverzekeraars Nederland

1. Introduction

The Covid-19 crisis has had a devastating impact on the world and is still affecting all sectors of the society. The virus has especially put a lot of pressure on the healthcare sector, which is charged with the heavy task of treating infected people in nursing wards and in intensive care units. Due to the infectious character of the virus, health care providers are forced to wear protective clothing and equipment to prevent the virus from spreading. This protective clothing and equipment is called personal protective equipment (PPE) and is defined as "equipment used to prevent or minimize exposure to hazards that could lead to injuries and illnesses" (WHO, n.d.). In this research, PPE includes gloves, face masks, goggles, face shields and gowns. Furthermore, this research especially focuses on the sustainability challenges related to the use of PPE and how this can be improved.

In the last two years, the global demand for PPE has increased tremendously due to the rapidly expanding COVID-19 pandemic (Mostaghimi et al., 2020). According to International Finance Organisation (2021), the global production of medical PPE has increased by at least 300% as a direct consequence of the pandemic. The estimated need on a monthly basis for PPE for healthcare workers (HCW) worldwide is 76 million gloves, 89 million medical masks and 1.6 million goggles (WHO, 2020). This increase in demand has caused shortages of PPE to emerge and thereby inhibits HCWs and their patients to protect themselves from being infected (WHO, 2020). Furthermore, most PPE items are single-use, meaning that they are disposed of after each use leading to large volumes of waste generation. In general, these single-use PPE items are made of synthetic fibres such as polypropylene and polyester (Udin et al., 2021). These materials have been used for PPE as they provide good protection against fluids whilst remaining breathability (Udin et al., 2021). However, the single-use of these items causes the creation of enormous amounts of plastic waste and the production of these synthetic fibres is associated with high carbon emissions. Peng et al. (2021) showed that worldwide more than 8 million tons of plastic waste caused by the single use of PPE already has been generated, with more than 25.000 tons ending up in the oceans. Thus, the increase in the demand for PPE has a significant impact on the environment and the deficit of PPE can have serious consequences for the safety of health care providers. In other words, there is an urgent need for circular PPE alternatives and more sustainable waste management (Dargaville et al., 2020; Adyel, 2020).

The search for more sustainable PPE alternatives is already going on and is stimulated, or even forced, by its global shortage. There are already existing reusable face shields and gowns, which were found to lower environmental impacts by up to 86% compared to the single-use versions (Udin et al., 2021). The reusable alternatives are made from woven fabrics that can endure multiple washing and sterilisation cycles[1](Advancells, 2020).

Many studies have been carried out on the need for and the importance of sustainable alternatives to single-use PPE. This has not yet led to integrating a circular approach in healthcare contributing to a transition to reusable alternatives and better waste management. Kazançoğlu et al. (2021) identified that there are multiple barriers related to the circular economy in the healthcare sector. The theory section gives a more in-depth literature overview about circular PPE. However, little has been published on the barriers of implementing circular PPE in the healthcare sector. This research aims to fill this gap by examining the barriers of the transition towards circular PPE alternatives that are present in academic hospitals in the Netherlands. The scope has been narrowed to academic hospitals as in these hospitals a combination of care and research are provided, which stimulates the implementation of

[1] PPE sterilisation to enable reuse will be possible on a large scale through hydrogen peroxide vapour, ultra-violet radiation or other spray-on disinfectants (Rizan et al., 2020).

innovation, that could potentially support the transition to a healthcare system using circular PPE alternatives (NFU, 2019).
The European Commission and the Dutch government have acknowledged that the healthcare sector contributes to environmental impacts and climate change (WHO, 2016). As a response, the Green Deal Duurzame Zorg 2.0 (Green Deal 2.0) has been set up in 2018 with the goal of promoting circularity and reducing carbon dioxide (CO_2) emissions (MPZ, n.d.). This Deal is part of the overarching European Green Deal, to which the Netherlands adheres by setting the goal to have a fully circular economy by 2050 (Dutch Ministery of Economic Affairs and Climate, 2019). The transition from single-use PPE towards circular PPE thus directly contributes to the mission of the Green Deal 2.0. Such a transition towards circular PPE alternatives requires a range of complementary actors, networks, institutions and dynamics involving a high number of parties and interactions (Botta et al., 2015). Therefore, an innovation system perspective is necessary to adequately study the complexity of this transition. The mentioned circular PPE alternatives can be seen as innovations. More specifically, a mission-oriented innovation system (MIS) approach is used to study the barriers of this transition towards circular PPE. The MIS perspective enables the opportunity to examine the development, diffusion and barriers of PPE alternatives that replace the existing single-use PPE with the aim of contributing to the Green Deal 2.0 (Elzinga et al., 2021). Thus, in order to contribute to the mission of the Green Deal 2.0, the main research question is:

"*What are the barriers for a transition from disposable personal protective equipment towards circular alternatives in Dutch academic hospitals?*"

This research has both scientific and societal relevance. Firstly, Rowan & Laffey (2020) state that there is a pressing need to explore perceptions, attitudes and possible barriers for the use of circular PPE by HCWs in order to initiate the transition towards a healthcare system using circular PPE. This research fills this gap in the literature by examining the barriers blocking the transition towards the use of circular PPE alternatives. Furthermore, the research adds to the existing literature on MIS, as it is the first case study applying the MIS framework to the Dutch healthcare sector. Secondly, this research maps the available circular PPE alternatives and the network of stakeholders and institutions. Furthermore, this research identifies the barriers in the innovation system which hinder the Green Deal 2.0 mission to be achieved. The societal contribution then lies in the fact that the identification of these barriers and instruments to overcome them, will contribute to achieving the goals of the Green Deal 2.0 mission. The identified barriers and recommendations of policy instruments to overcome them are useful for policy makers that are in charge of the Green Deal 2.0. Furthermore, the barriers and recommendations can be used by hospital boards, insurers, procurement departments and other key actors in the PPE innovation system.

Section 2 discusses the theory. It gives an overview of the literature on disposable PPE and circular PPE alternatives. Moreover, the innovation system perspective and the MIS approach are explained in more detail. Section 3 presents the methodology. It discusses the chosen research design, data collection, data analysis and research quality. This is followed by the results in section 4, wherein the first three steps of the MIS framework are applied. The analysis in section 5 identifies the systemic barriers and several policy instruments are recommended to overcome these barriers. The study ends with a discussion in section 6 and a conclusion in section 7.

2. Theory

This section discusses the theories, relevant background literature and a theoretical framework which are needed to answer the research question. First, the concept of the circular economy is explained with a focus on demarcating which circular strategies are relevant for this research. Second, a short literature review is carried out to emphasise the potential social, environmental and financial advantages of transitioning towards circular PPE alternatives. Finally, the mission-oriented innovation system framework is introduced which will be used to analyse the interaction between the Green Deal 2.0 mission of moving towards circular healthcare and the barriers towards transition towards circular PPE alternatives in Dutch academic hospitals.

2.1: Circular Economy

Traditionally society has operated along a linear economy, wherein raw materials were mined, processed into a product and thrown away after use. However, the linear economy causes the value of materials to be lost and has both economic and environmental disadvantages in the long-term (Heshmati, 2016). In order to create and preserve the value of materials, a new economic system was introduced known as the circular economy (CE). The circular economy is defined by the Ellen Macarthur Foundation (2015, p. 3) as a system that is "restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times". Potting et al. (2017) developed circular strategies, known as the 9 R's, with the purpose to reduce the consumption of natural resources and to minimise the production of waste. These circularity strategies can be seen in figure 1. Currently, the linear approach of immediate discarding after use is applied to PPE in hospitals resulting in a large accumulation of waste. The application of the circularity strategies to PPE in hospitals is an important solution that could minimise the generation of waste and address the issue of PPE shortages (Corrêa & Corrêa, 2021). In the result section, it is analysed which specific circular strategies have been applied per circular PPE alternative.

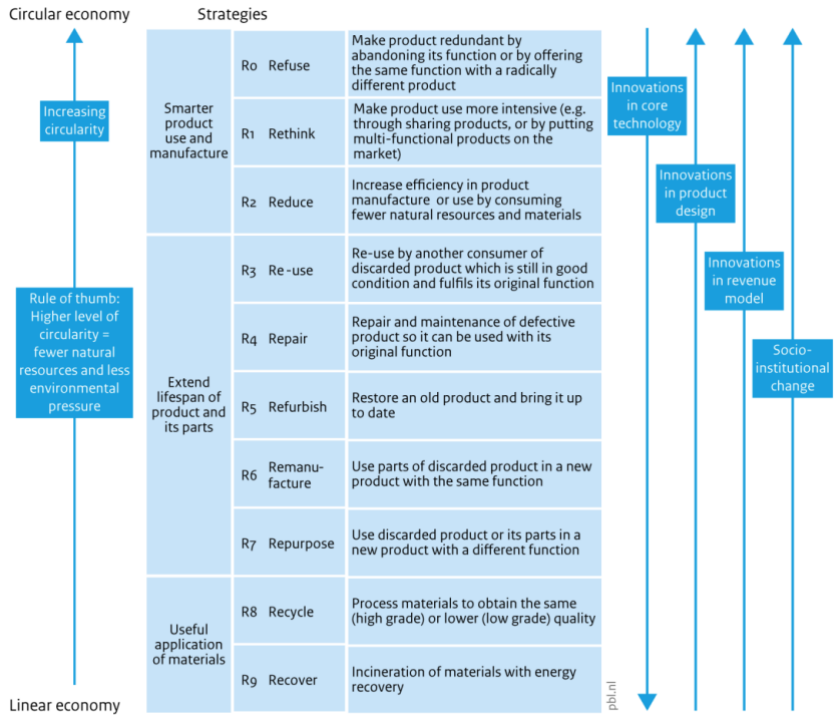


Figure 1: circularity strategies (Potting et al., 2017, p. 5)

2.2: Background of PPE

The alternatives for single-use PPE are not recently developed innovations that just entered the market. On the contrary, a few decades ago it was very common that PPE was reused after reprocessing. Different PPE items were regularly reused and reprocessed in healthcare by laundering on-site (PracticeGreenhealth, 2011). During that period, an abundance of research supported the use of reusable PPE over single-use protective clothing. Conrardy et al. (2010) showed that using reusable PPE generated a 65% reduction in medical waste and also reduced the costs of waste disposal. This financial advantage of using reusable PPE was emphasized by DiGiacomo et al. (1992) showing that a hospital could save over $100.000 by only reusing medical gowns. Moreover, survey studies on the health care worker's preference for disposable and reusable operation room (OR) clothing showed a clear preference towards reusable PPE (Conrardy et al., 2010). The preference for reusing PPE was thus primarily based on economic and environmental considerations (Haddad, 2014). Yet, currently the large majority of PPE is made from single-use plastics contributing to the global shortage and causing additional emissions of greenhouse gasses (EEA, 2021). This means that, even though much research supported the use of circular PPE, the healthcare system has transitioned from circular PPE to single-use PPE. This transition was mainly based on concerns about the quality of the reusable clothing to protect against exposure to infection (Choiniere, 2011). This concern proved to be large enough to transition the market of PPE to disposables. During that period, research supported this transition by concluding that PPE, especially during a pandemic, could not be decontaminated without compromising its effectiveness and therefore should not be reused (Institute of Medicine, 2006) (Carrico, 2006). However, the circular PPE alternatives have technologically advanced over the years. The textiles used in circular PPE have passed the tests against liquid barrier performance standards[2] and level of protection, meaning that they are safe for use in hospitals (Choinere, 2011).

2.3: Potential of transitioning to circular PPE

Transitioning to using circular PPE provides many advantages and solves multiple urgent problems. The use of disposable PPE results in the production of enormous amounts of plastic waste. Due to the possibility that this medical waste is infectious, the single-use PPE is disposed of through landfills and incineration (Prata et al., 2020). This entails that large amounts of plastic are burned, thereby increasing the carbon footprint and contributing to releasing hazardous components into the environment (Heidari et al., 2019). Rizan et al. (2021) performed a research on the environmental impact of PPE in the UK during the pandemic. The study showed that during a period of 6 months all PPE used in the healthcare sector amounted to over 106.000 tonnes of CO_2e, wherein 35% was derived from waste.

In developed countries, there is in general good waste management meaning that medical waste is incinerated and little waste ends up in the environment (Windfeld & Brooks, 2015). However, the generation of high amounts of medical waste caused by the pandemic puts a lot of pressure on the waste management of hospitals (UNEP, 2020). As a result, not all single-use PPE waste is properly disposed of after use causing plastic waste to end up in the environment and oceans (Peng et al., 2021). The disposal of plastic PPE waste in the oceans further worsens ocean plastic pollution and threatens marine life (Uddin et al., 2021). Moreover,

[2] A system of classification for protective apparel and drapes used in health care facilities based on the material's ability to prevent transmission of moisture or oxygen through the combined coating and substrate (Bishop, 2010).

plastic waste is broken down into micro- and nanoplastics, which can accumulate in food chains and ultimately threaten biodiversity and ecosystem functioning (Abbasi et al., 2020) (Boots et al., 2019).

Rizan et al. (2021) also modelled and compared alternative scenarios to the environmental impact of single-use PPE. The results of this study show the positive impact of reducing, reusing and recycling PPE on the variables of human health, ecosystems and resources (figure 3). These alternative scenarios would entail eliminating glove use, using reusable gowns and face shields, and maximising recycling PPE. As can be seen in figure 2, a combination of these alternative scenarios would significantly improve the aspects of human health[3], biodiversity and costs. Rizan et al. (2021) modelled that implementing these alternatives in the healthcare sector in the UK would save 183 disability-adjusted life years[4], 0.34 species.year[5], 6.5 million euros and reduce the carbon footprint by 75%. The reduced costs are related to the extra costs involved for future mineral and fossil resource extraction in the single-use PPE scenario. Prior research also emphasized this cost advantage of reusing and recycling PPE compared to the current scenario (Baker et al., 2020) (Chu et al., 2021) (McQuerry et al., 2021).

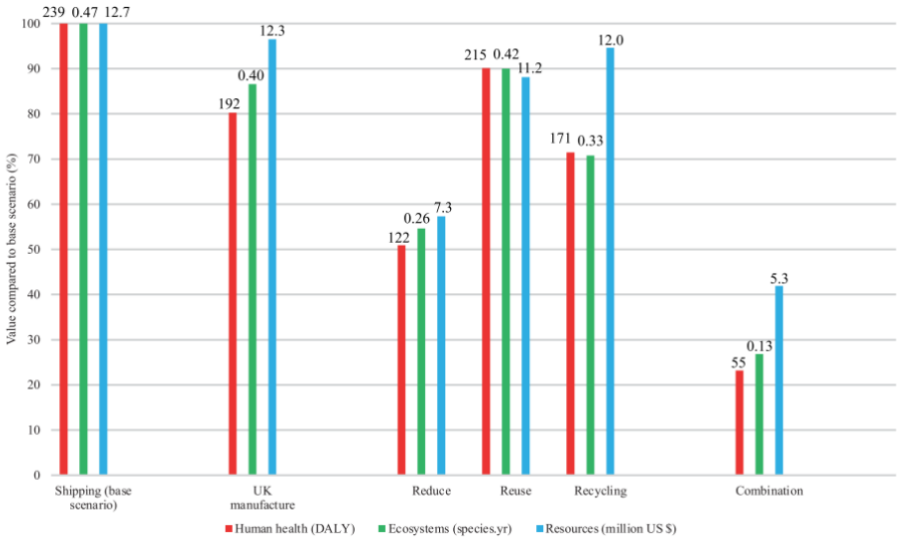


Figure 2: Environmental impact of alternative scenarios relative to single-use impact (Rizan et al., 2021)

2.4: Transition towards circular PPE: a MIS approach

The research question of this research is: *What are the barriers for a transition from single-use PPE towards circular PPE alternatives in Dutch academic hospitals?* The mentioned circular PPE alternatives can be seen as innovations. Innovations are not created following a linear path or in isolation, but rather emerge in systems consisting of a complex set of interactions and relationships among multiple actors, networks and institutions (Eduist, 1999; Lundvall, 2008). Consequently, a variety of different actors, institutions and networks are also involved in the potential diffusion and adoption of the circular PPE innovations. Furthermore, a transition requires a range of complementary factors and dynamics involving a high number of parties and interactions (Botta et al., 2015). Therefore, an innovation system perspective is

[3] The variable human health is based on the indirect health effects caused by toxicity and ozone formation

[4] The sum of the years of life lost (YLLs) to due to premature mortality and the years lived with a disability (YLDs) due to prevalent cases of the disease or health condition in a population (WHO, n.d.)

[5] Loss of local species

necessary to adequately study the complexity of this transition. An innovation system (IS) approach is appropriate to examine the functioning of these innovations, wherein the involved actors, institutions and networks and their interactions constitute the innovation system. Moreover, the innovations system approach is a useful tool to understand the activities and dynamics in the innovation system, to identify barriers that block the diffusion of innovations, and to provide recommendations to overcome these barriers (Botta et al., 2015).

A lot of innovation system studies focus on a technological innovation system (TIS). A TIS is a network of actors and institutions that are constructed around a specific technology (Hekkert et al., 2007). A TIS approach analyses the development and diffusion of a specific technology in the innovation system. (Hekkert & Negro, 2009). However, the focus of this study is to analyse the development of multiple circular PPE alternatives that contribute to a transition from single-use PPE and help to achieve the mission of the Green Deal 2.0. This cannot be analysed by only focussing on a TIS approach, which is less suitable to deal with a large variety of potential solutions and is not developed to study socio-institutional transformations (Elzinga et al., 2021). An innovation system perspective is needed that analyses the generation, development and diffusion of multiple solutions that contribute to a mission and potentially induce a system-wide change in the innovation system (Kivimaa & Kern, 2016). Hekkert et al. (2020) developed such a new system perspective, known as the mission-oriented innovation system (MIS). MIS is defined as "the networks of agents and set of institutions that influence the development and diffusion of innovative technological and social solutions that replace existing production and consumption systems with the aim to complete a societal mission" (Elzinga et al., 2021, p. 2).

The MIS perspective was created as a response to the shifting focus in innovation policy, wherein innovation policy has moved from solving market failures towards tackling societal problems. This transformation has driven the European Commission to formulate societal missions with clear targets (Hekkert et al., 2020). Such a shift in the policy focus is also present in the Dutch healthcare sector. Johansen et al. (2018) identified that the Dutch healthcare system is in the middle of a transition moving from a policy focus on affordability, accessibility, standardisation and financial performance towards focusing on increasing its sustainability performance. The Green Deal 2.0 mission has been formulated to set clear targets and to stimulate this transition towards more sustainable healthcare. Thus, the MIS framework is adequate to examine the transformation towards sustainable alternatives to single-use PPE. Furthermore, the MIS framework is suitable as, contrary to the other IS perspectives, the MIS perspective looks at the development and diffusion of multiple potential technologically innovations. This is important as it is not clear in advance which solutions offer the best opportunity to tackle the societal challenge of becoming more circular (Elzinga et al., 2020). Furthermore, the MIS approach is able to take these conflicting solutions directions into account. The MIS framework consists of 5 steps:

1. Problem solution diagnosis
2. Structural system analysis
3. Functional system analysis
4. Systemic barrier analysis
5. Identification of systemic instruments

In the problem solution diagnosis, the full complexity and scope of the mission are mapped out (Wesseling & Meijerhof, 2020). This step describes the societal problems and potential solutions related to the Green Deal 2.0 by explaining the concepts of problem directionality and solution directionality. Problem directionality refers to "the way the different societal problems are included and prioritised in the mission formulation" (Wesseling & Meijerhof, 2020, p. 6). Solution directionality refers to "those factors that determine how stakeholders search for and

invest in the solutions they deem promising for fulfilling the mission" (Wesseling & Meijerhof, 2020, p. 6). The focus in this step is especially on exploring and mapping the multiple existing circular PPE alternatives related to the Green Deal 2.0 and discussing how these solutions interrelate. Furthermore, this step also examines which circular strategies have been applied per circular PPE solution. The identification of the circular strategy will give a clear indication which solutions require a fundamental rethinking of the product and behavioural change of the users, and which solutions are less technologically oriented and require less system change (Kirchherr et al., 2017).

The second step identifies and maps out the structural components of the MIS. The structural components include the actors, institutions and networks that are involved in the circular PPE alternatives. In the structural analysis, a distinction is made between the overall structural components of the MIS and the components of the mission arena. The mission arena includes those actors that are engaged in the process of providing directionality to the MIS. These actors are for instance actively involved in the formulation of the Green Deal 2.0, the mobilisation of MIS components, or mission government by means of monitoring, coordination and evaluation (Wesseling & Meijerhof, 2020). However, it is important to understand that the mission arena consists only of a limited group of actors, while the performance of a MIS depends on a larger group of actors, including industrial actors and users that develop, diffuse and adopt the circular PPE alternatives. Furthermore, the institutional structures underlying the Green Deal 2.0 need to be identified and evaluated to see if these are well aligned with the institutional structures of the existing healthcare system.

The third step evaluates the performance of the functioning of the MIS by assessing the key innovation activities, known as 'system functions'. These system functions were developed to study a technological innovation system (TIS). Consequently, the system functions should be altered in order to be applied to the MIS, containing multiple alternatives that are interrelated, which is not accounted for by the TIS system functions. The system functions to assess a MIS are summarised in table 1. Specific indicators per system function of transformation to circular PPE alternatives in the Dutch academic hospitals are discussed in the methodology.

Table 1: System functions for MIS analysis (Wieczorek & Hekkert, 2012; Wesseling & Meijerhof, 2020; Elzinga et al., 2021)

System Function	MIS interpretation
F1: Entrepreneurial activities	Experiments to develop circular PPE alternatives to enable learning. Entering markets for new circular PPE alternatives. Upscaling new business models and phasing out of existing business models that obstruct the completion of the Green Deal 2.0 mission.
F2: Knowledge development	Learning by searching and doing resulting in new technical and socio-institutional knowledge to develop circular PPE solution directions through R&D, social and behavioural science research. It also includes phasing out knowledge development projects, research centres and networks that are hindering the Green Deal 2.0 mission.
F3: Knowledge diffusion	The dissemination of technical knowledge on the negative impacts of single-use PPE and

	on the circular PPE alternatives between actors in the form of stakeholder meetings, conferences, public consultations and mission progress.
F4a: Problem directionality	Actions with the goal of creating consensus regarding the urgency of the Green Deal 2.0 and the level of prioritisation over other societal problems.
F4b: Solution directionality	Actions with the goal of providing insight into possible circular PPE alternatives, aligning expectations regarding these alternatives, and providing strategies to converge around solution directions.
F4c: Reflexivity	Monitoring progress and potential of circular PPE alternatives to coordinate and structure solution directions.
F5: Market formation	The creation of (niche) markets and upscaling demand/support for circular PPE alternatives. It also includes diminishing support and destabilising markets for existing practices that are harmful to the Green Deal 2.0 mission.
F6: Resources mobilisation	Mobilisation of financial, human, material and infrastructural resources to enable all other system functions.
F7: Creation of legitimacy	The creation of a supportive socio-institutional environment for circular PPE alternatives that contribute to mission completion, through raising awareness for the Green Deal 2.0 mission and the circular PPE alternatives and lobbying for resources and supportive policies in line with this mission. Also includes lobbying for the reduction of support and phase out of practices that obstruct mission completion.

The fourth step identifies the systemic barriers of the MIS. Systemic barriers are structural components that are missing or unable to support the system functions in relation to the system functions they influence (Marsman, 2021). The systemic barriers are analysed by finding the underlying roots causing the system function to perform poorly. The goal of this step is to identify how the different systemic barriers are interrelated and if this results in a systemic lock-in.

The last step of the MIS framework is the identification of systemic instruments, which are policy interventions, that can overcome the identified systemic barriers. These systemic instruments should be focused on stimulating weak system functions or removing systemic barriers that prohibit the adequate functioning of the MIS (Hekkert et al., 2007).

3. Methodology

This section elaborates on the selected research design, data collection methods, data analysis, and the research quality and ethical considerations.

3.1 Research design

The aim of this research is to identify and understand the systemic barriers to the transition from single-use PPE towards circular PPE alternatives. Understanding these systemic barriers and selecting appropriate systemic instruments to address them will contribute to the Green Deal 2.0 mission of achieving a fully circular healthcare by 2030 in the Netherlands.

This research uses a qualitative embedded case study design to achieve the research aim. An embedded case study design examines more than one case and thus has multiple units of analysis (DePoy & Gitlin, 2016). In this research, the main units of analysis are the circular PPE alternatives. The specific units of analysis are chosen in the problem-solution diagnosis, in which the most impactful and potentially successful circular PPE alternatives have been selected.

The transition towards circular PPE alternatives is examined in the context of the Dutch healthcare sector. The geographical scope of the Netherlands is chosen as the circularity issues within the Dutch healthcare sector is an upcoming topic and the needed data for the research within this scope is adequately accessible. In this research, the Dutch healthcare sector is represented by examining the eight academic hospitals in the Netherlands. The academic hospitals are chosen as the scope of the research as these hospitals entail a combination of practising care, education and research, which potentially stimulate the development of circular PPE innovations. Therefore, the academic hospitals are considered to be a large source of relevant data to study the transition towards circular PPE alternatives, which are ultimately used and implemented by these academic hospitals.

The research focuses on technological circular PPE alternatives that are at least in the pre-development phase, with a research scope from 2016 until the present. The pre-development phase is the first of five development phases, which is developed by Hekkert et al. (2011). In this phase, the prototype of the circular PPE alternatives is being developed. This development phase is chosen as this research also wants to include circular PPE alternatives that are only at the beginning of their development but could have a very high potential. The research scope from 2018 has been chosen, as the Green Deal 2.0 has been formulated in 2018 in the Netherlands.

3.2 Data collection

The data necessary to carry out a MIS study (including the five MIS steps) is collected through three different methods: namely, literature research, a Lexis-Nexis study of media in the period 2016-now, and semi-structured interviews with relevant actors that are active in the circular PPE innovation system. The collected data through literature research is especially important in the structural system analysis, functional system analysis and identification of systemic instruments. The data collected through literature research has mainly extracted data from academic literature, policy documents and industry reports. These documents have been accessed through scientific databases including Google Scholar, Scopus and Web of Science. The required data was searched by using the following search terms, individually and in combination with each other: “innovation”, “personal protective equipment”, “healthcare”,

"circular", "innovation", "barriers", "recycling" and "reusable". The terms have also been searched in Dutch to access Dutch documents.

Another method for the collection of relevant data is done through Lexis-Nexis. Lexis-Nexis is a database that has access to a variety of publicly available information, public records, and non-public information (LexisNexis, n.d.). The database gives the opportunity to collect data from national and regional papers, newsmagazines, websites, social media, press-releases, blogs and forums. This data collection method is important as many new PPE alternatives could be mentioned in the previous sources, but not yet in published academic articles. This is especially relevant for PPE alternatives that are in the take-of phase of their development. Therefore, the Lexis-Nexis study has been especially relevant in the problem-solution diagnosis and the functional system analysis. The same search terms as in the literature research have been used to acquire data through Lexis-Nexis.

The other data was collected by conducting semi-structured interviews with relevant actors in the circular PPE innovation system. These actors include hospital staff using PPE, sustainability managers, hospital board members, procurement managers, circular PPE manufacturers, knowledge institutes, universities, and employees within the Ministry of Health, Welfare and Sport (VWS) influencing innovation by the introduction of laws and regulations. More specific actors have been reached through snowball sampling, where contact has been established with other relevant interviewees through initial contact with the first interviewees (Bryman, 2012). The data collection through interviews has been especially important in the first four steps of the MIS.

In total 21 interviews were conducted using a semi-structured approach. Each interview lasted between 40-60 minutes. During the interviews, an interview guide was followed containing standard questions, but the interviewer was free to deviate and ask further questions when a topic was considered relevant (Bryman, 2012). The interview guide can be found in Appendix A. A combination of purposive sampling and snowball sampling has been used in this research. Purposive sampling entails that participants are sampled in a strategic way, so that those interviewed are relevant to the research topic (Bryman, 2012). Snowball sampling entails that the initial interviewed participants proposed other participants that are relevant to the research. First, interviews have been conducted with key staff within the academic hospitals involved in circularity, such as the sustainability manager. Thereafter, other relevant interviewees were contacted through snowball sampling. The interviewees are summarised in table 2, by stating their function, organisation and the date of consultation. Each interviewee has been assigned an interview code, which is used in the results and analysis to refer to this interviewee. Table 3 gives an overview of the data collection methods in each MIS step.

Table 2: Overview of interviewees with organisation, interview code and date of consultation

Function description	Organisation	Interview Code	Date of consultation
Sustainability Policy Advisor	RadboudUMC	SPA1	02/03/2022
Manager Central Sterilisation	Leiden UMC	MCS1	24/03/2022
Sustainability Program Manager 1	UMC Groningen	SPM1	09/03/2022

Sustainability Program Manager 2	Intrakoop[6]	SPM2	18/05/2022
Purchasing/Product Manager 1	Intrakoop	PM1	18/05/2022
Purchasing/Product Manager 2	Intrakoop	PM2	18/05/2022
Consultant Medical Devices	Intrakoop	CMD1	18/05/2022
Manager LCH	Landelijk Consortium Hulpmiddelen [7]	LCH1	23/03/2022
Strategic Consultant LCH	Landelijk Consortium Hulpmiddelen	LCH2	23/03/2022
Manager CSA 1	Erasmus MC	CSA1	09/03/2022
Circularity Researcher	TU Delft	CR1	21/03/2022
Program Secretary Sustainable Care	Ministry of VWS	PSSC1	23/03/2022
Circular PPE Producer	TenCate Fabrics[8]	CP1	07/03/2022
Strategic Environmental Expert	UMC Utrecht	SEE1	10/03/2022
Commercial Manager	3M[9]	CM1	23/05/2022
Manger CSA 2	UMC Utrecht	CS2	23/05/2022
Expert Sterile Medical Equipment	Vereniging van Deskundigen Steriele Medische Hulpmiddelen	EME1	25/05/2022
Strategic Procurement	Erasmus MC	SP1	25/05/2022
Staf Anesthesist	Leiden UMC	SA1	25/05/2022
Infection Prevention Expert	Tensen & Nolte[10]	IPE1	03/06/2022
Senior Advisor Procurement	UMC Utrecht	SAP1	03/06/2022

Table 3: Data collection method per MIS step

MIS Step	Data collection method
Problem solution diagnosis	Academic literature Lexis-Nexis study Interviews with circular PPE manufacturers, health care workers and hospital board members
Structural system analysis	Academic literature Policy documents

[6] Intrakoop is a procurement cooperative for the healthcare sector in the Netherlands (Intrakoop, n.d.)

[7] a Dutch consortium in charge of the nationwide procurement and distribution of medical aid and protective equipment at the time of the corona crisis in the Netherlands (Rijksoverheid, n.d.)

[8] TenCate Protective Fabrics is a leading global manufacturer of protective clothing for the military, fire service and specialist professions (TenCate Fabrics, n.d.)

[9] 3M is a multinational company operating in the fields of industry, worker safety and health care (3M, n.d.)

[10] Tensen & Nolte is a company that provides support to health care institutions, training institutes and professional organisations in the field of infection prevention (Tensen & Nolte, n.d.)

Functional system analysis	Academic literature Policy documents Industry reports and websites Lexis-Nexis study Interviews with relevant actors
Systemic barrier analysis	Academic literature Industry reports Interview with all relevant actors
Identification of systemic instruments	Academic literature Policy documents

3.3 Data analysis

After conducting and recording the interviews, the recordings were transcribed. Thereafter, the transcripts were coded using Nvivo. Nvivo is a software program that can be used for the analysis of qualitative texts (KSU, 2022). First, open coding was applied to the interviews, in which specific fragments were labelled. Thereafter, selective coding was applied by assigning the codes created through open coding to pre-existing categories (Bryman, 2012). The pre-existing categories are the nine system functions.

In this research, the system functions serve as criteria that determine how well an innovation system is functioning in terms of transitioning to circular PPE alternatives and thereby contributing to the Green Deal. Therefore, the functional system analysis is an important step. The system functions are operationalized by assigning specific indicators to them, which enables the analysis of the MIS and the identification of weak system functions and barriers. Table 4 gives the operationalization of the system functions. The indicators of the system functions for the MIS analysis are adapted from Hekkert et al. (2011) and Elzinga et al. (2020).

The barriers blocking the transition towards circular PPE alternatives are identified in the system function analysis (step 3). After the interviews and coding process, an extra validation step was performed to identify the systemic barriers. This was done by sharing the list of the identified barriers with six experts, who were asked to select a top three of the largest barriers from their perspective. The six experts include a sustainability policy manager, program secretary of PDZ, sustainability program manager, two procurement managers and an anaesthetist. These specific experts were chosen as they represent the key MIS actors that were identified in the structural analysis. This validation step resulted in the identification of seven barriers, which have been categorised into four systemic barriers. These systemic barriers are analysed in detail in the systemic barrier analysis (step 4).

Table 4: Indicators per system function (Hekkert et al., 2011; Elzinga et al., 2020)

System Function	**Indicators**
F1: Entrepreneurial activities	Experiments to develop circular PPE alternatives. New business models supporting reusing PPE.
F2: Knowledge development	R&D projects related to circular PPE. Investment in R&D. Publications on circular PPE alternatives.

F3: Knowledge diffusion	Presence of stakeholder meetings, conferences, mission progress and network activities dedicated to the transition towards circular PPE.
F4a: Problem directionality	Presence of acknowledging the waste problem caused by single-use PPE in the academic hospitals, research institutes, PPE manufacturers. The degree to which the problem is on the agenda.
F4b: Solution directionality	Expectations in the field on circular PPE alternatives. Presence of stimulating regulations and institutions for circular PPE alternatives.
F4c: Reflexivity	Presence of a monitoring organisation evaluating progress towards the transition to circular PPE and contributing to the Green Deal 2.0.
F5: Market formation	Presence of regulations/institutions that oblige or stimulate to apply circular PPE alternatives. Presence of niche markets.
F6: Resources mobilisation	Availability of financial and human resources (through governments or companies) for innovation, research, pilots and investments in circular PPE alternatives. Availability of raw materials and infrastructure to produce circular PPE alternatives.
F7: Creation of legitimacy	Presence of the MIS stakeholder's support for the transition towards circular PPE alternatives. Presence of interest groups advocating against circular PPE alternatives.

3.4 Research quality: validity and reliability

In this research, data was collected through multiple methods including a literature study, Lexis-Nexis, and conducting interviews. This triangulation of data sources increases the internal validity of the research, as the findings from one data collection method have been validated by another method. It is difficult to achieve external validity because of the qualitative nature of the research design (Bryman, 2012). However, the research design entails examining multiple circular PPE alternatives in-depth with a research scope of eight academic hospitals in the Netherlands. This increases the external validity because the findings of the research can be generalised to all Dutch academic hospitals and to other Dutch hospitals that are similar to them. Furthermore, the validity of the results is enhanced by the additional validation step, in which six experts prioritised the identified barriers resulting in the categorisation of the systemic barriers. It is also difficult to achieve external reliability in this qualitative research as it is not possible to reproduce the findings under the exact same conditions (LeCompte & Goetz,

1982). However, the reliability has been increased by describing each step of the analytical framework in detail to enable other researchers to replicate the research (Bryman, 2012).

3.5 Ethical considerations

Before conducting each interview, the interviewees were asked to give their permission for the interview to be recorded, transcribed and used for the findings of the research. Furthermore, the interviewees remained anonymous in terms of name, organisation and other recognizable characteristics. Due to the Covid-19 pandemic, the interviews were conducted digitally or in a space where 1.5 m distance was maintained during the interview.

4. Results

The results section presents the first three steps of the MIS as described in the theory and methodology. The last two steps of the MIS are presented in the analysis section as these steps address the underlying dynamics of the MIS that cause the barriers. Firstly, the problems and alternatives related to disposable PPE are discussed. Secondly, the actors, networks, and institutions involved in the MIS are mapped out. Thereafter, the system functions are analysed and evaluated on the basis of interview data and literature.

4.1 Problem-solution diagnosis

This step discusses the societal problems and potential solutions related to the Green Deal 2.0. First, the concept of problem directionality is outlined by explaining how the different societal problems are included and prioritised in the mission formulation. Thereafter, the concept of solution directionality is discussed by mapping the existing circular PPE alternatives.

4.1.1 Problem directionality

Healthcare is an essential and indispensable sector of society. The healthcare sector is growing tremendously due to an exponentially growing population getting access to healthcare and due to an ageing population with a significantly longer life expectancy (Haseltine, 2018). These factors cause the healthcare systems to face significant challenges and increase the need for high amounts of energy, materials and water (Samah et al., 2020). This increasing need is translated into an enormous amount of CO_2 pollution and an accumulation of medical waste. Research conducted by Gupta Strategists (2019) showed that the Dutch healthcare sector is responsible for 11 Mton CO_2 per year, which is equal to 7% of the total CO_2-emissions of the Netherlands. Furthermore, an average Dutch hospital produces 430.000 kg of waste on a yearly basis (iPH, 2022). Moreover, most of the Dutch hospital waste ends up unsorted in the incinerators of waste processors, from which at best electricity is created by burning it (Kleijne, 2021). The severeness of the medical waste problem was especially exposed during the Covid-19 crisis, which greatly accelerated the discard of personal protective equipment. To tackle the problem of the growing sustainability impact of the healthcare sector, the Green Deal Duurzame Zorg was formulated in the Netherlands in 2014. This was succeeded by the Green Deal 2.0 which was signed in 2018 by more than 300 parties (MPZ, n.d.).

The overarching goal of the Green Deal 2.0 is to contribute to counteracting climate and environmental impacts and to contribute to the transition to a sustainable society. The ambitions of the Green Deal 2.0 are divided into 4 themes:

1. Reducing CO2 emissions from the healthcare sector
2. Promoting a circular way of working
3. Reducing the amount of medicine residues in surface water and groundwater
4. Creating a health-promoting living environment in and outside healthcare institutions

Until now, the focus has been clearly on the first theme. This is mainly caused due to the fact that this is the only theme that has formulated concrete goals to achieve its ambition. The goal of the first theme is to reduce the amount of CO_2 emissions with 49% by 2030 compared to 1990 (Green Deal, 2019). Furthermore, the healthcare sector should be climate neutral by 2050. The other themes have not yet been developed into concrete goals. However, there is an overarching goal set up by the Dutch government that is related to the second theme. The goal is to use 50% less raw materials in 2030 and to achieve a fully circular economy by 2050 in the Netherlands (Rijksoverheid, n.d.). Bureau Bartels, an independent organisation, has evaluated

the Green Deal 2.0 and has, among other things, investigated which themes the participating organizations[11] have been working on. Figure 3 shows that most organisations are actively focusing on the first theme followed by a strong emphasis on the second theme. The focus of this research is solely on the second pillar promoting a circular way of working in Dutch academic hospitals, with the main focus on the transition towards the use of circular PPE.

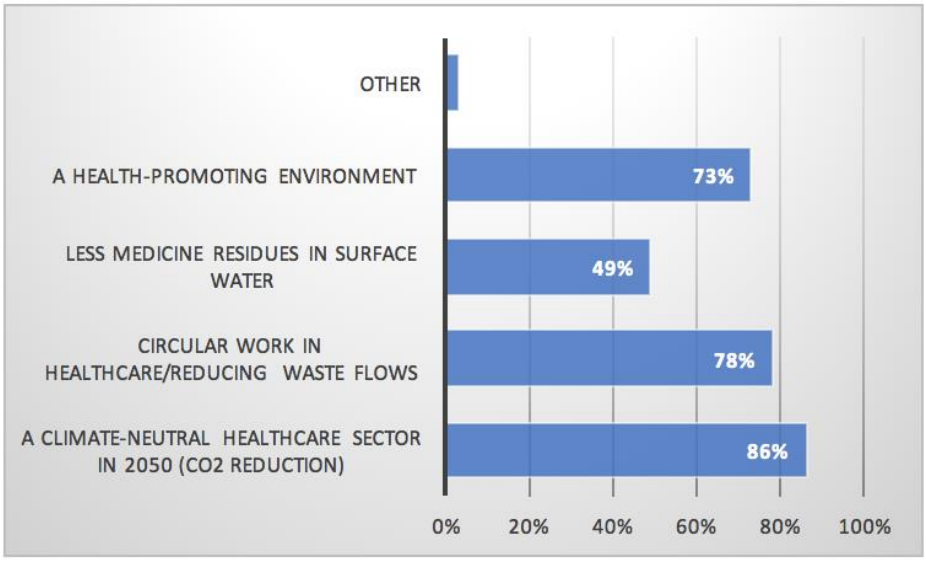


Figure 3: Focus of participating organisations (n=59) of the Green Deal 2.0 (Adapted from "Evaluatie Green Deal Duurzame Zorg," by Bureau Bartels, 2021, p. 18.)

4.1.2 Solution directionality

In this research, personal protective equipment (PPE) includes gowns, face masks, gloves, face shields and goggles. The state of the technological readiness of the circular alternatives and the applied circular strategies are discussed individually per equipment.

4.1.2.1 Isolation gowns

The main purpose of an isolation gown is to shield the employee against exposure to bodily fluids that can potentially transmit pathogens (FDA, 2021). Most isolation gowns are disposables and are produced using different plastic materials such as polypropylene and polyethylene (ICU Production, 2021). There are already some circular alternatives on the market in the Netherlands. For example, CleanLease produced a reusable isolation gown consisting of 99% polyester filament and 1% carbon craft (CleanLease, 2020). The product complies with the EN 13795-1[12] standard and is therefore certified to be used on the intensive care. The gown is also suitable to be recycled, after being reused numerous times (Reflow, n.d.). Cleanlease used an EcoTool to compare the environmental impact of the reusable isolation

[11] The respondents of this study are people who are involved in the Green Deal from a more general perspective. They are people from organisations involved in the Programma Duurzame Zorg (sectoral organisations and knowledge partners) (Bureau Bartels, 2021)

[12] The EN 13795-1 standard specifies information on the characteristics of single-use and reusable surgical gowns and surgical drapes used as medical devices for patients, clinical staff and equipment, intended to prevent the transmission of infective agents between clinical staff and patients during surgical and other invasive procedures (NEN, 2021)

gowns with the disposable isolation gowns. The results of this calculation can be seen in figure 4, wherein the comparison is made between cleaning the reusable isolation gown 100 times and the use of 100 disposable gowns. The results show that significantly less energy is required with the use of the reusable isolation gown, which also results in a significantly lower CO_2 production (37.1 Kg CO_2). Moreover, a life cycle assessment financed by the American Reusable Textile Association (ARTA) showed that the transition to reusable isolation gowns will result in an 84-87% reduction in medical waste (CleanLease, 2020).

ABN AMRO and the Amsterdam Economic Board have investigated the possibilities to switch to reusable alternatives for the isolation gown. Among others, the municipalities of Amsterdam and Haarlem, a water company, a laundry company and healthcare organisations were involved in this project. Two reusable isolation gowns have emerged from this collaboration. One isolation gown is made from cotton which can be reused a minimum of 70 times and one isolation gown is made from polyester which can be reused 100 times (Reflow, n.d.). The reusable isolation gowns reduce the amount of medical waste production by up to 15 percent (van Balen, 2021). The polyester gown last longer which results in the lowest CO_2 production, while the advantage of the cotton gown is that it is more comfortable to wear and that no micro-plastics are released into the environment during washing. Furthermore, Dutch organisations, such as HAVEP, TNO, Rentex and Springendal, have also developed reusable isolation gowns (Eppinga, 2021) (Willemsen, 2021). There can be concluded that there are adequate circular alternatives to the disposable isolation gown on the market indicating a high level of technological readiness. In terms of circularity strategies (9Rs), the circular alternatives to the disposable isolation gown decrease the consumption of materials by less products being needed for delivering the same function (R0), it can be reused for the same purpose (R3), and it can eventually be recycled at the end of its life cycle (R8).

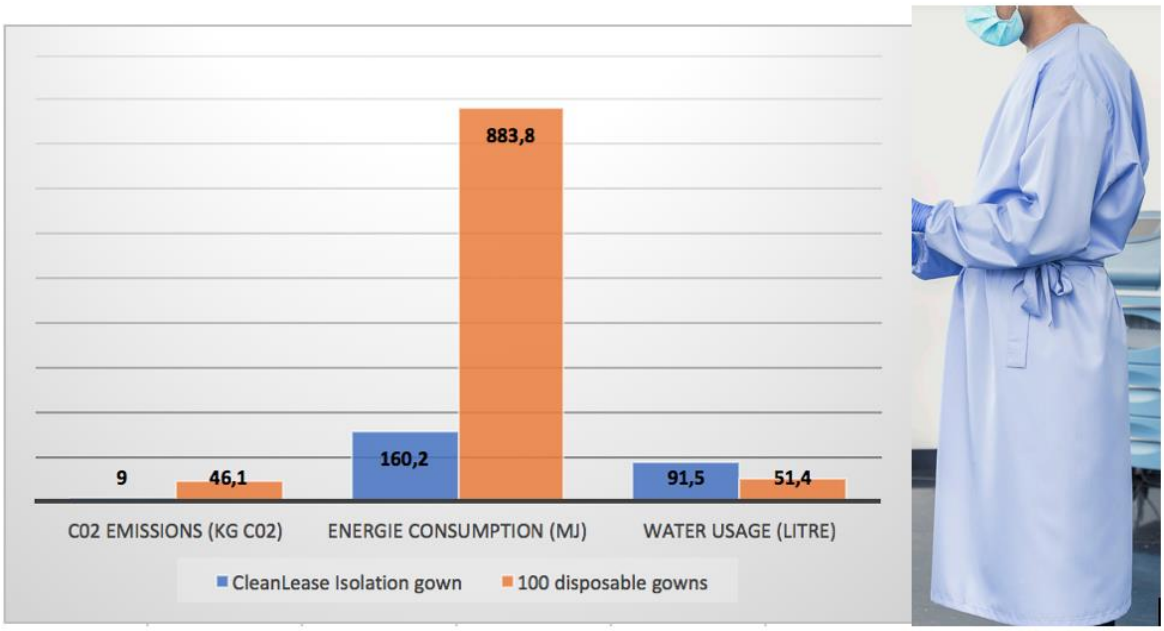


Figure 4: Environmental impact comparison between one CleanLease isolation gown and 100 disposable gowns. Adapted from "Comfortabele, Duurzame en herbruikbare isolatiejas" by CleanLease, 2020, p. 4

4.1.2.2 Face masks

FFP1, FFP2 and IIR[13] mouth masks are used in the intensive care units of Dutch hospitals. The difference in these masks lies in the bacteria filter efficiency, which is the lowest in FFP1 and the highest in IIR (WALO, n.d.). Furthermore, the IIR mouth mask is the only type that is splash resistant. Currently, these mouth masks are disposable as they are thrown away after use. In the case of circular face masks, there are no alternatives to disposable face masks but there is a new processing technique to collect used FFP1 and FFP2 masks from hospitals, sterilise them and return them as reusable masks (Renewi, 2020). This sterilising process to reuse face masks is developed by Van Straten Medical/GreenCycl in collaboration with Renewi and TU Delft in 2019. Renewi collects the used mouth caps and delivers them to GreenCycl. At GreenCycl the masks are sterilised using steam at 121 degrees. This new sterilisation procedure is different as it uses a lower temperature and takes a longer duration, which ensures that the masks remain intact (Wassink, 2022). The reused mouth masks have been tested on permeability. The results of these tests have shown that the filter capacity of the reused face masks remains above the limit of 94% (Renewi, 2020). The steam sterilisation method has also been approved by the RIVM. A major advantage of this new sterilisation procedure for face masks is that it can be implemented immediately at a large scale. This is the case as every hospital already has the necessary equipment to perform the sterilisation procedure. In terms of circularity strategies (9Rs), this circular alternative can be reused for the same purpose (R3) and can be recycled at the end of its life cycle (R8).

4.1.2.3 Gloves

Gloves are one of the most purchased types of PPE in an average hospital (Evans, 2022). In 2020, Erasmus MC used over 15.6 million disposable medical gloves (Kuijpers & Lamens, 2020). Consequently, gloves account for a huge share of the total medical waste produced by Dutch academic hospitals. This is mainly caused by a large part by its unnecessary overuse as HCWs use gloves very often in low-risk conditions out of habit or fear of infection (Schmidt, 2022). This is confirmed by interviewee MSCA2, who observes that gloves are used much more often in practice than is required by the guidelines of infection prevention. In the health care sector, only disposable medical gloves are available and can be made from plastic, latex, nitrile, or vinyl (Lurvink, 2020). These gloves can be recycled as long as they are not contaminated (Joseph et al., 2021). Another option is to retrieve energy through incineration (Siwal et al., 2021).

Various research argued that gloves should be changed between patients and cannot be disinfected and reused (Kampf, 2020; Lauer et al., 2020). Furthermore, WHO (2009) also discouraged the reuse of medical gloves in their latest guideline on hand hygiene in healthcare. However, new disinfection methods are developed to enable the reuse of medical gloves. A study by Esmizadeh (2020) found three different disinfection treatments that allow the reuse of medical gloves. These three treatments include disinfection by alcohol, UV and heat and allow the reuse of the gloves up to 20 cycles. This is a promising solution to make medical gloves more circular. However, further research is required to "ensure the proper functioning of medical gloves according to the existing protocols prior to the official recommendation for clinical reuse of medical gloves" (Esmizadeh, 2020, p. 452). Another solution that can reduce the amount of PPE waste is the use of biodegradable gloves. These biodegradable gloves have

[13] FFP stands for Filtering Facepiece Particle. The added number (1 or 2) expresses how strongly the inhaled air is filtered. Type IIR Face masks include a splash resistant layer to protect against blood and other bodily fluids. (Aarts, 2020).

been on the market for a decade and achieve biodegradation of 82.0% within 400 days, while normal gloves only achieve 1.9% over the same time period (SHOWA, 2018). To summarise, there is no fully circular alternative to disposable medical gloves on the market. However, research is carried out on different disinfection treatments allowing the reuse of medical gloves and biodegradable medical gloves are available on the market. In terms of circularity strategies (9Rs), this circular alternative can be recycled at the end of its life cycle (R8) or be incinerated to retrieve energy (R9).

4.1.2.4 Face shields & goggles

Most medical goggles are designed to be reused. Furthermore, both reusable and disposable face shields are available on the market (Patterson, 2020). According to Perencevich et al. (2020), both glasses and face shields are easily cleaned and can be used indefinitely. As a reaction to the shortage of PPE, WHO developed a reprocessing method for face shields and goggles. After the use of the face shields and goggles, they should be cleaned "with soap/detergent and water followed by disinfection using either sodium hypochlorite 0.1% (followed by rinsing with clean water) or 70% alcohol wipes" (WHO, 2020, p. 15). Furthermore, Armijo et al. (2021) presented a protocol for producing face shields using 3D printing including an effective decontamination protocol enabling their safe reuse. The decontamination protocol utilises a dilute bleach solution and achieves a 99.99% reduction in bacterial suspensions. To summarise, face shields and medical goggles can effectively be reused and are considered an adequate circular alternative to disposables. In terms of circularity strategies (9Rs), these circular alternatives can be reused for the same purpose (R3), and can eventually be recycled at the end of their life cycle (R8).

4.2 Structural Analysis

This step identifies and maps out the structural components surrounding the MIS of the circular mission of the Green Deal 2.0, which influence the development, adoption and diffusion of circular PPE alternatives. First, the structure of the Green Deal 2.0 is outlined by mapping the mission arena, other MIS actors and important networks. Thereafter, the institutional structures underlying the Green Deal 2.0 are discussed.

4.2.1 The Mission Arena

The Dutch national government is responsible to facilitate the implementation of the Green Deal 2.0. A specific programme has been set up for this task called the Programma Duurzame Zorg (PDZ) which falls under the Ministry of Health, Welfare and Sport (VWS). PDZ is responsible for the decision-making in the mission arena and for setting up activities that are linked to the following missions (Bureau Bartels, 2022):

- Enlarging the awareness of the impact of the healthcare sector on the climate and the environment.
- Inspiring and stimulating organizations and healthcare professionals to actively contribute to sustainability.
- Offering perspective for action to make the healthcare sector more sustainable.
- Securing the Green Deal 2.0 initiatives and scaling up successful pilots and experiments.

PDZ is supported by several interbranch organisations in the healthcare sector including Actiz, Nederlandse Federatie Universitair Medische Centra (NFU), de Nederlandse GGZ, Nederlandse Vereniging van Banken (NVB), Nederlandse Vereniging van Ziekenhuizen (NVZ) and Zorgverzekeraars Nederlands (ZN). These organisations are also responsible for stimulating, supporting and facilitating parties that have signed the Green Deal 2.0. Furthermore, they translate the demand for sustainability and circularity in health care organisation into a perspective for action. In 2018, 132 parties signed the Green Deal 2.0 (van Houtum, 2022). Currently over 300 parties have agreed to make the healthcare more sustainable by signing the Green Deal 2.0 (MPZ, n.d.)

There is also a Roundtable, initiated by the Ministry of VWS, specifically focused on circular healthcare since 2018. This roundtable's mission is to stimulate circularity in the healthcare sector and to develop and disseminate knowledge around this topic. This Roundtable includes among others Milieu Platform Zorg (MPZ), Rijksinstituut voor Volksgezondheid en Milieu (RIVM), Stichting Koninklijk Nederlands Normalisatie Instituut (NEN) and Intrakoop (MPZ, n.d.)

4.2.2 Overall MIS

When the parties sign the Green Deal 2.0, they confirm that they want to contribute to making healthcare more sustainable by writing down their own goals in a pledge (Bureau Bartels, 2022). This pledge is based on one of the 4 themes of the Green Deal 2.0 (see page 22). These parties include healthcare providers, municipalities, banks, interbranch organisations and health insurers (MPZ, n.d.). Furthermore, the other overall MIS components consist of universities, circular and disposable PPE manufacturers, HCWs and hospital procurement employees. These MIS components are mobilised by the structural components within the mission arena (Wesseling & Meijerhof, 2020). This mobilisation of structural components is translated through the implementation of different activities and instruments. These include a yearly

congress on sustainable healthcare, knowledge development and diffusion through Milieu Platform Zorg, RIVM, webinars and a Green Deal 2.0 newsletter (Bureau Bartels, 2022).

By means of the Green Deal 2.0, the Dutch government and the mission arena strive "to remove obstacles that parties experience, for example by solving bottlenecks in legislation and regulations, creating new markets, providing good information and ensuring optimal partnerships" (Bureau Bartels, 2022, p. 4). However, in practice the main influence of the Green Deal 2.0 lies in enlarging the awareness among relevant organisations of the urgency of making the healthcare sector more circular and sustainable (van Houtum, 2022). This is emphasized by the Programme Secretary at PDZ (PSSC1), who states that the current goal of the Green Deal 2.0 is raising awareness, agenda-setting and driving this movement by involving and reaching as many organisations as possible.

4.2.3 Networks

There are two important platforms dedicated to the mission of the Green Deal 2.0 in the Netherlands; Het Landelijk Netwerk de Groene OK[14] and De Groene Zorg Alliantie. Groene OK stimulates and supports individual healthcare professionals who work in the OR to work in a sustainable manner (de Groene OK, 2021). There are 15 associations of which one or more representatives are affiliated with the Groene OK. The platform arranges meetings and events, in which specialists and care professionals are connected with each other and encouraged to provide sustainable and circular care in the OR.

The Groene Zorg Alliantie acts as a knowledge and network platform that strives for a climate-neutral, circular healthcare sector in the Netherlands (MPZ, n.d.). This is achieved by setting up so-called Green Teams. Green Teams are teams consisting of medical specialists who are, besides their primary work, focused on making their department more sustainable and circular. The creation of Green Teams enables the opportunity to identify working methods and processes where CO_2 gains or implementation of circularity can be achieved. Furthermore, by sharing this knowledge and experiences, these initiatives can be further developed and implemented in other hospital departments and Dutch hospitals (Friedericy et al., 2020).

4.2.4 Institutional structure

The institutions within the MIS are organized by rules, regulations and norms (hard institutions) and encompass a set of habits, routines and established practices (soft institutions) (Wieczorek & Hekkert, 2012). Wearing PPE falls under the Arbowet[15] and is an infection prevention measure. The hard institutions related to PPE are represented in a guideline with general precautions developed by the Working group Infection Prevention (WIP). This general guideline contains a specific guideline for PPE use in hospitals, which describes how the risk of the transmission of micro-organisms can be reduced by wearing personal protective equipment by employees (RIVM, 2015). The guideline outlines that each PPE contains specific NEN standards, which describe the general requirements and test procedures each PPE must comply with. Currently, the guideline states that disposable PPE should be disposed of as regular waste in accordance with the waste policy of the institution (RIVM, 2015). Furthermore, five interviewees identify the current infection prevention (IP) guidelines as a serious barrier for the introduction of circular PPE alternatives. The guidelines are considered to be too strict and prefer the use of disposable PPE because of the associated low risk of infection. Interviewee

[14] referred to as Groene OK

[15] The Arbowet is a Dutch law that contains rules for employers and employees to promote the health, safety and well-being of employees and self-employed entrepreneurs (Rijksoverheid, n.d.)

IPE1 states that the current IP-guidelines are outdated and that they are in need of replacement. In 2021, the existing guidelines of the former Working Party on Infection Prevention (WIP) are revised and new guidelines will be introduced in the coming years (VHIG[16], n.d.).

Another important standard related to the use of PPE is the associated Conformité Européenne (CE) marking. All PPE that is placed on the European market should have a CE-marking. The CE-marking indicates that a product meets the minimum requirements for safety, health and the environment that are stated in the European directive for the relevant product group (RIVM, 2015). Therefore, it is essential for circular PPE manufacturers to obtain this CE-marking to compete with disposable PPEs.

The soft institutions include the habits, working routines and established practices of the hospital employees. A clear barrier is the habit of these employees of discarding the PPE after single-use or switching them between each patient (SA1). Interviewee IPE1 confirms this by stating that often PPE is used, especially gloves, even when this is not recommended in the WIP guideline. Wesseling & Meijerhof (2020) emphasize that in order to effectively initiate the development and diffusion of innovation contributing to a mission, the institutional structures underlying the mission should be well aligned with the existing system structures. In this case, in order for the institutional structure to align with the existing system structure, the circular PPE innovations should comply with the necessary NEN-standards, obtain the necessary CE-markings and overcome the lock-in of the current habits and routines. The structural analysis of the MIS related to the circular mission of the Green Deal 2.0 focused on circular PPE alternatives is visualised in figure 5 including the mission arena, overall MIS, networks and institutions.

[16] Vereniging voor Hygiëne en Infectiepreventie in de Gezondheidszorg (VHIG) is the professional association for infection prevention experts.

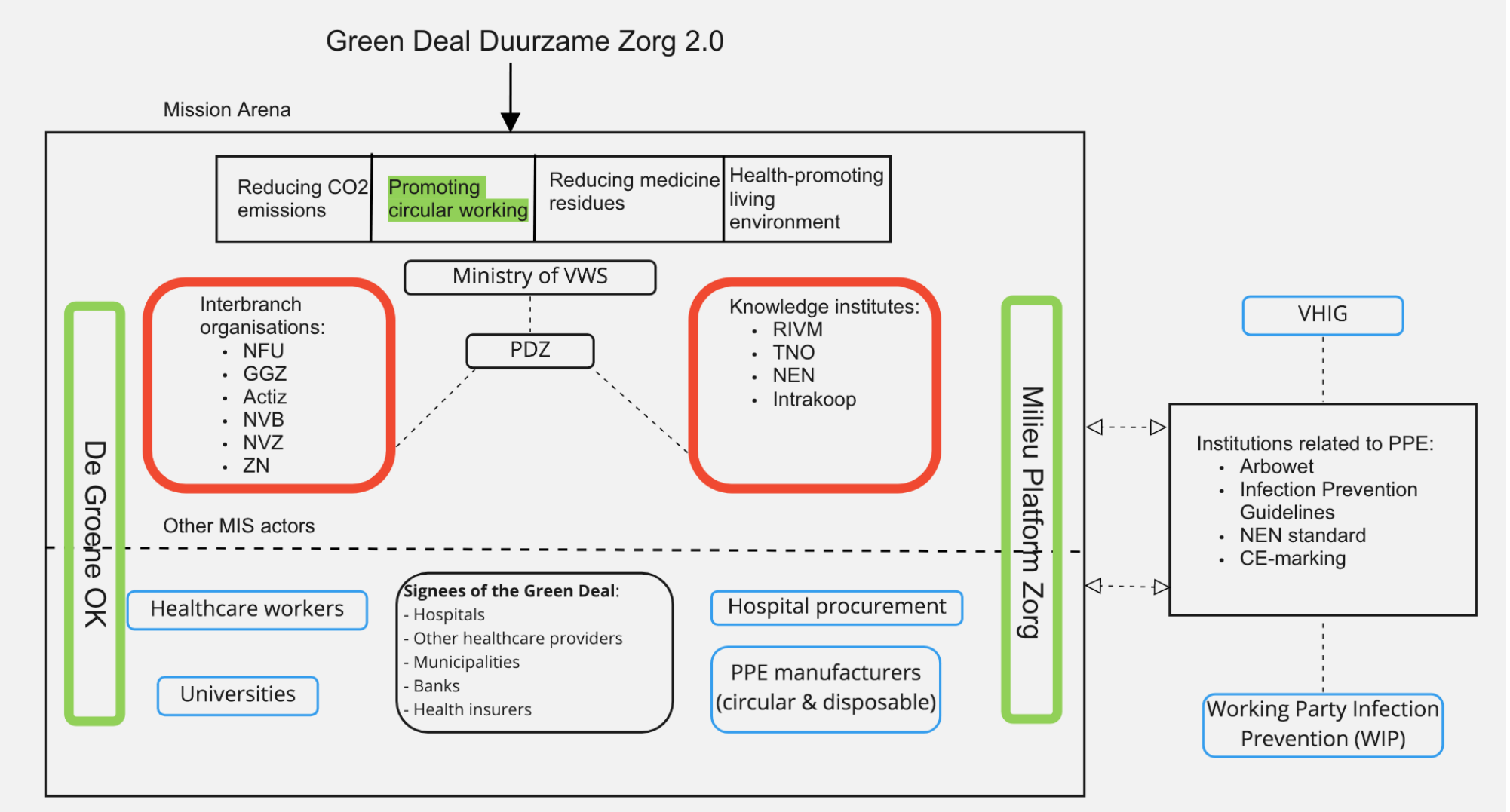


Figure 5: Visualisation of the structural analysis of the MIS including the mission arena, overall MIS, networks and institutions

4.3 Functional System Analysis

This step analyses the functioning of the MIS by assessing the system functions focused on circular PPE alternatives. The goal of the functional system analysis is to identify the specific barriers per system function. These barriers block the diffusion and adoption of the circular PPE alternatives, which hinder the circular mission of the Green Deal 2.0. An overview of the strengths and barriers of the system functions is shown in table 5.

4.3.1 Entrepreneurial activity (F1)

In the solution directionality part, it became clear that there are various circular alternatives for PPE that can be used in hospitals. Furthermore, innovative activity by hospitals and companies is taking place to sterilise PPE to enable them to be reused. An example of this is the sterilising process to reuse face masks developed by van Straten Medical (Renewi, 2020). Furthermore, Dutch hospitals are starting to implement new business models that stimulate circular working (Friedericy et al., 2020). The business model, known as the 3R approach, reduces waste generation by reducing, reusing and recycling. Currently, most progress in the Dutch hospitals is achieved in recycling, but the most environmental gain can be made by implementing reduce and reuse options (Desu et al., 2020). Furthermore, interviewee SPA1 states that the level of technological readiness of the circular PPE alternatives in general is not mature enough. There is still much innovation to be done and especially the amount of experience with the circular alternatives in hospitals is lacking. Only a small number of pilots (four pilots within four different academic hospitals) with circular PPE have been mentioned by the interviewees. One pilot introducing the use of reusable OR-gowns was carried out by LUMC in collaboration with a number of other hospitals. Interviewee SA1, who was involved in the pilot, mentioned that the results were very promising as the employees perceived the gowns as comfortable and the logistic process of washing the gowns was feasible. Unfortunately, the pilot has not led to a hospital-wide implementation of reusable OR-gowns as the associated costs were more than twice as expensive compared to the disposable OR-gowns (SA1) (MCS1).

According to interviewee SA1, the introduction of circular and sustainability initiatives originates through a bottom-up structure. This means that circular PPE initiatives are introduced by the HCWs themselves, who identify the problems of overusing disposable PPE as they encounter this problem on a daily basis. This group of HCWs form a Green Team aiming to resolve the problem of the disposables. By 2021, more than 130 Green Teams in the Dutch healthcare sector are actively engaged in circular and climate-neutral operations (Melkert et al., 2022). Interviewee SPA1 emphasizes the importance of Green Teams as drivers of circularity and sustainability at the departmental level in the hospitals. Furthermore, the interviewee states that the Green Teams identify the PPE and other instruments that could have a great impact if they are replaced with circular alternatives. On the other side, interviewee SAP1 stresses the fact that the members of the Green Teams are not sustainability experts, but healthcare professionals for which it remains a secondary activity.

The evaluation study on the Green Deal 2.0 by Bureau Bartels (2021) showed that healthcare professionals have a need for entrepreneurial activity in the form of good examples. They indicate that conducting more pilots will help prove the functionality of circular PPE and thereby inspire other hospitals to participate in the transition. Interviewee IPE1 observes that especially few pilots of circular PPE alternatives have taken place in the OR. This is caused by the fact that in the OR you have to work in a sterile environment as the risk of infection is the highest. To conclude, entrepreneurial activity in the form of conducting pilots of circular PPE

alternatives is of great importance to drive the transition and is preferably conducted outside the OR.

4.3.2 Knowledge development (F2)

There are several organisations, including RIVM, Intrakoop, MPZ, TNO and NEN, which are affiliated with the Green Deal 2.0 that are responsible for developing the knowledge needed to achieve the missions of the Deal. More specifically, these organisations form a so-called action table aimed at stimulating circular work in the Dutch healthcare sector by developing knowledge about it and disseminating this across the members of the Green Deal 2.0 (Bureau Bartels, 2021). Interviewee PSSC1 states that the Ministry of VWS directs these knowledge institutes to conduct research and pilots around the theme of circular working in healthcare. An example of such research is the study on the most used PPE in hospitals and their availability, which serves as a solid foundation to identify which PPE items are impactful to be replaced by circular alternatives (Rijksoverheid, 2020). Interviewee SEE1 states that the academic hospitals are also doing research on "*the important questions that need to be resolved to include circular PPE alternatives in large tenders*" (SEE1). These questions include the difference in cost, needed logistical changes, and financial availability of Dutch hospitals to afford the extra costs related to the circular PPE alternatives.

Three interviewees rated the degree of knowledge on reusable PPE alternatives as very strong. This view is based on the fact that it used to be very common in hospitals to sterilize and reuse PPE. Interviewee SEE 1 emphasizes this by stating "*the reusable alternatives are older than the disposables and therefore I actually see the disposables more as an innovation*" (SEE1). However, the majority of the interviewees (12 of the 21) believe that the degree of knowledge development related to the transition towards circular PPE alternatives is still far too limited in different aspects. First, there is still a lot of research required on the actual risks of infection associated with the current infection prevention guidelines and the reuse of PPE. Interviewee SPM1 states that: *"It is essential to investigate whether it is at all possible to use circular PPE alternatives in terms of infection prevention guidelines"* (SPM1). This highlights the fact that these infection prevention guidelines are one of the biggest barriers to the transition towards circular PPE alternatives. The problem is that it is very difficult to prove the effectiveness of the infection prevention guidelines as "the infection risk is so small that you would need gigantic studies" (SA1). Moreover, interviewee VDSM1 emphasizes that this lack of knowledge regarding the effectiveness of IP-guidelines is especially relevant in the operating rooms, where PPE and instruments have to be sterile. Interviewee VDSM1 identifies a problem here as "*you can't measure sterility, therefore, the guidelines are based on an assumption. We speak of sterility if there is a one in a million chance that a micro-organism will survive*" (VDSM1). On the other hand, interviewee SA1 emphasizes that it is as difficult to prove that the IP-guidelines are too strict. Secondly, three interviewees observe a lack of knowledge in the sterilising process of PPE to enable their reuse. Interviewee CM1 especially focuses on the lack of knowledge on the quality and characteristics of the materials in the PPE after being sterilised. Moreover, interviewee CM1 states that this specific knowledge barrier can only be resolved by the manufacturers performing extensive research on this. Thirdly, according to five interviewees there is a strong need for life cycle assessment (LCA) studies between reusables and disposables PPE. A LCA is method that examines the environmental impact of a product over the entire period of its life, which is commonly referred to as the analysis from "cradle-to-grave" (EEA, n.d.). The LCAs are needed for hospitals to make an informed choice between the purchase of reusable and disposable PPE. Interviewee SAP1 explains the need for LCAs by stating that employees in healthcare are open to the transition if it is based on scientific research. An example of such a study is a comparative LCA conducted by van Straten et al. (2021) on

the environmental impact of disposable and reusable face masks. Besides showing that reusable face masks have a lower climate change impact and lower costs[17], this study "may serve as an inspiration for investigating reprocessing of other products that may become scarce … advocates that circular design engineering principles should be taken into account when designing medical devices" (van Staten et al., 2021, p. 1). An important observed barrier by interviewee SP1 is that LCAs are very costly and take a lot of time. Furthermore, it is an important discussion on who is responsible to conduct these LCAs. On the one hand, three interviewees believe that the suppliers should bear the responsibility of conducting these LCAs. Interviewee SPM1 states that "*suppliers have to prove the environmental advantages of the circular PPE alternatives in order to make these products a business case to the disposables*" (SPM1). On the other hand, interviewee CSA1 acknowledges the importance of the LCA, but emphasizes that independent research from a university is more unbiased and better interpreted than from a firm. This discussion on who bears this responsibility has also been investigated by RIVM (2022), resulting in a clear preference for LCAs to be conducted by an independent knowledge institute. This can be seen in figure 6.

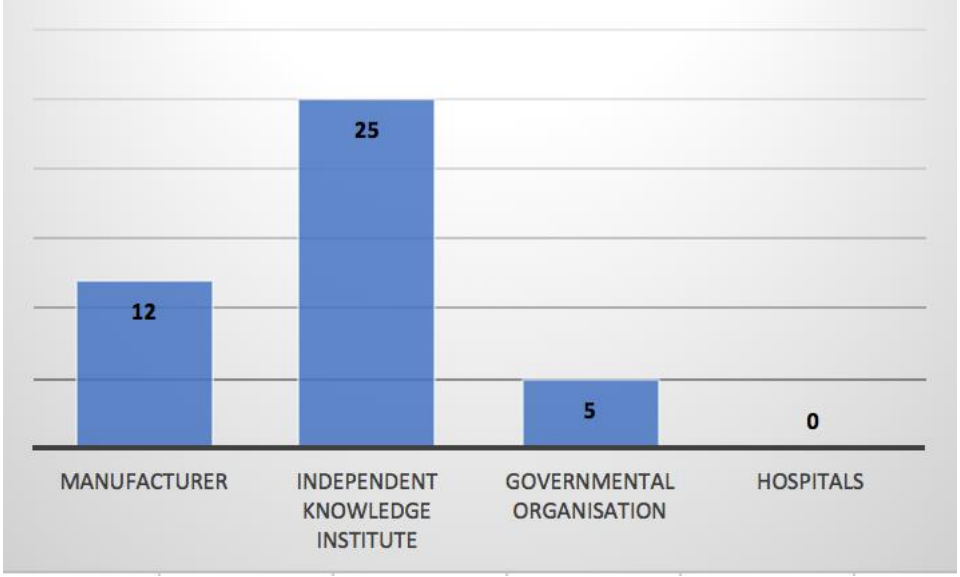


Figure 6: Survey results to whose responsibility it is to conduct sustainability analyses (RIVM, 2022, p. 38)

4.3.3 Knowledge dissemination (F3)

Knowledge about the circularity issues related to disposable PPE and possible circular PPE alternatives are disseminated amongst MIS actors through different platforms. The identified impactful disposables and possible circular alternatives are disseminated within the hospitals by a network of sustainable care professionals and Green Teams through webinars and newsletters focused on sustainability. Interviewee SEE1 acknowledges the importance of the Green Teams, but recognises the challenge of keeping a clear overview of the many initiatives related to both circularity and sustainability, which hinders the dissemination of the knowledge that arises from them.

According to three interviewees, there is a high degree of collaboration between the Dutch academic hospitals around the issue of circularity. An example of this is the pilot on the use of reusable isolation gowns led by LUMC in collaboration with 15 other hospitals. As a

[17] If the masks can be reused up to 5 times

result of this collaboration, the gained knowledge from the pilot is disseminated between all the hospitals. Furthermore, interviewee MCS1 states that the results of the pilots have been published in a Dutch medical journal and that they are still trying to publish them internationally. Interviewee SPA1 explains the high degree of knowledge dissemination by stating that there is little competition focused on profit between the hospitals. This enables academic hospitals to be in close contact with each other and to exchange useful knowledge and experiences. This dissemination of knowledge between the hospitals could help overcome the earlier identified knowledge barriers.

The Green Deal 2.0 itself also plays an important role in the dissemination of knowledge (MPZ, n.d.). Interviewee PSSC1 summarises this role of the Green Deal 2.0 by stating it acts as a platform for the exchange of knowledge, ideas and initiatives. PDZ organises a monthly newsletter on the most recent knowledge on the themes of the Green Deal 2.0 and the achievements of its members. Furthermore, PDZ created a LinkedIn page with the goal of raising awareness and building a community. However, the evaluation study of Bureau Bartels (2021) indicated that respondents indicate that there is too little central direction and that knowledge sharing is not stimulated enough from the Green Deal 2.0. It is also criticised that when knowledge sharing did take place, there was not enough room for interaction and collaboration. To summarise, there are many platforms, networks and websites where relevant knowledge is exchanged, but according to three interviewees there is a need for one central platform. Interviewee SPM1 confirms this by stating: "*I think there are many relevant contributions being made on many different platforms and networks, but because of that we are actually fragmenting information*" (SPM1).

4.3.4 Problem directionality (F4a)

The large majority of the HCWs are aware of the enormous production of plastic waste caused by the use of disposable PPE (Kleijne, 2021). Interviewee MCS1 observes that this awareness about the circularity issues has largely grown over the last few years. According to Livingstone et al. (2020), this awareness of circularity issues has grown because of the Covid-crisis, in which the large amounts of discarded plastic came to light because of the deficits of essential PPE. This opened the eyes of many MIS actors, especially HCWs in the Dutch academic hospitals, to how fast PPE is discarded and that developing and implementing circular alternatives would be a good solution for this (MSC1). The Covid-crisis forced hospitals to recycle PPE that was not meant for that cause and not allowed according to the IP-guidelines. Interviewee IPE1 explains that during times of such a crisis, an exception could be made for this. Furthermore, this enabled the emergence of initiatives for sterilising and reusing PPE, such as the new sterilisation method for face masks by Van Straten Medical. Interviewee CSA1 acknowledges that the state of crisis has accelerated the movement of circular PPE alternatives, but is sceptical whether this movement endures when everything goes back to normal.

From the previous paragraph, it can be concluded that the waste problem caused by single-use PPE is acknowledged by HCWs and other important MIS actors. The concept of sustainability is on the agenda of the Dutch hospitals, however many other aspects still have priority over sustainability (Donata, 2020). Interviewee MCS1 confirms this by stating that despite the growing awareness of sustainability and circularity, they are still relatively low on the priority lists of the hospitals. According to interviewee SA1, patient safety and finances will always have priority over circularity issues. Two interviewees also observe this prioritisation in the procurement processes of the hospitals, wherein safety and financial health are requirements and sustainability is included as a desire. Furthermore, interviewee SAP1 emphasizes that circularity is not high on the agenda of the PPE manufacturers and in the market in general. On the other hand, interviewee SAP1 mentions that: *"the manufacturers themselves*

recognise that this transition is going to take place in the coming decades and that at some point in time they will have to enter this new market" (SAP1). Moreover, the PPE manufacturers are aware of the concerns about the ongoing availability of the raw materials required to produce the PPE, which forces them in the long term to look at the circular alternatives (Cohen & van der Meulen Rodgers, 2020).

4.3.5 Solution directionality (F4b)

As described in the problem-solution diagnosis, there are already circular PPE alternatives available on the market which hospitals could potentially implement. However, three interviewees emphasise that these circular PPE alternatives are in an early stage of development. As a result, there is not a clear solution direction to achieve the full transition towards the use of reusable PPE. However, nine interviewees agreed on one important solution direction. This solution direction entails that the most effective way to reduce PPE waste is not to reuse them, but to reduce the overall use of the PPE. This is also in line with the 9R model of Potting et al. (2017), wherein this solution direction refers to refusing (R0) the use of PPE. Interviewee SAP1 acknowledges the fact that this circularity strategy (R0) is not realistic to implement in many parts of the hospitals, such as operating rooms, due to safety reasons. However, there are many possibilities for the reduced use of PPE outside of the operating rooms. An example of this is the reduced use of non-sterile gloves. Interviewee MCS1 states that non-sterile gloves are often worn unnecessarily, even when not required by the IP-guidelines. A study by Rizan et al. (2021), introduced in the theory section, showed the environmental gain achieved by the reduction of glove use. Moreover, interviewee SP1 stated that multiple LCA studies indicated that gloves are of the biggest hotspots, meaning that they cause the most negative environmental impact (Parent et al., 2013). Three interviewees state that the unnecessary use of PPE is caused by a lock-in of the HCWs' behaviour, which is discussed in more detail in the creation of legitimacy (F7).

Eight interviewees also revealed that the transition towards using circular PPE alternatives has especially potential to take place outside the operating rooms. IPE1 explains this by stating: "*Personal protective equipment is worn in the OR to prevent the patient from getting an infection during the operative process. So, the materials must be guaranteed clean, and for those at the operating table they must be sterile, so there are quite high requirements. If you look at the use elsewhere in the hospital, it is often more to protect the employee. In these departments, the requirements are not as high and the circular alternatives can be best implemented"* (IPE1). This view is strengthened by interviewee CM1 who believes that the IP-guidelines will never become less strict at the OR as it is so difficult to prove and guarantee safety, but that this is possible outside the OR. In other words, by implementing circular PPE alternatives outside the OR where the infection risk is less high, the barrier of the knowledge deficit of infection prevention is circumvented. Regarding PPE that is used in the OR, interviewee CM1 sees potential in the development of innovations of the materials wherein they increase their recyclability (R8).

The majority (14 of the 21) of the interviewees expect that many circular PPE alternatives are implemented in the hospitals within a time frame of 10 years. Interviewee SEE1 is sceptic about this transition by mentioning the pressure on cutting costs in the healthcare sector. Furthermore, the interviewee emphasizes that a transition towards circular PPE would entail significantly more costs, thereby creating a barrier for this transition. Interviewee SA1 nuances this view by stating that the transition towards the use of circular PPE alternatives would become financially more interesting in the long term. This is caused by the fact that the production of circular PPE alternatives and related sterilisation processes will become more efficient (Duru & Pal, 2021). In addition, the production of waste will become more expensive,

which would also increase the cost-competitiveness of the circular PPE alternatives (Janssen, 2017). According to interviewee SPA1, the importance and awareness of circularity in the healthcare sector will keep growing, thereby increasing "*the acceptance of paying more for reusables for the cause of reducing the environmental impact*" (SPA1).

4.3.6 Reflexitivity (F4c)

The overall goal of the Green Deal 2.0 is to make the Dutch healthcare more sustainable (MPZ, n.d.). Four interviewees state that the Green Deal 2.0 mainly contributes through the creation of awareness of the sustainability issues in the healthcare sector. A large variety of actors have signed the Green Deal 2.0, which indicates that important MIS actors in the Dutch healthcare sector are aware of and committed to achieving the missions of the Green Deal 2.0. Furthermore, interviewee PSSC1 emphasizes that the Green Deal 2.0 functions as a source of inspiration for the emergence of Green Teams and other initiatives. However, there is also some criticism about the Green Deal 2.0. The evaluation of Bureau Bartels (2021) showed that members found the missions of the Green Deal 2.0 too broad, including the mission of circular working. This absence of clear goals creates a barrier for organisations to work towards clear solutions directions and limits the introduction of new circular PPE alternatives to the market (Wesseling & Meijerhof, 2020**).** Furthermore, the absence of clear goals makes it very difficult to monitor the progress of the theme of circular working (Bureau Bartels, 2021). On the other hand, some hospitals themselves have concretised the ambition of circularity into objectives and created monitoring methods. Interviewee SPA1 states that the RadboudUMC is able to identify the progression of the transition from disposables to reusables by monitoring the hospital's residual waste. However, interviewee SPA1 also emphasizes that the concept of circularity is difficult to measure and monitor. Moreover, the interviewee states that the degree of recycling is adequately possible to monitor, but the difficulty lies more in monitoring the other Rs of the 9R model.

4.3.7 Market Formation (F5)

There are already some circular PPE alternatives available on the market. However, according to Melkert et al. (2022) due to strict IP-guidelines and the lack of knowledge on and experience with these alternatives, there is currently a deficit of sustainable alternatives on the market. This is caused by a multitude of factors. A prominently mentioned factor by six interviewees is the view that the production of disposable PPE is a very profitable business model for the manufacturers. Two important Dutch PPE manufacturers are Medica Europe and Interster. Examples of large international PPE manufacturers are 3M, Dupont, Honeywell, Medline Europe and Mölnlycke (IFC, 2021). In the PPE market, current business models "incentivize single-use disposables over reusable alternatives because single-use disposables maximize profits through high-volume consumption" (MacNeil et al., 2020, p. 2091). Moreover, manufacturers profit greatly from the disposable characteristic of their PPE as hospitals continuously need to buy enormous amounts to prevent shortages. Interviewee SEE1 summarises this by stating: *"there is little to no incentive for the manufacturers to change their profitable business model"* (SEE1). Interviewee CM1 suggests that the lack of knowledge on circular PPE alternatives is another factor why the large disposable PPE manufacturers will not transition to producing reusables. Interviewee SAP1 agrees that a high degree of knowledge and effort is required to adapt the production chain to circular alternatives. Therefore, it is expected that in the long-term they will make their disposable PPE more sustainable instead of adapting their entire production chain. Four interviewees observe that especially smaller companies are trying to respond to this 'gap in the market'. A clear disadvantage is that these

companies also have smaller product lines, thereby not being able to profit from economies of scale resulting in the circular PPE alternatives being significantly more expensive (Kenton, 2022). The difference between the initial costs of disposable PPE and circular PPE alternatives can be found in Appendix B. Interviewee CP1 states that it is very difficult for circular PPE manufacturers to compete against the mass production and resulting low prices of disposables manufacturers. Interviewee MCS1 concludes that *"As long as the disposables are cheaper than the alternatives and also safer from an infection prevention point of view, everyone will keep doing it. It only becomes interesting for companies to move towards reusable products when it also provides a business case"* (MCS1). Therefore, a clear barrier is an absence of stimulating financial regulations or institutions that make the circular alternatives a competitive business case against the disposables. Examples of such institutions are subsidies for manufacturers who start producing circular PPE alternatives or funding for hospitals to afford the alternatives. Interviewee SEE1 observes that due to this absence of stimulating regulations or institutions, many innovations and pilots of circular PPE alternatives do not scale up. On the other hand, five interviewees state that also large disposable manufacturers know that transition towards reusables is going to take place over the long-term. However, they are waiting for the profitable moment to enter this market and this is not yet the case without stimulating regulations.

Another important factor in the market formation is the market influence of hospitals related to their demand for circular PPE alternatives. Seven interviewees state that the Dutch hospitals have little to no influence on the large international PPE markets. Companies from China and the United States account for 60% of the global production of most PPE-items[18] (IFC, 2021). The lack of market influence is directly related to the relatively low purchasing power of the Dutch hospitals. Interviewee SP1 states that the demand of the Dutch hospitals will not influence the international market, as long as the majority of the hospitals in the world will continue to buy disposables. In other words, the manufacturers will only change their business model and enter the circular PPE market when there is a significant international demand for more circular PPE alternatives.

An option to stimulate companies to enter the market is to provide subsidies to incentivise them to come up with circular alternatives. As stated earlier, there is an absence of these regulations and institutions specifically stimulating the development of circular PPE alternatives. However, interviewee CSA1 and interviewee CP1 observe that companies can also make use of more broadly focused subsidies. An example of this is Small Business Innovation Research (SBIR), which is an innovation competition wherein the government subsidises companies to create innovative products which help to solve societal issues (RVO, 2010). The program consists of three phases, in which first a feasibility study is conducted, thereafter a product is developed, and finally the product is commercialised. In 2021, a SBIR was organised with the goal of developing sustainable isolation gowns for healthcare (RVO, 2021). This has resulted in the development of a reusable isolation gown by HAVEP, a producer of workwear, in collaboration with TNO and Eindhoven Engine, which is an innovation booster for meaningful and impactful projects (Modint, 2021) (Eindhoven Engine, n.d.).

4.3.8 Mobilisation of resources (F6)

In the former part on market formation (F5), it became apparent that the available circular PPE alternatives are expensive compared to the conventional disposables. Moreover, according to Mayer et al. (2022) switching to reusables requires high initial investments. Interviewee CSA1 states that the Dutch hospitals have too little budget available for such investments. It can be concluded that the relative expensive circular alternatives and low budgets are a financial

[18] Gloves are mostly produced in Malaysia and Thailand (IFC, 2021)

barrier for the transition towards circular PPE alternatives. This barrier is located in the procurement department of the Dutch academic hospitals, as they are responsible for selecting and procuring the PPE. Furthermore, interviewee CSA1 observes that there is a culture within the Boards of the hospitals that such (circular) initiatives are only supported if they save money in the short-term. According to Bureau Bartels (2021), hospitals require financial support from the government to overcome this financial barrier. Several healthcare organisations have already sent two letters to the Parliament requesting financial support and funding for making the healthcare sector more sustainable (Melkert, 2022). Interviewee SPA1 explains that the goal of the letters is that the Dutch healthcare sector will receive a share of the Climate Fund to reduce its CO_2 production and to support initiatives of circular working. Furthermore, according to six interviewees the Dutch hospitals have a limited amount of influence on the PPE market. Four interviewees mention an option to alleviate this barrier by the joint procurement and tendering of multiple Dutch hospitals. This will increase their purchasing power and their influence on the PPE market. Interviewee MCS1 explains that the joint procurement will result in the purchase of larger volumes, making it more financially appealing for manufacturers to develop cheaper circular PPE alternatives. On the other hand, in the market formation part (F5) was discussed that Dutch hospitals had little influence on the large international PPE market. SPA1 states that ideally Dutch hospitals would only depend on PPE production chains that are very local or within Europe at the minimum. This enables them to have more purchasing power to stimulate the development of circular PPE alternatives. In addition, van der Elsen (2021) states that it is crucial to have access to raw materials close to home in order to establish a sustainable production chain of PPE in the long term. Interviewee SA1 agrees with this and adds that this issue clearly came to light during the Covid-crisis, in which delivery problems and deficiency of PPE were caused by the dependence on the distant international production chains. According to Kleijne (2021), this dependency can be an important driver to transition from disposables to reusables.

The presence of human capital in the Dutch academic hospitals is also essential for the transition towards circular PPE alternatives. According to Bureau Bartels (2021), there have been relevant issues and themes that also require adequate attention or priority, which causes less time and human capital to be devoted to making the healthcare sector more circular. Especially the Covid-crisis has caused the lack of human (and financial) resources to take the steps needed to contribute to the circular mission of the Green Deal 2.0. Furthermore, interviewee SAP1 emphasizes that stimulating circularity, for instance through Green Teams, in the hospitals remains a secondary activity for the HCWs.

Another factor limiting the transition towards circular PPE alternatives mentioned by four interviewees is the absence of the logistical infrastructure in the hospitals to reuse the PPE. Interviewee CM1 addresses this barrier by explaining that a logistical process has to be realised to collect the used PPE, sterilise them (possibly at an external location) and return them so that they can be used again. The barrier is mainly located in the resistance against adapting the internal logistical processes as this is experienced as very difficult. On the other hand, two interviewees see no decisive obstacles to realising this logistical process for the circular alternatives, but they point out that it will take a transition period to work efficiently.

4.3.9 Creation of legitimacy (F7)

The creation of legitimacy in the form of support from relevant MIS actors is essential to initiate a transition (Elzinga et al., 2021). However, the implementation of necessary circular strategies to achieve the transition towards circular PPE alternatives requires engagement and support from multiple hospital departments, including the HCWs, procurement, sterilization, logistics and waste management (Mayer et al., 2022). Especially the HCWs are important actors with

significant influence, as they are the ones that have to use the (circular) PPE (Kleijne, 2021). Rowan & Laffey (2021) identify that an important barrier to the reuse of PPE is the trust and acceptance of HCWs of the alternatives to disposables. Interviewee SPM1 also sees the importance and dependence of the HCWs' acceptance of the circular PPE alternatives by stating: "*If they insist very much on this, then we will make much faster progress. But if they don't support it and complain to the board about the circular PPE alternatives, then the transition will be very difficult*" (SPM1). According to Baker et al. (2020), an important factor for the acceptance of health care workers of reusable PPE alternatives is the degree of comfort for the HCWs of these alternatives. The importance of the comfort of the PPE alternatives is also mentioned by six interviewees. Interviewee MCS1 explains that the reusable gowns used in LUMC are considered to be comfortable because of their fine material and good transpiration. Another frequently mentioned factor by five interviewees is the importance of the functionality of the circular PPE alternatives. Interviewee CSA1 summarises this by stating: *"I don't think they (HCWs) have a huge preference for reusable or disposable. I think they have a preference in terms of wearing comfortable PPE and functionality. So, these factors are essential to make the transition to reusable PPE"* (CSA1). This shows that the priority in hospitals remains on providing care and that the discussion about circularity comes in second place.

Six interviewees observe a lock-in with the use of disposable PPE. Lock-in refers to the organisational lock-in to decision processes that continue to reproduce the status-quo outcome and give rise to inertia (Hedgren, 2013). This lock-in of HCWs favouring the use of disposable PPE is caused by several factors. Mayer et al. (2022) indicate that in general HCWs have a personal preference towards disposables as they have become the standard used product over the last decade. Furthermore, there are some clear advantages of the use of disposables which form a barrier for HCWs to support and accept the transition of the use of circular alternatives. Firstly, disposables have a consistent quality (Kleijne, 2021). Moreover, there is little effort required for HCWs in using disposables as they are discarded directly after their use. In contrast to circular PPE alternatives, where the PPE have to be collected separately. Another observed barrier, mentioned by interviewee SEE1 is the fear of HCWs that the circular alternatives are not 100 percent clean or sterile after the washing or sterilisation process. Interviewee IPE1 states that this fear has been clearly strengthened by the Covid-crisis as the HCWs feel safer if they can put on PPE that from their perspective does not involve any risk of infection. According to Argawal et al. (2021), it is very difficult to change HCW's behaviour and way of working during and after such a crisis. Interviewee IPE1 appoints that this is well reflected in the use of medical gloves by giving the following example: "*If employees have been wearing gloves for two years due to all those COVID outbreaks, they suddenly feel unsafe when they are no longer allowed to wear or wear those gloves*" (IPE1). According to Rimmer (2020), this lack of knowledge about the perceived safety of reusing PPE forms a barrier to the use of circular PPE alternatives. Therefore, this barrier can also be overcome by the provision of research that proves the safety of reusing PPE and emphasizes the environmental gain of this transition. Interviewee MCS1 stresses that this is being explicitly examined to provide this creation of legitimacy. On the other hand, nine interviewees emphasize that there is a great deal of support for the use of circular PPE alternatives within the hospitals. Interviewee SPA1 explains that this is well reflected in the growing number of Green Teams, which are actively working on this.

Table 5: Overview of the identified barriers and strengths per system function

System function	Barrier	Strength
F1: Entrepreneurial activities	Pilots with circular PPE alternatives are lacking Difficulty in translating pilots to hospital-wide implementation of circular PPE alternatives Due to infection risk, pilots are best conducted outside the OR	Presence of an entrepreneurial climate in hospitals (especially by means of the Green Teams)
F2: Knowledge development	Lack of knowledge on the risk of affection and effectiveness of current IP-guidelines Lack of LCAs comparing the environmental impact of disposables and circular PPE alternatives Discussion about who is responsible for developing such knowledge	Many organisations active in the knowledge development related to the Green Deal 2.0 missions A strong knowledge base of hospitals on sterilisation and reusing PPE through past experience
F3: Knowledge diffusion	There is a need for a central platform where important knowledge is disseminated	Knowledge regarding circularity issues and solutions are disseminated through multiple platforms reaching important MIS actors A high degree of collaboration between hospitals leads to high degree of knowledge dissemination
F4a: Problem directionality	In hospitals, patient safety and financial aspects are prioritised over the PPE circularity problem PPE is not high on the agenda of the PPE manufacturers and in the market in general	Awareness on the circularity problem has grown tremendously amongst the MIS actors (largely caused by Covid-crisis)
F4b: Solution directionality	There is not a clear solution direction to transition towards circular PPE alternatives and achieve the missions of the Green Deal 2.0	A strong solution directionality that PPE use can be reduced and made more circular outside the OR

F4c: Reflexivity	There is an absence of clear goal formulation, making it very difficult to monitor the mission progress The concept of circularity is difficult to measure and monitor	The Green Deal 2.0 contributes significantly to creating awareness regarding the sustainability and circularity issues in hospitals
F5: Market formation	There is a deficit of circular PPE alternatives on the market The current business model of disposable PPE is very profitable Circular PPE alternatives are not yet a business case for manufacturers to change their business model & for hospitals to purchase them in bulk There is an absence of stimulating financial regulations or institutions Dutch hospitals have little influence on the large international PPE market	
F6: Resources mobilisation	Hospitals have too little financial resources to transition to purchasing circular PPE alternatives Missing logistic infrastructure necessary for the sterilisation of circular PPE alternatives	Several healthcare organisations are trying to gain financial resources from the Climate Fund Joint procurement of hospitals will increase their purchasing power and influence on the PPE market
F7: Creation of legitimacy	The transition towards using circular PPE alternatives requires engagement and support from many departments and actors There is a current lock-in in which HCWs favour using disposable PPE	Especially from bottom-up, there is a great deal of support within hospitals for the use of more circular and sustainable PPE alternatives

5. Analysis

This section executes the last two analytical steps of the MIS. First, taking to account the structural and system function analysis, the systemic barriers are identified. These systemic barriers are analysed by examining their underlying root causes. Thereafter, systemic instruments and intervention strategies are discussed with the goal to overcome these structural barriers.

5.1 Systemic Barrier Analysis

In the system function analysis, the system functions were analysed by identifying their strengths, weaknesses and barriers which hinder or enable the transition towards the use of circular PPE alternatives in Dutch academic hospitals. The identified barriers were shown to six key respondents, who were asked to select the most significant barriers that hinder this transition. According to these experts these barriers include 1) lack of LCAs proving the environmental advantage of transitioning to circular PPE alternatives, 2) current strict infection prevention (IP) guidelines, 3) no incentive for companies to develop circular PPE alternatives, 4) lack of available budget of hospitals to procure more expensive 5) lack of knowledge on infection risk associated with using circular PPE, 6) HCWs preferring using disposable PPE, and 7) absence of logistics infrastructure for sterilising and reusing PPE. These barriers are categorised into four systemic barriers and are discussed in more detail below. The systemic barriers and their interrelatedness are visualised in figure 8.

5.1.1 Institutional Barriers

A clear barrier that came to light in the system function analysis is the strictness of the current IP-guidelines. This systemic barrier is caused by the Working Party on Infection Prevention (WIP), which is responsible for the establishment of these guidelines. This barrier is caused by the WIP as the infection prevention specialists strongly favour the provision of IP guidelines focused on minimising the risk of infection. Currently, the strictness of the IP-guidelines leads to the discouragement of PPE manufacturers to start developing and producing circular alternatives (F1) as they cannot be implemented hospital-wide. However, the current IP-guidelines are less strict outside the OR. This has a positive influence on the solution directionality (F4b); steering the solution directionality in the direction of implementing the circular PPE alternatives outside the OR.

Another institutional barrier is the absence of the formulation of clear circularity goals. This absence of clear goals is both present in the circular mission formulation of the Green Deal 2.0 and in the circular goal formulation of individual hospitals. Both create a barrier for hospitals and other members of the Green Deal 2.0 to work towards clear solution directions. Furthermore, this absence of clear goals makes it very difficult to monitor the progress (F4c) of the transition towards circular PPE and the Green Deal 2.0's circular mission in general.

5.1.2 Knowledge Barriers

According to the interviewees, there is a lack of scientific-based evidence that proves the environmental advantages of transitioning from disposable PPE towards using circular PPE alternatives. An appropriate research method to examine and prove this is by conducting a comparative LCA. This barrier is identified in the knowledge development system function (F2) and is especially relevant for the HCWs. The HCWs are crucial actors in the MIS as they

will have to use the circular PPE alternatives. Therefore, the lack of knowledge in the form of LCAs on the environmental impact of disposable PPE and circular alternatives, also forms a barrier in the creation of legitimacy (F7) amongst HCWs. Furthermore, the lack of the LCAs limits the creation of awareness (F4a) of the importance and urgency of the disposable PPE problem. It is also not clear who should be responsible for developing this knowledge by conducting these LCAs. The barrier of this lack of knowledge is strengthened by the fact that LCAs are very time-consuming and costly. The hospitals have no budget (F6) and the PPE manufacturers have no incentive (F5) to conduct these LCAs.

Another knowledge barrier is the lack of knowledge on the risk of infection of sterilising, washing and reusing PPE. This knowledge barrier is strongly interrelated to the institutional barrier of the strictness of the IP-guidelines. There is a strong need for scientific-based evidence that proves or disproves the effectiveness of the current IP-guidelines. Without this scientific foundation, the IP-guidelines will be based on the approach of minimising the risk of infection. This knowledge barrier is strengthened by the fact that it is very difficult to scientifically prove the effectiveness of the IP-guidelines, as it would entail large-scale studies that are ethically questionable.

5.1.3 Market barriers

In the system function analysis, it became apparent that there is a systemic market barrier, which is related to the classical supply and demand problem. Firstly, it is currently not financially interesting for large PPE manufacturers to develop and produce circular PPE alternatives. This is caused by the fact that the current business model of disposable PPE production is very profitable and there is currently no incentive (F5) to change this business model to the development of circular PPE alternatives. The disposable business model is profitable due to the high-volume consumption of hospitals, as the disposables have to be discarded after use. Furthermore, the large PPE manufacturers would have to change their production chain in order to develop circular PPE alternatives. Nine interviewees indicated that there is a great deal of support for the implementation of circular PPE alternatives. However, the purchasing power of the Dutch hospitals is too little for large PPE manufacturers to respond to this demand. Currently, only smaller companies respond to this "gap in the market". However, it is very difficult for these companies to compete against the large disposable PPE manufacturers due to their large volume production, low costs of production and lower prices. This discourages companies to develop and produce these circular PPE alternatives (F1).

Another market and financial barrier are present within the procurement department of the hospitals. The current available circular PPE alternatives are significantly more expensive than the conventional disposables. Moreover, the transition towards circular PPE alternatives in hospitals would entail significantly more costs taking into account these purchase costs, infrastructure investment and logistic costs. Three of the five experts, validating the identified barriers, emphasized these additional costs of the circular PPE alternatives are currently too high for the available budget (F6) at the procurement department.

5.1.4 Behavioural barriers

Another clear barrier that was identified in the system function analysis is the lock-in of HCWs favouring the use of disposable PPE. This barrier can also be seen as a soft institutional barrier, but it is categorised as a behavioural barrier as it specifically concerns a lock-in amongst the HCWs. This lock-in is caused by the fact that HCWs are used to wearing disposable PPE. According to three interviewees, a transition towards using circular PPE alternatives would be opposed by resistance amongst a small group of HCWs based on the extra required effort

associated with these alternatives. Moreover, this resistance to using circular PPE alternatives is strengthened by the perception that this is not possible without the presence of risk of infection. According to MCS1, this fear even results in HCWs wearing PPE in situations where it is not required at all by IP-guidelines. This behavioural barrier is mainly present in the creation of legitimacy amongst HCWs.

The systemic barriers hindering the circular mission of the Green Deal 2.0 and the diffusion of circular PPE alternatives are visualised in figure 8. In the figure, a distinction is made whether the system functions are located in the mission arena or in the overall MIS. This is based on whether the systemic barriers are caused by or influence the actors in the mission arena or the actors within the overall MIS.

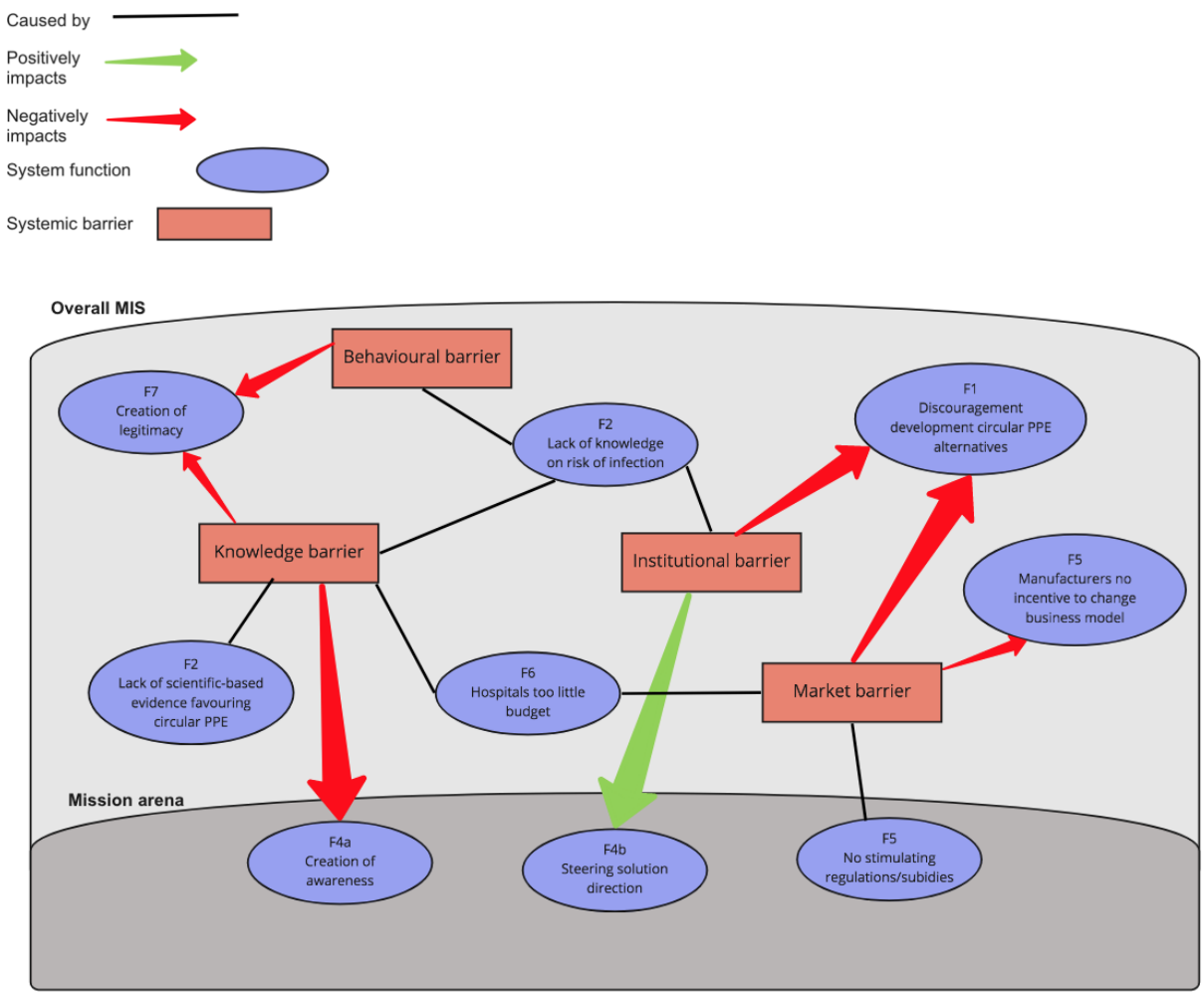


Figure 7: Visualisation of systemic barriers within the MIS of the Green Deal 2.0 focused on circular PPE alternatives

5.2 Identification of systemic instruments

In the previous step of the MIS, the systemic barriers as identified by several experts were analysed in detail. This subsection proposes policy instruments and intervention strategies with the goal to overcome these specific systemic barriers. Ultimately, the implementation of these instruments and interventions will lead to an acceleration in the transition towards circular PPE alternatives.

The institutional barriers are partly caused by the strict IP-guidelines focused on minimising the risk of infection. There are two possibilities to deal with these institutional barriers. Firstly, the institutional barrier of the strict IP-guidelines is closely linked to the knowledge barrier. Therefore, the policy instrument to overcome the knowledge barrier is similar for the institutional barrier; the provision of scientific research and knowledge on the risk of infection associated with the use of circular PPE alternatives. On the other hand, four interviewees were sceptic about whether the IP-guidelines will ever be relaxed, with an emphasis on inside the OR. In this case, this barrier can best be dealt with by steering the solution direction; focusing on the implementation of circular PPE alternatives outside the OR where the risk of infection is less high.

There is a clear presence of systemic knowledge barriers. These systemic barriers are caused by the lack of LCAs proving the environmental advantage of circular PPE alternatives and the lack of knowledge on the risk of infection associated with these alternatives. This barrier can be lowered by the adequate organisation of the mission arena. In the structural analysis (section 2.4) is outlined that the PDZ, a programme of Ministry of VWS, is responsible for the decision-making in the mission arena. Therefore, PDZ is able to direct the knowledge institutes to focus on the specific knowledge deficits creating the systemic knowledge barriers that are mentioned above. The provision of this knowledge would increase the general support (F7) for circular PPE alternatives, as these knowledge institutes are able to provide scientific research and evidence. Furthermore, the direction of knowledge institutes to address the knowledge barriers would be a suitable policy instrument as research conducted by an independent institute is considered more unbiased and better interpreted by the HCWs.

Another strategy to tackle the knowledge barriers is to include the provision of a LCA as a requirement in a tender. A tender is a procurement process in which an organisation, that is in need of a product, invites other parties to submit a proposal to provide these products (Kenton, 2022). In this case, the procurement department of the hospitals asks the possible PPE suppliers to provide a LCA on the PPE products. This provision of the LCAs will increase their chance to be chosen as the supplier for the hospital. SP1, who occupies a procurement function at Erasmus MC, explained that sustainability and circularity perspectives are already included in their tenders in the form of the provision of LCAs and working conditions associated with the products.

The systemic market barriers are caused by the fact that it is not financially interesting for PPE manufacturers to start developing circular PPE alternatives and that the procurement department has too little budget available to cover the extra costs of these alternatives. These two barriers can be tackled by the introduction of stimulating financial regulations and institutions. The policy instruments needed to overcome the first barrier are financial institutions and regulations that are focused on making circular PPE alternatives a competitive business case against the disposables. This can be achieved by the implementation of the following three policy instruments: pricing, standardising, and subsidising. Pricing is the adjustment of market prices to account for environmental costs (de Bruyn et al., 2017). In this case, the price of the disposable PPE would be increased by taxing the landfill and incineration of these products. This levy will make the disposables more expensive and more competitive to the business case of the circular PPE alternatives (Ministry of BZK, 2021). Standardising

entails the setting of standards by the government that a product must meet and is legally enforced (Chabot, 2021). For example, the government could standardize the use of circular PPE and ban the use of disposables. However, with the current high costs and relatively low state of technological readiness, this is not yet feasible. A more realistic example could be the obligation for hospitals to at least recycle their PPE (R9), which could later be adjusted by standardizing higher-end circular strategies. The last financial policy instrument is subsidising, which can be implemented in different ways. One option is subsiding the difference in the purchase price between the circular and disposable PPE with the goal to make them competitive with each other (Ministry of BZK, 2011). Interviewee SSPC1 mentioned the possibility to provide subsidies to suppliers to develop circular PPE strategies and subsidies to conduct relevant research to be able to produce these alternatives. The essence of a successful circularity policy is to achieve a good balance of the implementation of pricing, standardizing and subsidizing (Chabot, 2021).

The second market barrier can be tackled by the provision of a fund from the government to the Dutch hospitals with the goal to improve their circularity. This fund can be used for different purposes but has the main goal to cover the extra costs of the transition towards the use of circular PPE alternatives. The most obvious use of the fund would be to procure the more expensive circular alternatives. However, interviewee SPA1 states that the fund can also be used to finance more pilots with new circular alternatives, which increases the change of these initiatives to scale up. Another possibility is to use the fund to finance the extra costs of the logistics associated with washing, sterilizing and transporting the circular PPE alternatives. Interviewee CSA2 explains that this could be done by financing the necessary infrastructure to enable these logistics within the hospitals or by outsourcing it to external parties.

The behavioural barriers are caused by the fact that a part of the HCWs is "locked-in" to the use of disposable PPE. This lock-in is based on the fear of infection leading to resistance against circular PPE alternatives and to the overuse of disposable PPE even when this is not required by the IP-guidelines. Interviewee IPE1 suggests that this systemic barrier can be overcome by providing education for HCWs on the proper use of PPE, when it is necessary to use or safe not to use PPE. The lock-in is best opposed by informing and convincing the HCWs of the safety and environmental gain of using circular PPE alternatives. However, due to the current knowledge barrier regarding the risk of infection associated with the circular PPE alternatives, it is not yet possible to apply his intervention strategy. The proposed policy instruments and intervention strategies per systemic barrier are summarised in table 6.

Table 6: Policy instruments and intervention strategies per systemic barrier

Systemic barrier	**Policy instrument / intervention strategy**
Institutional barriers	Provision of scientific research and knowledge on the risk of infection of circular PPE alternatives Focus on implementation of circular PPE alternatives outside the OR
Knowledge barriers	Directing independent knowledge institutes to conduct research on the identified knowledge gaps Include LCA as requirements in PPE tenders for suppliers

Market barriers	Pricing, standardising & subsidising Government funding for hospitals to cover extra costs of transition towards circular PPE alternatives
Behavioural barriers	Education for HCWs on when PPE is essential or not essential to be worn

6. Discussion

This section discusses the results and analysis from chapters 4 and 5 in relation to the theory and methodology. First, the theoretical implications of the study are discussed. Thereafter, the limitations of the research are presented. Recommendations for further research are included in both sections.

6.1 Theoretical implications

This thesis empirically contributes as it is the first case study that applies the MIS framework to the Dutch healthcare sector with a focus on circular PPE alternatives. The MIS framework is a relatively new and not often applied theoretical concept. Furthermore, this study examines multiple units of analysis, which in general innovation system studies are often limited to only one unit of analysis. Lastly, the study extends the body of literature by showing how MIS dynamics differ along different dimensions as each mission is unique (Wesseling & Meijerhof, 2021).

Previous research by Kazançoglu et al. (2021) on the systemic barriers for the implementation of circular economy initiatives in the healthcare sector resulted in the identification of two main barriers: 1) high cost requirement for circular technologies and implementations and 2) unfavourable government legislation and execution on circular healthcare. These systemic barriers, identified in the analysis section as the institutional barriers and market barriers, are also found in the results of this study, thereby strengthening this finding in the literature. However, this study identified two more systemic barriers: the lock-in of HCWs in using disposable PPE (behavioural barrier), lack of evidence on the environmental advantage and risk of infection associated with the use of circular PPE alternatives (knowledge barriers). This is another empirical contribution to the literature. In the last step of the MIS, policy instruments and intervention strategies were recommended to overcome these systemic barriers. However, these recommendations are rather general and do not relate to overcoming the barriers of the specific individual circular PPE alternatives. This could be examined in further research.

The theory section shows that previous research has especially focused on examining the environmental impact of disposable PPE. However, the results of this study indicate that there is a clear need for research that compares the environmental impact of disposable PPE and circular alternatives. This is an essential focus point for future research, which would have a significant impact on the general support for the transition towards circular PPE alternatives. Rizan et al. (2021) did in fact conduct such a study by comparing the environmental impact of conventional disposable PPE and the scenario of reusing gowns, face shields and maximizing PPE recycling. Interestingly, the results of this study by Rizan et al. (2021) not only indicated a significantly lower environmental impact of the reusable scenario, but also huge savings in terms of cost[19]. However, the results of this thesis indicate that the extra costs associated with the transition towards using circular PPE alternatives are actually an important barrier. The extra costs are caused by the higher initial costs of circular PPE alternatives and the extra logistics costs. This contrast in findings indicates that the difference in total costs between disposable and circular PPE alternatives is another important focus point for future research.

This thesis aims to understand the MIS dynamics and barriers related to the transition towards circular PPE alternatives within the scope of the eight Dutch academic hospitals. This research scope causes a strong external validity as the findings can be generalized to other academic and conventional hospitals, as the organisational structure and dynamics are generally

[19] 6.5 million euros on a yearly basis in the UK

the same (Weggelaar-Jansen, 2015). However, the results of this study indicate that it would be interesting to extend the research scope, besides the mission arena and overall MIS, with a third element; the international context. In the systemic market barriers part, it came to light that the PPE manufacturers are very important MIS actors, which are large international companies. These PPE manufacturers could be the key to the transition if they switch their profitable business model from producing disposables to circular PPE alternatives. However, the combined purchasing power and demand of the Dutch hospitals is too little to influence the large international PPE manufacturers. Therefore, it would be an interesting topic for further research to examine the dynamics of the MIS when the international context is included in the research scope. The improved understanding of the international institutions and large international actors could result in the identification of more influential policy instruments and intervention strategies to accelerate the transition.

A final theoretical contribution of this thesis is the combination of the MIS framework with the 9R framework by Potting et al. (2017). The 9R framework is especially applied in the problem-solution diagnosis, examining which circular strategies are applied per specific circular PPE alternative. The application of the 9R framework shows which circular PPE alternatives require a fundamental rethinking of the products and which alternatives are less technologically oriented and therefore require less systemic change.

6.2 Limitations

The first limitation is related to the scope of the research. The research scope includes the transition to circular PPE alternative in eight Dutch academic hospitals. During the data collection period, all academic hospitals were approached to participate in this research by interviewing the key stakeholders committed to the circular mission of the Green Deal 2.0 or involved in circularity within the hospitals. However, it was not possible to interview key stakeholders from each academic hospital due to their time constraints. In the end, data was collected through interviews within five out of the eight academic hospitals: LUMC, UMCG, RadboudUMC, Erasmus MC, UMC Utrecht. The missing hospitals are AMC, VUmc and AZM. Moreover, most interviews were conducted with actors that obtain the function of sustainability or procurement manager within the hospital. Therefore, more interviews with a wider variety of experts within all the Dutch academic hospitals would have added to the multidimensionality of the analysis. This could enable the opportunity to examine why different hospitals, such as Radboudumc, are clear frontrunners in the field of circularity. This could be an interesting topic for further research.

Another limitation is found in the data collection methods of this study. To ensure the internal validity of the results, multiple methods of data collection were chosen. However, in practice most data was collected by means of interviews. There is an abundance of literature on disposable PPE and possible circular PPE alternatives. However, the literature specifically on the development and implementation of circular PPE alternatives in the Netherlands is limited. In addition, the amount of LCA studies on circular PPE alternatives in the setting of Dutch hospitals was also limited. The limited availability of studies and literature within the research scope resulted in difficulty to express the indicators of the system function in numbers. On the other hand, the Lexis-Nexis study enabled the collection of data from other sources than published articles, which provided actual data focused within the Netherlands.

A third limitation can be found in the 5th step of the MIS framework in which the policy instruments were identified to overcome the systemic barriers. In this chapter, some general policy instruments and intervention strategies were discussed to overcome these barriers to accelerate the transition. However, these are still rather abstract and are not provided yet with

a clear implementation plan. This thesis empirically contributes by identifying the systemic barriers of the transition towards circular PPE alternatives within hospitals. The more adequate and specific identification of policy instruments to overcome this barrier would need further research.

A final limitation is the fact that this study was conducted in the middle of the execution of the Green Deal 2.0 mission in the Netherlands. This means that the role of the stakeholders and policies implemented by PDZ are still being formed and the effects of these governance actions are still in development as well. Furthermore, the global Covid-19 pandemic, which has played a huge part in exposing the overuse and negative environmental impact of disposable PPE, still has a major effect on the MIS and the use of PPE. For example, the infection prevention guidelines concerning PPE were constantly changed due to the extreme importance of infection prevention and shortages of PPE in hospitals (WHO, 2020). It is very difficult to adequately take this influence of the Covid-19 pandemic and governance actions which are in development into account. This would require a more longitudinal MIS approach with a time period of at least two years, considering the long-term impact and effects of the pandemic on the Dutch healthcare sector.

7. Conclusion

The Covid-19 pandemic has put a lot of pressure on the Dutch healthcare sector. In addition, the pandemic shed light on the enormous amount of waste production caused by the single-use of personal protective equipment (PPE) in hospitals. The transition from these disposable PPE to the use of circular alternatives would save tons of plastic waste production and significantly reduce the environmental impact. However, this transition has not yet taken place within the Dutch academic hospitals, indicating the presence of barriers blocking the acceleration of this transition. This research aims to fill this research gap by examining these barriers of the transition towards circular PPE alternatives that are present within Dutch academic hospitals

In this study, the Mission-oriented Innovation System (MIS) framework has been used to answer the following research question: "*What are the barriers for a transition from disposable personal protective equipment towards circular alternatives in Dutch academic hospitals?*" This transition would directly contribute to the mission of the Green Deal Duurzame Zorg 2.0 of making the Dutch healthcare sector more circular. The research question is examined according to five analytical steps of the MIS approach: problem-solution diagnosis, structural analysis, functional system analysis, systemic barrier analysis, and the identification of systemic instruments. These analytical steps allow the mapping of the circular PPE alternatives, the network of stakeholders and institutions, system strengths and systemic barriers. In the final step of the MIS, recommendations are provided in the form of policy instruments to overcome the identified system barriers. Below the main findings per analytical step are discussed. Thereafter, the main research question is answered.

In the problem-solution diagnosis came to light that Dutch academic hospitals are responsible for enormous amounts of waste production. The increase in single-use PPE has greatly contributed to this waste production. The Green Deal 2.0 was formulated to make the healthcare sector more sustainable, where one of the missions is to work in a more circular way. It was found that there are already several circular PPE alternatives, which could serve as an adequate alternative for the current disposables thereby reducing the amount of waste production and environmental impact. Especially gowns, face shields and goggles have adequate circular alternatives that are available on the market and have also already been used in certain hospitals. Face masks are able to be reused by a steam sterilization method. Lastly, recycling is the best applicable circular strategy for gloves as they are often used in situations where the risk of infection needs to be minimized.

In the structural analysis, the roles of the key actors in the mission arena and the overall MIS were described. It was found that PDZ, a programme under the Dutch Ministry of Health, Welfare and Sport, is responsible for the decision-making in the mission arena and for setting up the activities that are linked to the circular mission of the Green Deal 2.0. PDZ is supported by several interbranch organisations (who are responsible for stimulating, supporting and facilitating parties who have signed the Green Deal 2.0) and knowledge institutes (who are responsible for developing knowledge on circularity in healthcare). However, it was found that in practice the only main influence of the mission arena is the creation of awareness of the urgency of making the healthcare sector more circular and sustainable. The overall MIS consists of all the parties who have signed the Green Deal 2.0 and other remaining actors, such as the PPE manufacturers. Two important institutions were identified in the structural analysis. Firstly, an important hard institution is the infection prevention guidelines within hospitals, which have a clear preference for the use of disposable PPE because of the associated low risk of infection. Secondly, an observed soft institution is the habit of unnecessary overuse of disposable PPE even when it is not obligated by the IP-guidelines.

In the functional system analysis and the systemic barrier analysis, multiple barriers were identified in the overall MIS. It was found that the transition from disposable PPE towards

circular PPE alternatives in Dutch academic hospitals faces four interrelated systemic barriers. Firstly, institutional barriers are caused by the strictness of the IP-guidelines that are currently focused on the risk of infection minimisation. This leads to the discouragement of PPE manufacturers to develop circular alternatives, but provides solution directionality; replacement of disposable PPE with circular alternatives outside the OR. Secondly, knowledge barriers are found due to the lack of research on the environmental advantages of circular PPE alternatives compared to the conventional disposables. These life cycle analyses are essential to creating legitimacy for healthcare workers (HCWs), which are key influential MIS actors in the transition towards circular PPE alternatives. Moreover, the knowledge barriers are also caused by the lack of knowledge on the risk of infection related to sterilising, washing and reusing circular PPE alternatives. This specific knowledge barrier is strongly related to the institutional systemic barrier. It is very challenging to overcome this knowledge barrier as the interviewees emphasized that it is very difficult to prove or disprove the effectiveness of the IP-guidelines. Thirdly, market barriers are caused by the fact that it is not financially interesting for large PPE manufacturers to start developing circular PPE alternatives. Currently, these large international PPE manufacturers have a very profitable disposable PPE business model. More importantly, there is no incentive in the form of financial regulations or institutions from the government to stimulate this. In hospitals, the market barrier is located in the procurement department, which is often open to circular PPE alternatives but does not have the budget to purchase these more expensive alternatives. Fourthly, the behavioural barriers are formed by the lock-in of HCWs favouring the use of disposable PPE. This resistance is caused by their fear of infection and extra effort associated with the use of circular PPE alternatives.

Several policy instruments and intervention strategies were recommended with the goal to overcome the systemic barriers. The identified systemic barriers are used ex-ante to the policy recommendations, meaning that policy instruments are suggested to effectively target these MIS barriers. This is done as there are little to no governance actions in place or planned to be analysed. PDZ is recommended to direct the knowledge institutes of the mission arena to focus on the specific knowledge deficits responsible for the systemic knowledge barriers and institutional barriers. Furthermore, the knowledge barriers can partly be tackled by including the provision of a life cycle analysis as a requirement in a tender. Market barriers should be tackled by the introduction of stimulating financial institutions and regulations with the goal of making circular PPE alternatives a competitive business case against the disposables. Suggestions of such stimulating financial institutions are pricing, standardising and subsidising. Furthermore, the Ministry of Health, Welfare and Sport could organise a circularity fund which hospitals can use to cover the extra costs of the transition towards the full implementation of circular PPE alternatives. Finally, the behavioural barriers of HCWs to disposables are best opposed by educating them by means of informing and convincing the HCWs of the safety and environmental gain of circular PPE alternatives.

To conclude and to answer the main research question, the lack of knowledge on the risk of infection and relative environmental gains of the circular PPE alternatives, strict infection prevention guidelines, high costs related to these circular alternatives and the lock-in of HCWs to disposable PPE form the barriers that hinder the acceleration of the transition to the use of circular PPE alternatives in the Dutch academic hospitals. In addition, there is a lack of government action and intervention stimulating the development of these circular PPE alternatives, which is needed to incentivise large PPE manufacturers to consider changing their business model focused on disposable PPE production. By implementing the recommended policy instruments and intervention strategies to address the identified systemic barriers, the circular PPE alternatives are able to develop and diffuse more effectively which contributes to the circular mission of the Green Deal Duurzame Zorg 2.0.

References

3M. (n.d.). *3M History*. Retrieved 15 August 2022, from https://www.3m.com/3M/en_US/company-us/about-3m/history/#:~:text=As%203M%20employees%20celebrated%203M's,Minnesota%20Mining%20and%20Manufacturing%20Company.

Aarts, F. (2020, May). *Mondneusmaskers: dit moet je weten*. Nursing. Retrieved 1 August 2022, from https://www.nursing.nl/mondneusmaskers-dit-moet-je-weten/

Adyel, T. M. (2020). Accumulation of plastic waste during COVID-19. *Science*, *369*(6509), 1314-1315. https://www.science.org/doi/10.1126/science.abd9925

Akber Abbasi, S., Khalil, A. B., & Arslan, M. (2020). Extensive use of face masks during COVID-19 pandemic: (micro-)plastic pollution and potential health concerns in the Arabian Peninsula. *Saudi Journal of Biological Sciences*, *27*(12), 3181–3186. https://doi.org/10.1016/j.sjbs.2020.09.054

Advancells. (2020, September 26). *Disposable Versus Reusable PPE Kits*. Retrieved 13 December 2021, from https://advancellsgroup.com/blog/disposable-versus-reusable-ppe-kits/

Agarwal, A., Ranjan, P., Saraswat, A., Kasi, K., Bharadiya, V., Vikram, N., ... & Chakrawarty, A. (2021). Are health care workers following preventive practices in the COVID-19 pandemic properly?-A cross-sectional survey from India. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, *15*(1), 69-75. https://doi.org/10.1016/j.dsx.2020.12.016

Allison, A. L., Ambrose-Dempster, E., Bawn, M., Casas Arredondo, M., Chau, C., Chandler, K., ... & Ward, J. M. (2021). The impact and effectiveness of the general public wearing masks to reduce the spread of pandemics in the UK: a multidisciplinary comparison of single-use masks versus reusable face masks. *UCL Open Environment*, *3*. https://ucl.scienceopen.com/hosted-document?doi=10.14324/111.444/ucloe.000022

Armijo, P. R., Markin, N. W., Nguyen, S., Ho, D. H., Horseman, T. S., Lisco, S. J., & Schiller, A. M. (2021). 3D printing of face shields to meet the immediate need for PPE in an anesthesiology department during the COVID-19 pandemic. *American journal of infection control*, *49*(3), 302-308. https://doi.org/10.1016/j.ajic.2020.07.037

Baker, N., Bromley-Dulfano, R., Chan, J., Gupta, A., Herman, L., Jain, N., Taylor, A. L., Lu, J., Pannu, J., Patel, L., & Prunicki, M. (2020). COVID-19 Solutions Are Climate Solutions: Lessons From Reusable Gowns. *Frontiers in Public Health*, *8*. https://doi.org/10.3389/fpubh.2020.590275

van Balen, A. (2021, June 1). *Duurzame zorg vereist herbruikbare isolatiejassen*. ABN AMRO. Retrieved 9 May 2022, from https://www.abnamro.nl/nl/zakelijk/insights/sectoren-en-trends/healthcare/duurzame-zorg-vereist-herbruikbare-isolatiejassen.html

Bishop, C. A. (2011). Process Diagnostics and Coating Characteristics. *Vacuum Deposition onto Webs, Films and Foils*, 81–114. https://doi.org/10.1016/b978-1-4377-7867-0.00005-2

Boots, B., Russell, C. W., & Green, D. S. (2019). Effects of Microplastics in Soil Ecosystems: Above and Below Ground. *Environmental Science & Technology, 53*(19), 11496–11506. https://doi.org/10.1021/acs.est.9b03304

Botta, E., McCormick, C., & Eis, J. (2015). A Guide to Innovation System Analysis for Green Growth. *Global Green Growth Institute Publication, Seoul*.

de Bruyn, S., Ahdour, S., Bijleveld, M., de Graaff, L., Schep, E., Schroten, A., & Vergeer, R. (2017). *Handboek Milieuprijzen 2017: methodische onderbouwing van kengetallen gebruikt voor waardering van emissies en milieu-impacts*. Delft, The Netherlands: CE Delft.

Bryman, A. (2012). *Social Research Methods* (4th ed.). Oxford University Press.

Bureau Bartels. (2021). *Evaluatie Green Deal Duurzame Zorg*. https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2021/12/20/evaluatie-green-deal-duurzame-zorg/evaluatie-green-deal-duurzame-zorg.pdf

Carrico, R. (2006). Recommendations for Personal Protective Equipment Use During an Avian Influenza Pandemic. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.547.6573&rep=rep1&type=pdf
Cohen, J., & van der Meulen Rodgers, Y. (2020). Contributing factors to personal protective equipment shortages during the COVID-19 pandemic. *Preventive medicine, 141*, 106263. 10.1016/j.ypmed.2020.106263

Chabot, M. (2021, September 30). *Subsidies om te verduurzamen helpen weinig: ze verworden tot elitespeeltje*. De Volkskrant. Retrieved 25 July 2022, from https://www.volkskrant.nl/columns-opinie/subsidies-om-te-verduurzamen-helpen-weinig-ze-verworden-tot-elitespeeltje~b6d07cfe/?referrer=https%3A%2F%2Fwww.google.com%2F

Choinere, D., Ayers, C., & Moyle, J. (2011). *The Business Case for Greening the OR*. https://www.c4spgh.org/HCW1_Presentations/GOR_FullSet_Guidance%20Docs_Web_042711.pdf

Chu, J., Ghenand, O., Collins, J., Byrne, J., Wentworth, A., Chai, P. R., Dadabhoy, F., Hur, C., & Traverso, G. (2021). Thinking green: modelling respirator reuse strategies to reduce cost and waste. *BMJ Open*, *11*(7). https://doi.org/10.1136/bmjopen-2021-048687

CleanLease. (2020). *COMFORTABELE, DUURZAME EN HERBRUIKBARE ISOLATIEJAS*. https://nl.cleanlease.com/sites/default/files/cleanlease_isolatiejas_brochure_2020-2021.pdf

Conrardy, J., Hillanbrand, M., Myers, S., & Nussbaum, G. F. (2010). Reducing Medical Waste. *AORN Journal*, *91*(6), 711–721. https://doi.org/10.1016/j.aorn.2009.12.029

Corrêa, H. L., & Corrêa, D. G. (2021). The Covid-19 Pandemic—Opportunities for Circular Economy Practices Among Sewing Professionals in the City of Curitiba-Brazil. *Frontiers in Sustainability*, *2*. https://doi.org/10.3389/frsus.2021.644309

Dargaville, T., Spann, K., & Celina, M. (2020). Opinion to address the personal protective equipment shortage in the global community during the COVID-19 outbreak. *Polymer*

Degradation and Stability, *176*, 109162. https://doi.org/10.1016/j.polymdegradstab.2020.109162

DePoy, E., & Gitlin, L. N. (2016). Mixed Method Designs. *Introduction to Research*, 173–179. https://doi.org/10.1016/b978-0-323-26171-5.00012-4

Desu, R. M., Sanginela, S. K., & Ram, G. (2020). Facilitating Sustainable Waste Management Strategies Within the Hospital—An Explorative Study. *Solid Waste Policies and Strategies: Issues, Challenges and Case Studies*, 57–72. https://link-springer-com.proxy.library.uu.nl/chapter/10.1007/978-981-15-1543-9_6

DiGiacomo, J.C., Odom, J.W., Ritota, P.C., & Swan, K.G. (1992). Cost containment in the operating room: use of reusable versus disposable clothing. *The American surgeon, 58 10,* 654-6 .

Donata, J. (2020, August 16). *Dit ziekenhuis is koploper in de transitie naar circulaire zorg*. ChangeInc. Retrieved 25 June 2022, from https://www.change.inc/circulaire-economie/dit-ziekenhuis-is-koploper-in-de-transitie-naar-circulaire-zorg-34301

Duru, S. D., & Pal, R. (2021). Innovation in manufacturing Personal Protective Equipment: Toward Sustainability and Circularity. https://www.ifc.org/wps/wcm/connect/9c307ecf-b68d-4638-9a0c-df3a65f65c3b/IFC+PPE+FA+v2_WEB.pdf?MOD=AJPERES&CVID=nQ0WWOj

Eindhoven Engine. (n.d.). *About*. Retrieved 2 August 2022, from https://eindhovenengine.nl/about-eindhoven-engine/

(EEA) Environmental Energy Agency. (2021, June 22). *Impacts of COVID-19 on single-use plastic in Europe's environment*. European Environment Agency. Retrieved 15 December 2021, from https://www.eea.europa.eu/publications/impacts-of-covid-19-on

Ellen MacArthur Foundation. (2015). Ellen MacArthur Foundation—The circular economy concept—Regenerative economy. Retrieved 5 January 2022, from www.ellenmacarthurfoundation.org/circular-economy/overview/concept

van der Elsen, A. (2021, May 7). *Dutch PPE Solutions starts large-scale production of filter material for medical facemasks*. DSM. Retrieved 27 June 2022, from https://www.dsm.com/corporate/news/news-archive/2021/2021-05-07-dsm-ppe-solutions-starts-large-scale-production-of-filter-material-for-medical-facemasks.html

Elzinga, R. Janssen, M. Negro, S. O.. Hekkert, M. P. (2020). Het Missie-gedreven Innovatiesysteem: Uitbreiding 'Technologisch Innovatie Systeem'-raamwerk ter monitoring van de Circulaire Economie. *Internal working paper UU.* *https://zenodo.org/record/4005752#.Ye1QCljMKDU*

Elzinga, R. Janssen, M. Negro, S. O.. Hekkert, M. P. (2021). Mission-oriented Innovation Systems Dynamics: Towards an assessment framework. *Internal working paper UU.* *https://conference.druid.dk/acc_papers/pp2nja3sy8855w5u9f73x3s7dg46uo.pdf*

Eppinga, A. (2022, January 11). Eindhoven Engine competes with cheap face masks from abroad. Innovation Origins. Retrieved 9 May 2022, from https://innovationorigins.com/en/eindhoven-engine-competes-with-cheap-face-masks-from-abroad/

Esmizadeh, E., Chang, B. P., Jubinville, D., Ojogbo, E., Seto, C., Tzoganakis, C., & Mekonnen, T. H. (2020). Can Medical-Grade Gloves Provide Protection after Repeated Disinfection? ACS Applied Polymer Materials, 3(1), 445–454. https://doi.org/10.1021/acsapm.0c01202

European Environment Agency. (n.d.). life cycle assessment. Retrieved 22 June 2022, from https://www.eea.europa.eu/help/glossary/eea-glossary/life-cycle-assessment

Evans, L. (2022, January 24). New criteria for sustainable healthcare products. Healthcare Without Harm. Retrieved 11 May 2022, from https://noharm-europe.org/articles/news/europe/new-criteria-sustainable-healthcare-products

Food & Drug Administration. (2021). Medical Gowns. Retrieved 9 May 2022, from https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/medical-gowns

Friedericy, H., Beelen, M., van der Eijk, A., & Jansen, F. W. (2020). Zo vermindert het LUMC z'n CO2-voetafdruk. Medisch Contact. https://www-medischcontact-nl.proxy.library.uu.nl/nieuws/laatste-nieuws/nieuwsartikel/zo-vermindert-het-lumc-zn-co2-voetafdruk.htm

Green Deal. (2019, May). Green Deal: duurzame zorg voor een gezonde toekomst. (C–226). https://www.greendeals.nl/sites/default/files/2019-05/Deal%20tekst%20GreenDeal%20226%20Duurzame%20zorg%20voor%20gezonde%20toekomst_0.pdf

De Groene OK. (2021). Over de Groene OK. Retrieved 18 May 2022, from https://degroeneok.nl/over-ons/over-de-groene-ok/

Gupta Strategists. (2019). *Een stuur voor de transitie naar duurzame gezondheidszorg Kwantificering van de CO2-uitstoot en maatregelen voor verduurzaming*. https://gupta-strategists.nl/storage/files/1920_Studie_Duurzame_Gezondheidszorg_DIGITAL_DEF.pdf

Haddad, S. (2014, September). *Disposable vs reusable gowns: A battle for infection control and sustainability*. Healio. Retrieved 15 December 2021, from https://www-healio-com.proxy.library.uu.nl/news/orthopedics/20140911/j205_3409_14_news_print_3

Haseltine, W. A. (2018, April 2). *Aging Populations Will Challenge Healthcare Systems All Over The World*. Forbes. Retrieved 4 May 2022, from https://www.forbes.com/sites/williamhaseltine/2018/04/02/aging-populations-will-challenge-healthcare-systems-all-over-the-world/

Hedgren, E. (2013). *Overcoming organizational lock-in in decision-making: construction clients facing innovation* (Doctoral dissertation, Luleå tekniska universitet). https://www.diva-portal.org/smash/get/diva2:999391/FULLTEXT01.pdf

Heidari, M., Garnaik, P. P., & Dutta, A. (2019). The Valorization of Plastic Via Thermal Means. *Plastics to Energy*, 295–312. https://doi.org/10.1016/b978-0-12-813140-4.00011-x

Hekkert, M. P., Janssen, M. J., Wesseling, J. H., & Negro, S. O. (2020). Mission-oriented innovation systems. *Environmental Innovation and Societal Transitions*, *34*, 76–79. https://doi.org/10.1016/j.eist.2019.11.011

Hekkert, M. P., & Negro, S. O. (2009). Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. *Technological Forecasting and Social Change*, *76*(4), 584–594. https://doi.org/10.1016/j.techfore.2008.04.013

Hekkert, M.P., Negro, S.O., Heimeriks, G., Harmsen, R.O., & Jong, S.D. (2011). Technological Innovation System Analysis A manual for analysts. UU report

Hekkert, M., Suurs, R., Negro, S., Kuhlmann, S., & Smits, R. (2007). Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change*, *74*(4), 413–432. https://doi.org/10.1016/j.techfore.2006.03.002

Heshmati, A. (2016). A Review of the Circular Economy and its Implementation. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2713032

van Houtum, D. (2022, January 13). *Transitie duurzaamheid vraagt forse investering van zorgsector*. Finance Ideas. Retrieved 16 May 2022, from https://finance-ideas.nl/transitie-duurzaamheid-vraagt-forse-investering-van-zorgsector/

ICU Production. (2021, August). *HOW TO EVALUATE AND SELECT ISOLATION GOWNS*. Retrieved 9 May 2022, from https://www.icu-production.com/how-to-evaluate-and-select-isolation-gowns/#:~:text=Like%20their%20Level%201%20counterparts,%2C%20or%20polyethylene%20(PE).

Institute for Positive Health. (2022, February 2). *Zorgverleners roepen de overheid op om klimaat en gezondheid met spoed te integreren in het onderwijs, binnen de zorg en in het overheidsbeleid*. Retrieved 4 May 2022, from https://zoek.officielebekendmakingen.nl/kst-32813-557.html

Institute of Medicine. (2006). Reusability of Facemasks During an Influenza Pandemic: Facing the Flu. Washington, DC: The National Academies Press. https://doi.org/10.17226/11637.

Intrakoop. (n.d.). *Intrakoop, dé inkoopcoöperatie voor de zorg*. Retrieved 15 August 2022, from https://www.intrakoop.nl/over-ons/onze-organisatie

Janssen, T. (2017, October 27). *Rutte III maakt afval duurder: mooi maar niet echt circulair*. Rabobank. Retrieved 25 June 2022, from https://economie.rabobank.com/publicaties/2017/oktober/rutte-iii-maakt-afval-duurder--mooi-maar-niet-echt-

circulair/#:~:text=Op%2010%20oktober%20presenteerde%20de,ook%20op%20huishoudens%20en%20bedrijven.

Johansen, F., Loorbach, D., & Stoopendaal, A. (2018). Exploring a transition in Dutch healthcare. *Journal of Health Organization and Management*, *32*(7), 875–890. https://doi.org/10.1108/jhom-07-2018-0185

Jones, R. (2020, July 30). *REUSABLE VS. DISPOSABLE PPE: WHY SWITCHING TO GEAR YOU CAN REUSE MAKES GOOD FINANCIAL SENSE*. MSC. Retrieved 15 August 2022, from https://www.mscdirect.com/betterMRO/safety/reusable-vs-disposable-ppe-why-switching-gear-you-can-reuse-makes-good-financial-sense#:~:text=According%20to%20PIP%20calculations%2C%20the,polyurethane%20coating)%20can%20achieve%20monthly

Joseph, B., James, J., Kalarikkal, N., & Thomas, S. (2021). Recycling of medical plastics. *Advanced Industrial and Engineering Polymer Research*, *4*(3), 199-208. https://doi.org/10.1016/j.aiepr.2021.06.003

Kampf, G., Scheithauer, S., Lemmen, S., Saliou, P., & Suchomel, M. (2020). COVID-19-associated shortage of alcohol-based hand rubs, face masks, medical gloves, and gowns: proposal for a risk-adapted approach to ensure patient and healthcare worker safety. *Journal of Hospital Infection*, *105*(3), 424–427. https://doi.org/10.1016/j.jhin.2020.04.041

Kazançoğlu, Y., Sağnak, M., Lafcı, I., Luthra, S., Kumar, A., & Taçoğlu, C. (2021). Big Data-Enabled Solutions Framework to Overcoming the Barriers to Circular Economy Initiatives in Healthcare Sector. *International Journal of Environmental Research and Public Health*, *18*(14), 7513. https://doi.org/10.3390/ijerph18147513

Kenton, W. (2022b, July 4). *Corporate Finance: M&A*. Investopedia. Retrieved 25 July 2022, from https://www.investopedia.com/terms/t/tender.asp
Kenton, W. (2022, May 14). *Economies of Scale*. Investopedia. Retrieved 26 June 2022, from https://www.investopedia.com/terms/e/economiesofscale.asp#:~:text=Key%20Takeaways,savings%20and%20higher%20production%20levels.

(KSU) Kent State University. (2022, January 12). *STATISTICAL & QUALITATIVE DATA ANALYSIS SOFTWARE: ABOUT NVIVO*. Kent State University. Retrieved 19 January 2022, from https://libguides.library.kent.edu/statconsulting/NVivo

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kivimaa, P., Kern, F., 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. Res. Policy 45, 205–217. https://doi.org/10.1016/j.respol.2015.09.008

Kuijpers, M., & Lamens, D. (2022, December 17). *VAN RECHTENSTUDENTEN NAAR PIONIERS IN DUURZAME MEDISCHE ZORG*. Life Sciences & Health. Retrieved 13 August 2022, from https://www.lifesciencesandhealth010.nl/nieuws/van-rechtenstudenten-naar-pioniers-in-duurzame-medische-zorg/

Lauer, J. K., Acker, K. P., Saiman, L., Advincula, A. A., & Berkowtiz, R. L. (2020). PPE during a pandemic: The experience of obtaining PPE and lessons learned from a department of obstetrics and gynecology in New York city. *Seminars in Perinatology*, *44*(6), 151293. https://doi.org/10.1016/j.semperi.2020.151293

LeCompte, M. D., & Goetz, J. P. (1982). Problems of Reliability and Validity in Ethnographic Research. *Review of Educational Research*, *52*(1), 31–60. https://doi.org/10.3102/00346543052001031

LexisNexis. (n.d.). *Onderzoek voor universiteiten en Hogescholen*. Retrieved 19 January 2022, from https://www.lexisnexis.nl/research/nexis-uni

Lundvall, B. Å. (2008). Innovation system research: Where it came from and where it might go. Georgia Institute of Technology.

Lurvink. (2020, June). *Wegwerphandschoenen voor medisch gebruik*. Retrieved 11 May 2022, from https://www.carellurvink.nl/submenu/actueel-en-acties/blog/wegwerphandschoenen-voor-medisch-gebruik-latex-vinyl-of-nitril

MacNeill, A. J., Hopf, H., Khanuja, A., Alizamir, S., Bilec, M., Eckelman, M. J., ... & Sherman, J. D. (2020). Transforming the medical device industry: Road map to a circular economy: Study examines a medical device industry transformation. *Health Affairs*, *39*(12), 2088-2097. https://doi.org/10.1377/hlthaff.2020.01118

Malerba, F. (2005). Sectoral systems of innovation: a framework for linking innovation to the knowledge base, structure and dynamics of sectors. *Economics of Innovation and New Technology*, *14*(1–2), 63–82. https://doi.org/10.1080/1043859042000228688

Marsman, G. (2021). *Reducing lifestyle and living environment related burden of disease in the Netherlands: a Mission-Oriented Innovation Systems Approach* (Master's thesis). https://studenttheses.uu.nl/bitstream/handle/20.500.12932/40972/Master%20Thesis%20Gianna%20Marsman%205516161.pdf?sequence=1&isAllowed=y

Mayer, J., Maier, B., Moors, E., & Pruijn, M. (2022). Disposable medical products used in the OR at the University Medical Center Utrecht: Defining barriers and circular strategies. https://dspace.library.uu.nl/bitstream/handle/1874/421049/Mayer_et_al_2022_Final_Report_Research_Disposable_medical_products_used_at_UMCU.pdf?sequence=1

McQuerry, M., Easter, E., & Cao, A. (2021). Disposable versus reusable medical gowns: A performance comparison. *American Journal of Infection Control*, *49*(5), 563–570. https://doi.org/10.1016/j.ajic.2020.10.013

Melkert, A., Schneider, M., Westerlaken, A., Peetoom, R., van der Ham, B., van den Berg, D., & van der Laan, M. (2022, March 8). *Position Paper Green Deal Duurzame Zorg 2.0*. Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. (2021, March). *Normeren en beprijzen van stikstofemissies*. https://www.aanpakstikstof.nl/binaries/aanpakstikstof/documenten/rapporten/2021/03/19/rapport-normeren-en-beprijzen-van-stikstofemissies/Rapport+Normeren+en+Beprijzen+van+stikstofemissies+2021.PDF

(MPZ) Milieu Platform Zorgsector. Retrieved 20 June 2022, from https://milieuplatformzorg.nl/media/medialibrary/2022/03/Brief_aan_minister_Jetten_inzake_duurzaamheid.pdf

(MPZ) Mileuplatform Zorgsector. (n.d.). *Green Deal Zorg*. Mileuplatform Zorgsector. Retrieved 21 January 2022, from https://milieuplatformzorg.nl/green-deal/

Ministry of Economic Affairs and Climate. (2019). *Missiegedreven Topsectoren- en Innovatiebeleid* (No. 19070216). https://www.rijksoverheid.nl/documenten/kamerstukken/2019/04/26/kamerbrief-over-missiegedreven-topsectoren-en-innovatiebeleid

Modint. (2021, March 16). *Modint leden actief in project duurzame medische isolatiejassen*. Retrieved 27 June 2022, from https://modint.accept.yard.nl/nieuws/853-modint-leden-actief-in-project-duurzame-medische-isolatiejassen

Mostaghimi, A., Antonini, M. J., Plana, D., Anderson, P. D., Beller, B., Boyer, E. W., Fannin, A., Freake, J., Oakley, R., Sinha, M. S., Smith, L., Van, C., Yang, H., Sorger, P. K., LeBoeuf, N. R., & Yu, S. H. (2020). Regulatory and Safety Considerations in Deploying a Locally Fabricated, Reusable Face Shield in a Hospital Responding to the COVID-19 Pandemic. *Med*, *1*(1), 139–151. https://doi.org/10.1016/j.medj.2020.06.003

NEDERLANDSE FEDERATIE VAN UNIVERSITAIR MEDISCHE CENTRA. (2019, April). *Onderzoek en innovatie met en voor de gezonde regio*. https://www.nfu.nl/sites/default/files/2020-08/19.2122-NFU_Onderzoek__innovatie_met_en_voor_de_gezonde_regio_0.pdf

NEN. (2021, April 1). *NEN-EN 13795–1:2019*. Retrieved 9 May 2022, from https://www.nen.nl/nen-en-13795-1-2019-en-257813

Nghiem, L. D., Iqbal, H. M., & Zdarta, J. (2021). The shadow pandemic of single use personal protective equipment plastic waste: A blue print for suppression and eradication. *Case Studies in Chemical and Environmental Engineering*, *4*, 100125. https://doi.org/10.1016/j.cscee.2021.100125

Parent, J., Cucuzzella, C., & Revéret, J. P. (2013). Revisiting the role of LCA and SLCA in the transition towards sustainable production and consumption. *The International Journal of Life Cycle Assessment*, *18*(9), 1642-1652. https://doi.org/10.1007/s11367-012-0485-9

Paterson, A. (2020, June). *Planning for the new normal: is PPE reusable?* Streamline. Retrieved 12 May 2022, from https://www.brandedbystreamline.com/2020/06/is-ppe-reusable/

Peng, Y., Wu, P., Schartup, A. T., & Zhang, Y. (2021). Plastic waste release caused by COVID-19 and its fate in the global ocean. *Proceedings of the National Academy of Sciences*, *118*(47). https://doi.org/10.1073/pnas.2111530118

Perencevich, E. N., Diekema, D. J., & Edmond, M. B. (2020). Moving personal protective equipment into the community: face shields and containment of COVID-19. *Jama*, *323*(22), 2252-2253. https://doi.org/10.1001/jama.2020.7477

Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). *Circular economy: measuring innovation in the product chain* (No. 2544). PBL Publishers.

Prata, J. C., Silva, A. L., Walker, T. R., Duarte, A. C., & Rocha-Santos, T. (2020). COVID-19 Pandemic Repercussions on the Use and Management of Plastics. *Environmental Science & Technology*, *54*(13), 7760–7765. https://doi.org/10.1021/acs.est.0c02178

Reflow. (n.d.). *THE DEVELOPMENT OF CIRCULAR ISOLATION GOWNS*. Retrieved 26 June 2022, from https://reflowproject.eu/blog/the-development-of-circular-isolation-gowns-a-case-study/

Rijksoverheid. (n.d.). *Landelijk Consortium Hulpmiddelen (LCH)*. Retrieved 15 August 2022, from https://www.rijksoverheid.nl/contact/contactgids/landelijk-consortium-hulpmiddelen-lch

Rijksoverheid. (2020, October 12). *Voldoende beschermingsmiddelen voor de zorg beschikbaar*. Retrieved 22 June 2022, from https://www.rijksoverheid.nl/actueel/nieuws/2020/10/12/voldoende-beschermingsmiddelen-voor-de-zorg-beschikbaar

Rijksoverheid. (n.d.). *Arbobeleid*. Arbobeleid. Retrieved 6 June 2022, from https://www.rijksoverheid.nl/onderwerpen/arbeidsomstandigheden/arbobeleid

Rijksoverheid. (n.d.). *Nederland circulair in 2050*. Retrieved 4 May 2022, from https://www.rijksoverheid.nl/onderwerpen/circulaire-economie/nederland-circulair-in-2050#:~:text=203050%25%20minder%20gebruik%20van,mineralen%2C%20metalen%20en%20fossiel).

Rimmer, A. (2020). Covid-19: Experts question guidance to reuse PPE. https://doi.org/10.1136/bmj.m1577

RIVM. (2015). *Algemene voorzorgsmaatregelen Persoonlijke beschermingsmiddelen*. https://www.rivm.nl/sites/default/files/2018-11/150922%20Persoonlijke%20beschermingsmiddelen-DEFINITIEF.pdf

RIVM. (2022, May). *RIVM en duurzame zorg*.

Rizan, C., Reed, M., & Bhutta, M. F. (2020). Environmental impact of Personal Protective Equipment supplied to health and social care services in England in the first six months of the COVID-19 pandemic. *MedRxiv*. Published. https://doi.org/10.1101/2020.09.21.20198911

Rowan, N. J., & Laffey, J. G. (2021). Unlocking the surge in demand for personal and protective equipment (PPE) and improvised face coverings arising from coronavirus disease (COVID-19) pandemic – Implications for efficacy, re-use and sustainable waste management. *Science of The Total Environment*, *752*, 142259. https://doi.org/10.1016/j.scitotenv.2020.142259

RVO. (2021, February 26). *Publieke samenvattingen SBIR oproep Duurzame isolatiejassen voor de zorg fase 1*. Retrieved 27 June 2022, from https://www.rvo.nl/subsidies-financiering/sbir/abc-sbir/duurzame-isolatiejassen-zorg/publieke-samenvattingen

Samah, I. H. A., Rashid, I. M. A., Husain, W. A. F. W., Ibrahim, S., Hamzah, H., & Amlus, M. H. (2020). THE IMPACT OF HEALTHCARE EXPENDITURE AND HEALTHCARE SECTOR GROWTH ON CO2 EMISSION USING DYNAMIC PANEL DATA SYSTEM GMM ESTIMATION MODEL DURING COVID 19 CRISIS. *International Journal of Energy Economics and Policy*, *10*(6), 235–241. https://doi.org/10.32479/ijeep.9769

Schmidt, C. (2022, March 7). *Tons of COVID Medical Garbage Threaten Health*. Scientific American. Retrieved 11 May 2022, from https://www-scientificamerican-com.proxy.library.uu.nl/article/tons-of-covid-medical-garbage-threaten-health/#

SHOWA. (2018). *SHOWA Gloves*. https://www.showagroup.com/wp-content/uploads/2021/02/SHOWA_6110PF.pdf

Siwal, S. S., Chaudhary, G., Saini, A. K., Kaur, H., Saini, V., Mokhta, S. K., ... & Thakur, V. K. (2021). Key ingredients and recycling strategy of personal protective equipment (PPE): Towards sustainable solution for the COVID-19 like pandemics. *Journal of Environmental Chemical Engineering*, *9*(5), 106284. https://doi.org/10.1016/j.jece.2021.106284

van Straten, B., Ligtelijn, S., Droog, L., Putman, E., Dankelman, J., Weiland, N. H., & Horeman, T. (2021). A life cycle assessment of reprocessing face masks during the Covid-19 pandemic. *Scientific reports*, *11*(1), 1-9. https://doi.org/10.1038/s41598-021-97188-5

Suurs, R. A., & Hekkert, M. P. (2009). Cumulative causation in the formation of a technological innovation system: The case of biofuels in the Netherlands. *Technological Forecasting and Social Change*, *76*(8), 1003–1020. https://doi.org/10.1016/j.techfore.2009.03.002

TenCate Fabrics. (n.d.). *Who we are*. Retrieved 15 August 2022, from https://eu.tencatefabrics.com/about-us

Tensen & Nolte. (n.d.). *Specialistische advisering in de zorg*. Retrieved 15 August 2022, from https://tensennolte.nl/#:~:text=Tensen%20%26%20Nolte%20Infectiepreventie%20verzorgt%20sinds,bij%20klanten%20door%20heel%20Nederland.

Uddin, M. A., Afroj, S., Hasan, T., Carr, C., Novoselov, K. S., & Karim, N. (2021). Environmental Impacts of Personal Protective Clothing Used to Combat COVID- 19. *Advanced Sustainable Systems*, 2100176. https://doi.org/10.1002/adsu.202100176

United Nations Environment Programme. (2020). *Waste Management during the COVID-19 Pandemic: From Response to Recovery*. https://wedocs.unep.org/bitstream/handle/20.500.11822/33416/WMC-19.pdf?sequence=1&isAllowed=y

VHIG. (n.d.). *Richtlijnen*. Retrieved 30 June 2022, from https://vhig.nl/vereniging-voor-hygiene-infectiepreventie-in-de-gezondheidszorg/richtlijnen/

WALO. (n.d.). *Wat is het verschil tussen een chirurgisch- en FFP mondmasker?* WALO. Retrieved 9 May 2022, from https://www.walo.nl/nieuws/8/wat-is-het-verschil-tussen-een-chirurgisch-en-ffp-mondmasker-zo-zit-dat#:~:text=FFP%20maskers,-FFP%20maskers%20moeten&text=FFP1%20maskers%20hebben%20een%20effici%C3%ABntie,niet%20meer%20dan%208%25%20zijn

Wassink, J. (2022, March 26). *Masks reusable after sterilisation*. Delta. Retrieved 9 May 2022, from https://www.delta.tudelft.nl/article/masks-reusable-after-sterilisation

Weggelaar-Jansen, A. M., De Bruyne, M. C., Wagner, C., & Bal, R. (2015). Kwaliteitsverbetering opleidingsziekenhuis blijkt maatwerk: Structuur organisatie is bepalend. *Boardroom zorg*, (1), 236-239. https://www.eur.nl/eshpm/media/2019-01-artikel-boardroom-zorg-nfu-onderzoek-kwaliteitsgovernance

Wesseling, J. H., & Meijerhof, N. (2020). Development and application of a Mission-oriented Innovation Systems (MIS) approach. *Internal working paper UU.* *https://www.uu.nl/sites/default/files/Wesseling%20and%20Meijerhof%202020_working%20paper.pdf*

Willemsen, A. (2021, April 7). *Duurzaam werken in herbruikbare isolatiejassen*. Intrakoop. Retrieved 9 May 2022, from https://www.intrakoop.nl/nieuws/details/2021/04/07/duurzaam-werken-in-herbruikbare-isolatiejassen

Windfeld, E. S., & Brooks, M. S. L. (2015). Medical waste management – A review. *Journal of Environmental Management*, *163*, 98–108. https://doi.org/10.1016/j.jenvman.2015.08.013

(WHO) World Health Organization. (2009). WHO guidelines on hand hygiene in health care. In *WHO guidelines on hand hygiene in health care* (pp. 270-270). Retrieved 11 May 2022, from https://apps.who.int/iris/rest/bitstreams/52455/retrieve

(WHO) World Health Organization. (2020). *Infection prevention and control during health care when coronavirus disease (COVID-19) is suspected or confirmed: interim guidance, 29 June 2020* (No. WHO/2019-nCoV/IPC/2020.4). World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/332879/WHO-2019-nCoV-IPC-2020.4-eng.pdf

(WHO) World Health Organization. (2020). *Rational use of personal protective equipment for coronavirus disease (COVID-19) and considerations during severe shortages: interim guidance, 6 April 2020* (No. WHO/2019-nCov/IPC_PPE_use/2020.3). World Health Organization. Retrieved 12 May 2022, from https://apps.who.int/iris/bitstream/handle/10665/331695/WHO-2019-nCov-IPC_PPE_use-2020.3-eng.pdf?sequence=9&isAllowed=y

(WHO) World Health Organization. (n.d.). *Disability-adjusted life years (DALYs)*. Retrieved 6 January 2022, from https://www.who.int/data/gho/indicator-metadata-registry/imr-details/158

(WHO) World Health Organization. (n.d.). *Health product and policy standards*. Retrieved 9 December 2021, from https://www.who.int/teams/health-product-policy-and-standards/assistive-and-medical-technology/medical-devices/ppe

(WHO) World Health Organization. (2020, March 3). *Shortage of personal protective equipment endangering health workers worldwide*. Retrieved 9 December 2021, from https://www.who.int/news/item/03-03-2020-shortage-of-personal-protective-equipment-endangering-health-workers-worldwide

(WHO) World Health Organization. (2016). *Towards environmentally sustainable health systems in Europe*. https://www.euro.who.int/__data/assets/pdf_file/0012/321015/Towards-environmentally-sustainable-HS-Europe.pdf

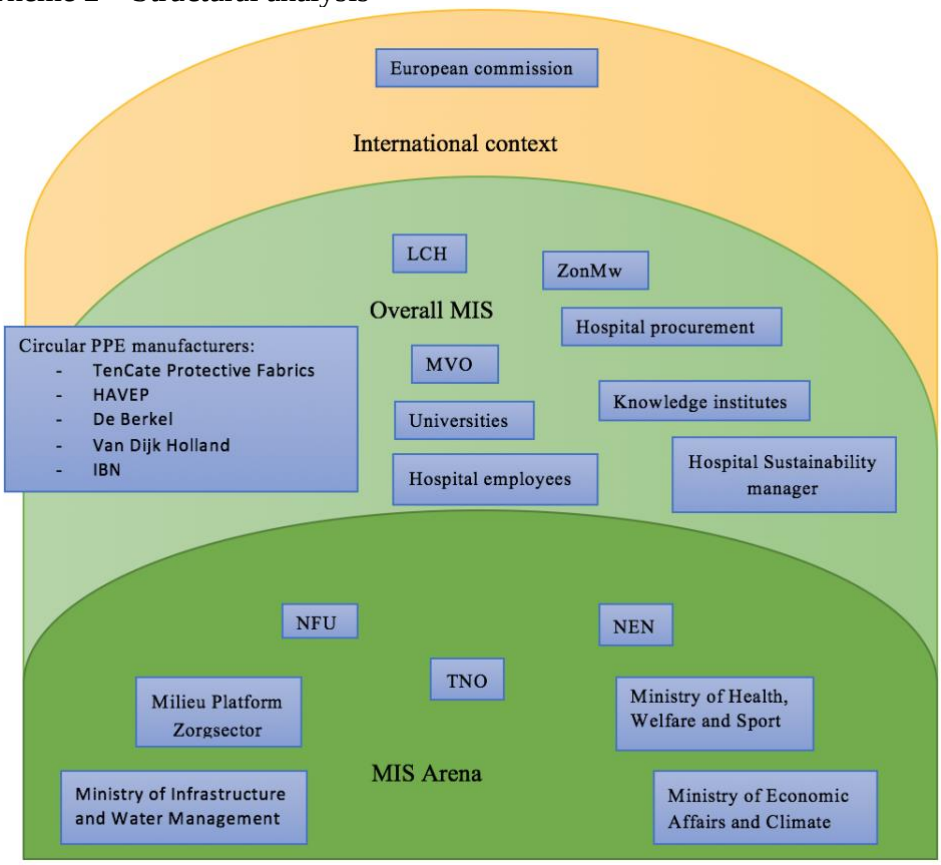
Appendix A: Interview guide

I would like to record this interview in order to analyse the data afterwards. In the thesis, your contribution will remain anonymous. Do you agree that the interview is recorded and this data is used?

Theme 1 - Solution diagnosis

Which existing circular alternatives to single-use PPE do you know? If yes, which solutions do you consider to have the highest potential to lower the amount of medical waste? What is the state of technical and market development?

Theme 2 – Structural analysis



Here is a visualisation of the actors in the mission-oriented innovation system that influence the transition towards circular PPE solutions. Are there any actors that are missing in this picture? Which institutions (rules and regulations) have the biggest influence on the transition?

Theme 2 – Entrepreneurial activities

Description system function	Experiments to develop circular PPE solutions to enable learning. Entering markets for new circular PPE solutions. Upscaling new business models and phase out of existing business models that obstruct the completion of the Green Deal Duurzame Zorg 2.0 mission.
Indicators	Presence of: - experiments to develop circular PPE solutions. - new business models supporting reusing PPE.
To what extent are these entrepreneurial activities adequate to achieve the transition towards circular healthcare?	

Theme 3 – Knowledge development

Description system function	Learning by searching and doing resulting in new technical and socio-institutional knowledge to develop circular PPE solution directions through R&D, social and behavioural science research.
Indicators	Presence of: - R&D projects related to circular PPE. - Investments in R&D. - Publications on circular PPE solutions. - new patents.
Is knowledge to develop existing and new circular PPE solutions, created sufficiently rapidly to support the transition? To what extent is the knowledge development adequate to support the transition towards using circular PPE. Are actors sufficiently unlearning practices that are harmful to the transition, such as discarding PPE after single-use?	

Theme 4 – Knowledge diffusion

Description system function	The dissemination of technical knowledge on the negative impacts of single-use PPE and on the circular PPE solutions between actors
Indicators	Presence of: - stakeholder meetings, conferences, mission progress and network activities dedicated to the transition towards circular PPE.

Is knowledge about the societal problem, of medical waste production and shortage of PPE, shared and diffused sufficiently to support the circular mission of the Green Deal 2.0? Is the knowledge to develop and use circular PPE solutions shared and diffused sufficiently amongst all actors of the IS?

Theme 5 – Problem directionality

Description system function	Actions with the goal of creating consensus regarding the urgency of the Green Deal Duurzame Zorg 2.0 and the level of prioritisation over other societal problems.
Indicators	- Presence of acknowledging the waste problem caused by single-use PPE in the academic hospitals, research institutes, PPE manufacturers. - Degree to which the problem is on their agenda.
How do the stakeholders prioritise the sustainability problem of single-use PPE in relation to other societal problems (safety, financial, etc.)? To what extent is priority given to transitioning to circular PPE in relation to other relevant challenges in the healthcare sector?	

Theme 6 – Solution directionality

Description system function	Actions with the goal of providing insight in possible circular PPE solutions, aligning expectations regarding these solutions, and providing strategies to converge around solution directions.
Indicators	- Expectations in the field on circular PPE solutions. - Presence of stimulating regulations and institutions for circular PPE solutions.
What circular PPE solutions are prioritized by actors in the healthcare sector? To what extent do you think there is a consensus among actors in the healthcare sector about what circular PPE solutions have the priority to achieve the Green Deal 2.0 mission?	

Theme 7 – Reflexivity

Description system function	Monitoring progress and potential of circular PPE solutions to coordinate and structure solution directions.
Indicators	- Presence of a monitoring organisation evaluating progress towards the transition to circular PPE and contributing to the Green Deal.
Is the Green Deal 2.0 mission monitored? And are the policy instruments supporting the Green Deal 2.0 mission regularly evaluated, and designed when necessary?	

To what extent is the progress of the transition to circular healthcare monitored and evaluated and redesigned to achieve the Green Deal 2.0 mission?

Theme 8 – Market formation

Description system function	The creation of (niche) markets and upscaling demand/support for circular PPE solutions.
Indicators	Presence of: - regulations/institutions that oblige or stimulate to apply circular PPE solutions. - niche markets.
Are there any formal or informal policies supporting the diffusion of circular PPE solutions in the healthcare sector? What do you think about the level of the attractiveness of the market for developing and diffusing circular PPE alternatives that contribute to the Green Deal 2.0 mission? To what extent do you observe a destabilisation of the existing single-use PPE markets?	

Theme 9 – Mobilisation of resources

Description system function	Mobilisation of financial, human, material and infrastructural resources to enable all other system functions.
Indicators	Availability of: - financial and human resources (through governments or companies) for innovation, research, pilots and investments in circular PPE solutions. - raw materials and infrastructure to produce circular PPE solutions.
What kind of resources (human, financial or material) are mobilised to fulfil the transition towards circular PPE use in healthcare? To what extent are there resources available that contribute to the circularity in hospitals?	

Theme 10 – Creation of legitimacy

Description system function	The creation of a supportive socio-institutional environment for circular PPE solutions that contribute to mission completion, through raising awareness for the Green Deal Duurzame Zorg 2.0 mission and the circular PPE solutions and lobbying for resources and supportive policies in line with this mission.
Indicators	Presence of:

	- MIS stakeholder's support for the transition towards circular PPE solutions. - interest groups advocating against circular PPE solutions.
Do you experience resistance amongst actors in the healthcare sector against the transition towards using circular PPE? To what extent is resistance counteracted and more legitimacy created for circular PPE in order to achieve the Green Deal 2.0 mission? What solutions receive the strongest lobby support or opposition?	

Theme 11 – Additional barriers

Do you experience or know any additional barriers to transitioning towards circular PPE solutions in the Dutch healthcare sector that have not already been discussed?

Appendix B: Table comparing initial costs of disposable and circular PPE-items

	Disposable	Circular alternative	Source
Isolation Gown	€1,00	€1,75	(van Balen, 2021)
Face masks	€0,31	€2,42	(Allison et al., 2021)
Gloves	€0,36	€0,60	(Jones, 2021)