A macro level of assessment of material circularity

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Chapter 5

Macroeconomic, social, and environmental impacts of a circular economy up to 2050: A meta-analysis of prospective studies

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Abstract

The potential impacts on gross domestic product, employment, and carbon emissions of implementing a circular economy have been modelled at the national and multiregional levels using multiple scenarios. However, there is still no consensus on the magnitude of the impacts of a transition to a circular economy and on whether it will generate a 'win-win-win' situation in terms of macroeconomic, social and environmental benefits. In this chapter, we review more than 300 circular economy scenarios in the time frame from 2020 to 2050. We classify each scenario according to the degree of intervention (i.e. ambitious or moderate), and perform a meta-analysis of the changes in gross domestic product, job creation, and CO_2 emissions generated by each circular economy scenario compared with a business-as-usual scenario. Among other results, we find that in 2030 the implementation of ambitious circular economy scenarios could generate a 'win-win-win' situation with marginal or incremental changes in gross domestic product (median (mdn) = 2.0%; interquartile range (IQR) = [0.4–4.6]%) and employment (mdn = 1.6%; IQR = [0.9–2.0]%), while reducing CO_2 emissions in a more substantial way (mdn = -24.6%; IQR = -[34.0–8.2]%). Furthermore, we discuss the modelling features (e.g. resource taxes, technology changes, and consumption patterns) suggested in the literature which yield the greatest changes in gross domestic product, job creation, and CO_2 emissions. The outcomes of this chapter are relevant to the scientific community and policy makers for understanding the magnitude of the macroeconomic, social and environmental impacts of circular economy scenarios.

Keywords: circular economy, resource efficiency, computable general equilibrium, input-output analysis, scenario analysis

5.1. Introduction

Society currently faces the challenges of satisfying human needs and preserving biological diversity and resources as well as tackling climate change (de Coninck et al., 2018). These aspects have been considered in the sustainability field, which integrates economic, social and environmental dimensions (Bonan & Doney, 2018; Valdivia et al., 2013). In the context of sustainability policies, resource efficiency has been proposed as a key measure to reach prosperity (Allwood et al., 2010; IRP, 2019). In particular, the circular economy is recognized as a paradigm that enables changes in global resource management and contributes to achieving sustainability (Ghisellini et al., 2016; WEF, 2014).

Several literature reviews have been carried out in the field of circular economy. Most researchers have focused on the concept of circular economy and its implementation in business models and new technologies (see, for example, Geissdoerfer et al., 2017; Kirchherr et al., 2017; Pan et al., 2015; Tukker, 2015). Nevertheless, as shown in Chapter 2, there is still little understanding of the magnitude of potential socio-economic and environmental impacts of a transition to a circular economy at the macro level, i.e. on national, multinational and global scales (Wiebe et al., 2019; Woltjer, 2018). The macro-level perspective is essential for identifying which policy measures can be implemented to promote a cost-effective circularity transition (Geng et al., 2012a; McDowall et al., 2017). Due to the dearth of literature on the macro-level implications of a transition to a circular economy, our study is specifically focused on the macro-level perspective of circularity.

Moreover, multiple measures that enhance resource use and retain materials inside the economy - here, circularity interventions - have been proposed by McDowell et al. (2017) and the Ellen MacArthur Foundation (EMF, 2013). As described in Chapter 2, circularity interventions can be grouped into four types: closing supply chains, residual waste management, product lifetime extension, and resource efficiency (Aguilar-Hernandez et al., 2018). Currently, governments are increasingly interested in monitoring the performance of circularity interventions (Geng et al., 2012; Linder et al., 2017; Mayer et al., 2018). This has led to the emergence of a plethora of studies that try to understand what the impacts of a widespread adoption of circularity interventions (i.e. a circularity transition) will be. To do so requires elaborating circular economy scenarios (CESs), i.e., consistent and coherent descriptions of possible future developments if circularity interventions were implemented (van Notten, 2006; Woltjer, 2018). Several previous publications, which we survey in the following paragraphs, report critical reviews of CESs. The reason for reviewing these publications is that they revised CESs at country and global scales.

McCarthy et al. (2018) surveyed journal articles and grey literature on the macroeconomic assessment of a circular economy. The authors provided an overview of the methods used to analyze the effects of circular economy policies. They focused on studies using macroeconomic models, such as the computable general equilibrium model (CGE) and CGE-based models (see, for example, Cambridge Econometrics, European Commission, 2014; Winning et al., 2017). Furthermore, they assessed the macroeconomic models in 4 dimensions: geography, sectors, material coverage, and economic instruments. Most of the models reviewed by McCarthy et al. (2018) reported CESs which by 2030 contribute to changes of 0 to 15% in gross domestic product (GDP) compared to a baseline scenario. The researchers also discussed how modelling circularity interventions could involve a shift in material extraction and material use across different countries. The authors also highlighted the importance of model assumptions regarding the level of productivity growth, the quantity and quality of materials, and consumption patterns for the magnitude of the model outcomes.

Best et al. (2018) examined the literature on the potential effects of circularity interventions in the European Union (EU). The authors summarized the studies regarding material efficiency and CES. Furthermore, they provided quantitative evidence of GDP and employment changes based on the scenario analysis. The numerical values reported in that study were retrieved from the Circular Impacts Project (CI, 2018), which provides a comprehensive and publicly available online library of circular economy studies. Their findings showed that CESs ranged from -6% to 7% of GDP, and from -0.1% to 1% of job creation compared to baseline scenario in 2030. Best et al. (2018) also suggested that the wide range of macroeconomic indicators is caused by the assumptions used in each model, which include rebound effects, technological changes, recycling feasibility, consumer behavior, and trade-offs between countries.

Besides the macroeconomic and integrated assessment models reviewed above, some studies also used structural models to assess the impact of CESs. Structural models use the connections between economic sectors and final demand to estimate the socioeconomic and environmental impacts of consumption (de Koning, 2018; Donati et al., 2020). A particular type of structural models uses environmentally extended input–output analysis (EEIOA), and several EEIOA-based models have explored the socioeconomic and environmental impacts of CESs at national and multi-regional levels.

Even though the reviews mentioned above compiled extensive literature on CESs and their potential impacts, the researchers did not statistically analyze the socioeconomic and environmental impacts of the CESs surveyed. Furthermore, to the best of our knowledge, no published study has examined the interactions between the impacts of circularity interventions across different indicators, i.e., whether there are trade-offs between macroeconomic, social or environmental impacts. We aim to fill this research gap by performing a statistical analysis of CES literature that correlates macroeconomic, social and environmental indicators in order to determine if circularity interventions could result in a ‘win-win-win’ situation at the macro scale.

In this chapter, we perform a meta-analysis of CESs from 2020 to 2050, assessing changes in GDP, employment, and CO_2 emissions at the macro scale. Our aims are to examine whether there is a consensus among existing prospective studies and to statistically quantify the changes in each indicator (GDP, employment, CO_2 emissions) compared to a baseline scenario, which will be explained in section 2. We then combine the three indicators and perform a correlation analysis between these indicators to determine whether a circularity transition could lead to a ‘win-win-win’ situation in terms of macroeconomic, social and environmental impacts. Finally, we discuss the modelling features (i.e. the specific attributes or aspects modelled in each CES, such as resource taxes, technology changes, etc.) that yield the major changes in GDP, employment, and CO_2 emissions suggested by the literature. This chapter presents a novel approach to harmonizing values across CESs from multiple publications, and to performing a meta-analysis in a consistent framework. Our findings are relevant to the scientific community and policy makers, as these results provide insight into the magnitude of the macroeconomic, social, and environmental impacts of CESs.

The chapter proceeds as follows: Section 5.2 presents methods and data, including literature search, eligibility criteria and meta-analysis; Section 5.3 shows the outcomes of the literature review and meta-analysis; Section 5.4 discusses the findings in the context of the key measures proposed in the literature to promote a circularity transition, the modelling limitations and suggestions for further research; Section 5.5 presents the final conclusions.

5.2. Method and data

The following section is divided into two parts: literature search and eligibility criteria, and meta-analysis. First, we explain the literature search and eligibility criteria, including the steps in which publications were retrieved from search engines as well as the reasons for including or excluding certain records (i.e. specific scientific journal papers or technical reports that are publications from grey literature). Second, we describe the steps of the meta-analysis, which includes collecting data from selected publications, harmonizing their values, and performing a correlation analysis.

5.2.1. Literature search and eligibility criteria

We conducted a literature search on December 2019 following the PRISMA guidelines for reporting a transparent systematic review and meta-analysis (Moher et al., 2015). The PRISMA guidelines have been widely applied to meta-analyses in medicine and other fields for developing systematic reviews and meta-analyses in a consistent way (Liberati et al., 2009; Zumsteg et al., 2012), thus providing a suitable framework for our own literature search. Although several studies report other approaches for performing literature reviews and meta-analysis (Horváthová, 2010, for example, 2012; Luederitz et al., 2016), the PRISMA guidelines provide a suitable framework to perform systematic reviews and meta-analysis in a transparent way, and their application in sustainability studies has increased in recent years (see, for example, Blanco et al., 2020; Jin et al., 2019; van Zalk & Behrens, 2018).

The three indicators assessed in this chapter were GDP, employment (or job creation), and CO_2 emissions. These indicators can be used to represent the macroeconomic, social and environmental impacts, which are three main dimensions considered in the sustainability field (Valdivia et al., 2013). Assessing the impacts of CESs on these indicators is essential to evaluate the implementation of circular economy policies (McDowall et al., 2017).

We used the web search engines Web of Science, Circular Impact Project Library (CI, 2018), and Google Scholar to retrieve peer-reviewed and grey literature in English without restrictions on the time period. We searched for terms describing ‘circular economy’ combined with macro-indicators terms, such as ‘GDP’ OR ‘job creation’ OR ‘employment’ OR ‘carbon emission’ OR ‘CO2’ (see worksheet figure_1 in file data_source.xlsx of Supplementary Material for a detailed list of key words used in each search engine). We also completed these searches with the snowballing procedure described by Wolhin (2014). The expected result of this step is that we collect the CES literature in a systematic way.

The search resulted in the retrieval of 595 publications (see figure 5.1), which were eligible for the meta-analysis if the studies met all of the following 4 criteria:

At least one circularity intervention type (i.e. closing supply chain, product lifetime extension, residual waste management, or resource efficiency based on Aguilar-Hernandez et al. (2018)) was assessed;

At least one macroeconomic, social or environmental indicator – here, GDP, job creation and CO_2 emissions, respectively - was quantified as a model outcome;

The impacts at national, multi-national or global scales were assessed with structural, macro-economic or integrated assessment models (as described by de Koning (2018));

And prospective scenarios were analyzed from 2020 to 2050 in comparison with a respective baseline scenario.

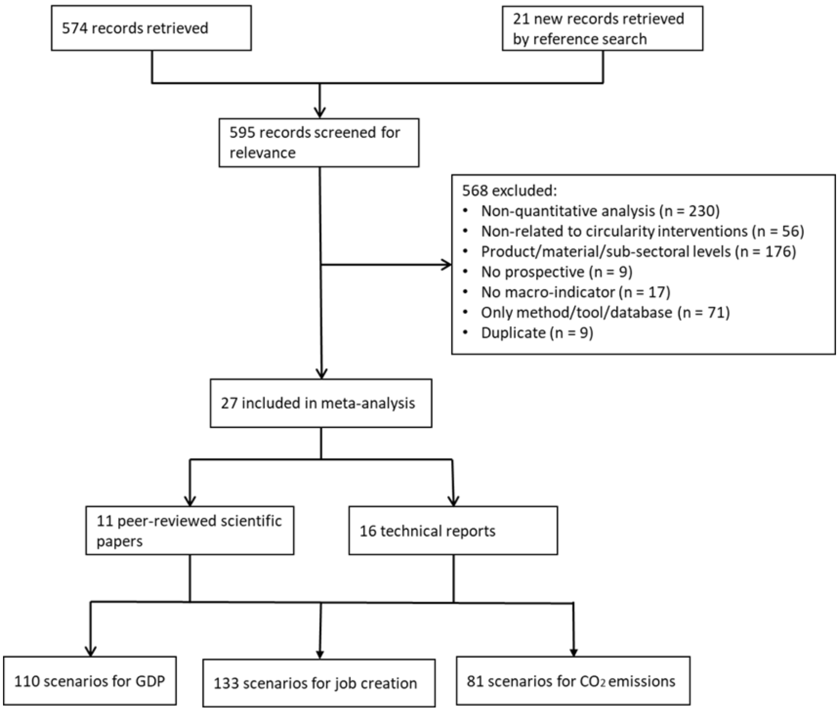

Figure 5.1. Flowchart of the inclusion of selected publications (status in December, 2019). A record is a scientific journal paper and/or technical report (i.e. publication from grey literature). Retrieved records are the publications that were found using the search engines. Excluded records are the publications that did not meet the eligibility criteria and were discarded from the meta-analysis.

The literature search resulted in 27 relevant papers, which accounted for 324 CESs (see table 1). Of the 27 studies, 6 (22% of the total) estimated only CO_2 emissions, 3 (11%) estimated job creation, 1 (4%) estimated GDP, and 17 (63%) combined the three indicators. The geographical dimension consisted of 8 (30%) studies focused on the national level, 9 (33%) related to a multi-regional level, and 11 (37%) that combined national, multi-national and global scales. Regarding the circularity intervention types, 8 publications (30%) assessed resource efficiency, 3 (11%) assessed closing supply chains, 1 (4%) assessed residual waste management only, and 15 (55%) integrated product lifetime extension, closing supply chains, residual waste management and resource efficiency.

The exclusion of almost 95% of records was due to the fact that these publications did not meet the eligibility criteria mentioned above. They were excluded for not being quantitative assessments of CESs (40% of all excluded records); for not being a macro-level assessment but focusing on product, material, or sectoral scales (31%); for lacking at least one of the 4 circularity interventions (10%); for lacking at least one of the three macro-level indicators (3%); for lacking any estimation and instead only showing methods, tools, or databases (12%); for not being prospective CESs from 2020 to 2050 (2%); and for being duplicates retrieved from different search engines (2%).

We extracted the numerical values directly from tables and text in the selected documents, or from figures by using the WebPlotDigitalizer version 4.2 (Rohatgi, 2019). We also collected information about historical data and input parameters for each study (e.g. changes of recycling market shares, technological market penetration, investment levels, taxation rates, and price elasticities). Further information on the selected literature is available in worksheet selected_literature in the file data_source.xlsx of the Supplementary Materials.

Table 5.1. Overview of models used by the selected 27 publications

Type*	Number of studies	Model name abbreviation**	References
Macro-economic models	17	ICES/MEMO/MEWA	Bosello et al. (2016)
		E3ME	Cambridge Econometrics (CE, 2018; European Commission, 2014)
		PANTA RHEI	Distelkamp et al. (2010)
		EXIOMOD/LPJmL	Hu et al. (2015)
		GINFORS/LPJmL	Meyer et al. (2015)
		GINFORS3	Meyer et al. (2018)
		GTAP	Lee (2018)
		NewERA	Tuladhar et al. (2016)
		GTEM, GLOBIOM	UNEP (UNEP, 2017)
		ENGAGE-material	Winning et al. (2017)
		Miscellaneous	Böhringer and Rutherford (2015)
			Ellen MacArthur Foundation (EMF, 2015)
			Ellen MacArthur Foundation and McKinsey Center (Ellen MacArthur Foundation, 2015)
			Hatfield-Dodds et al. (2017)
			Rademaekers et al. (2017)
			Groothuis (2016)
Structural models	9	EMEC/NatWaste/SWEA	Söderman et al. (2016)
		Miscellaneous	Beasley and Georgeson (2014)
			Beccarello and Di Foggia (2018)
			European Environmental Agency (EEA, 2014)
			Mitchell and Doherty (2015)
			Morgan and Mitchell (2015)
			Wiebe et al. (Wiebe et al., 2019)
			Wijkman and Skånberg (2015)
			Xuan and Yue (2017)
Integrated assessment models	1	GIAM	Schandl et al. (Schandl et al., 2016)

*Model types are categorized according to the de Koning (2018) classification

**A list of model names is provided in table_1 spreadsheet, data_source.xlxs file in supplementary information

5.2.2. Meta-analysis

We performed a meta-analysis following 3 steps: 1) we extracted the numerical values of CESs and normalized them in order to compare them between different studies, 2) we classified the CESs into categories we ourselves defined as ambitious or moderate scenarios, and 3) we performed statistical analyses including an assessment of correlation between the indicators.

In this study, CESs are consistent and coherent descriptions of possible future impacts if circularity interventions were implemented (van Notten, 2006; Woltjer, 2018). In other words, CESs are exploratory scenarios of 'what-if' a circularity transition was put into action. The impacts of such a transition are expressed by specific numerical values of the macroeconomic, social, and environmental impacts retrieved from each model. We focus on CESs that contain numerical values of GDP, job creation and CO_2 emissions compared to a business-as-usual (BAU) scenario in the time frame from 2020 to 2050. Notice that the impacts are yielded in a particular year. In the beginning we have over 300 CESs in total across different years and studies, which will be combined as described below.

We harmonized the values across the studies by normalizing each CES with respect to a BAU scenario reported by each publication. BAU scenarios were calibrated in each publication by considering the trend of GDP, population growth, and energy and material consumption based on projections from the United Nations Statistics Division, the International Energy Agency, Eurostat, or national statistical offices (Groothuis, 2016; UNEP, 2017; Wiebe et al., 2019). We estimated the difference between a CES and a BAU scenario as follows:

$$\Delta CES_{i,t} = \frac{CES_{i,t} - BAU_{i,t}}{BAU_{i,t}} \times 100, \qquad [5.1]$$

where $\Delta CES_{i,t}$ represents the changes in indicator i (i.e. GDP, job creation, or CO_2 emissions) for year t (from 2020 to 2050), $CES_{i,t}$ and $BAU_{i,t}$ denote the absolute value of the circular economy scenario and the business-as-usual scenario for i in t, respectively. We used $\Delta CES_{i,t}$ as an indicator to compare the macroeconomic, social, and environmental impacts of circularity interventions across the literature.

As an example of the normalization procedure, the study of the Ellen MacArthur Foundation and McKinsey Center (2015) showed two GDP scenarios for the European Union in 2030: 104 billion euros for BAU, and 111 billion euros for CESs. Following equation 1, we normalized these values and calculated a change in GDP of 6.7% (i.e.$\Delta CES_{GDP,2030} = [(111 - 104)/104] \times 100$).

We classified the CESs into two categories: moderate or ambitious. Previous studies on the assessment of policy scenarios showed that classifying scenarios as BAU, moderate and ambitious is a suitable system for comparing and connecting groups of multiple scenarios (Best et al., 2018; Wang et al., 2019). If a study reported more than two scenarios, we classified those as ambitious scenarios that presented the largest impact on GDP, job creation, or CO_2 emissions compared to the BAU scenario. All other scenarios reported in a study besides the BAU and the ambitious scenarios are considered moderate. For studies that only contain one CES, we categorized the scenarios based on the number of economic sectors covered by the CES. We considered a CES ambitious if circularity interventions were implemented in two or more economic activities simultaneously, and moderate if the interventions were applied to only one economic sector.

A single study always has one ambitious scenario and can have either zero, one or multiple moderate scenarios per country or region. To assign equal weight to each study, all moderate scenarios within each study were combined into a single moderate 'study' scenario by calculating the arithmetic average of all moderate scenarios. Furthermore, countries and regions within each study were combined into a single average per scenario type. Thus, in the final analysis we considered 27 studies, with one ambitious scenario and at the most one average moderate scenario each. Figure 5.2 shows an example of data harmonization using the CESs reported by UNEP (2017).

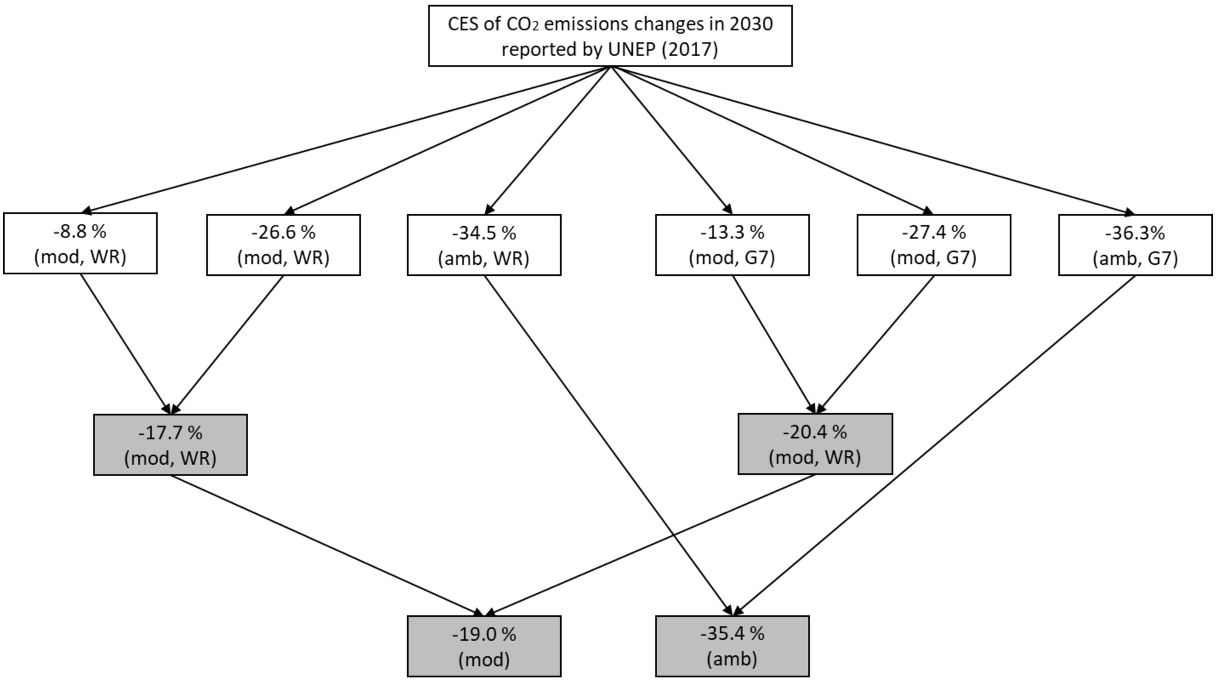

Figure 5.2. Example of data harmonization using the values reported by UNEP (UNEP, 2017). Numerical values represent changes in CO_2. Texts in parenthesis indicate scenario type and country/region. Abbreviations: mod = moderate scenarios; amb = ambitious scenarios; WR = world; G7 = Group of Seven (i.e. Canada, France, Germany, Italy, Japan, the United Kingdom and the United States). Solid blocks in grey indicate the calculated average of each scenario type.

Note that not all studies cover all years from 2020 to 2050 and not all studies cover the three types of impact (GDP, employment, and CO_2). File results_time_ser.xlsx in Supplementary Material presents the details of how many ambitious and moderate CES are available for each year and impact type.

To analyze the trajectory of macroeconomic, social, and environmental impacts, we plotted the changes in GDP, job creation, and CO_2 emissions from 2020 to 2050, as reported in the Results section. There, we also report the median, minimum and maximum values, and the interquartile range (IQR) as a measure of statistical dispersion.

We applied a traditional Pearson product-moment correlation coefficient (r) to analyze if the association between the changes in GDP, job creation, and CO_2 emissions is positive or negative. This method also allows us to identify the strength of a linear connection between the indicators (Rodgers & Nicewander, 1988). It is important to notice that a 'win-win' situation for some indicators involves different sign values of r. For instance, a correlation between GDP and employment can be interpreted as a 'win-win' if GDP and employment increased simultaneously, which is indicated by a positive Pearson correlation coefficient ($0 < r \leq 1$). In contrast, a 'win-win' in terms of macroeconomic and environmental impacts can be interpreted as an increase of GDP while CO_2 emissions are reduced, which would imply a negative Pearson correlation coefficient ($-1 \leq r < 0$).

Data sources and the Python code used for the meta-analysis are provided in Supplementary Material, in online version at: DOI: 10.5281/zenodo.3820181.

5.3. Results

We now assess the macroeconomic, social, and environmental impacts of a circularity transition reported by the selected literature, using as metrics changes in GDP, job creation, and CO_2 emissions. First, we present the trajectories of moderate and ambitious CESs from 2020 up to 2050. Second, we perform a statistical analysis of CESs in 2030. Finally, we perform a correlation analysis to determine if a circularity transition could contribute to a 'win-win-win' situation for macroeconomic, social, and environmental impacts in 2030.

5.3.1. Trajectory of changes in GDP, job creation, and CO_2 emissions for 2020-2050

Figure 5.3 presents the range of changes in GDP, job creation, and CO2 emissions calculated in the selected publications. The results are reported in relation to each study's business-as-usual (BAU) scenario (see equation [5.1]).

The trajectories of ambitious CESs for GDP (figure 5.3.a) are characterized by a wide range of values, varying from -0.1% (Cambridge Econometrics, European Commission, 2014) to 14.0% (Distelkamp et al., 2010). In general, the impacts of CESs on GDP are expected to be positive, as the median value rises from 0.2% in 2020 to 3.0% in 2050. In contrast, moderate CESs present a narrow range of impacts on GDP, ranging from 0.0% (Rademaekers et al., 2017) to 2.5% (Lee, 2018), and remaining almost constant through time (from a median of 0.0% in 2020 to 0.7% in 2050).

In a similar way, the effects of ambitious CESs on employment (figure 5.3.b) show an increase of job creation from a median of 0.9% in 2020 to 4.1% in 2050, while the impacts on employment in moderate scenarios are negligible, with a median of 0.0%. However, the trajectories from 2030 onwards only rely on 2 ambitious scenarios estimated by Meyer et al. (2015) and the Ellen MacArthur Foundation (EMF, 2015), and on moderate scenarios presented by Bosello et al. (2016) and the Ellen MacArthur Foundation (2015). Due to the limited number of CESs assessing employment after 2030, there is not enough data to perform a statistical analysis on that time period.

Regarding CO_2 emissions, CESs show a decrease in CO_2 emissions in both ambitious and moderate scenarios. The decrease of CO_2 emissions in ambitious scenarios ranges from -0.1% (Tuladhar et al., 2016) to -71.0% (EEA, 2014), with median values varying from -2.5% in 2020 to -55.3% in 2050. Likewise, CO_2 emissions in moderate scenarios fluctuate between 0.1% (Tuladhar et al., 2016) and -45.6% (UNEP, 2017), with a median value of -0.4% in 2020, and -37.4% in 2050.

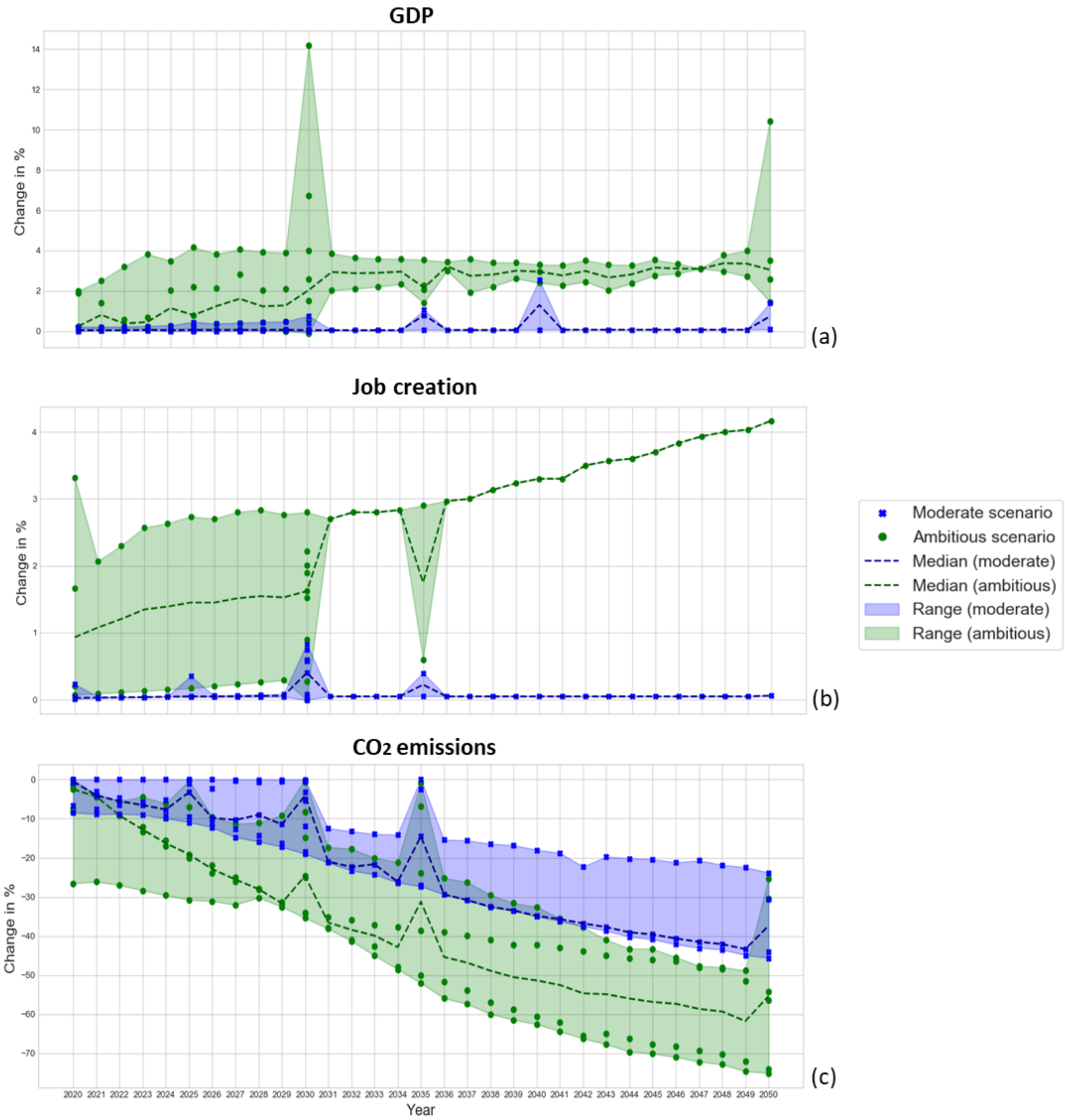

Figure 5.3. Range of changes in (a) GDP, (b) job creation, and (c) CO_2 emissions from 2020 to 2050 as estimated in the selected studies. Blue crosses indicate the values of moderate scenarios in each study. Green dots indicate the values of ambitious scenarios in each study. Blue and green dashed lines denote the median of moderate and ambitious scenarios in each year, respectively. Light blue and green areas denote the range between the maximum and minimum values for moderate and ambitious scenarios per year, respectively.

5.3.2. The macroeconomic, social, and environmental impacts of circularity up to 2030

We can use the trajectories presented above to assess the macroeconomic, social, and environmental implications of circularity in a specific period. Due to the fact that most of the scenarios were modelled in 2030 (with 9 of10 publications related to each indicator per scenario type), we perform a statistical analysis for the results in this year. Figure 4 presents a boxplot of CES impacts in 2030 summarizing the changes in GDP, job creation, and CO_2

emissions per scenarios type in the selected publications. The values of each CES are reported in relation to values of the respective BAU scenario in 2030.

The median ambitious CESs value for changes in GDP corresponds to 2.0% growth, with an interquartile range (IQR) between 0.4% and 4.6%. Most of the studies focused on impacts within the EU, with GDP scenarios varying from 0.0% to 0.6% at the country level (CE, 2018; Rademaekers et al., 2017), and from 2.8% to 6.7% at the regional level (Ellen MacArthur Foundation, 2015; B. Meyer et al., 2015). The other studies present the impacts on a global scale, with the most optimistic scenarios expecting a mean global GDP increase of 5.8% (B. Meyer et al., 2015; M. Meyer et al., 2018). An outlier value results from Distelkamp et al. (2010), as the authors reported a 14.0% increase of GDP in Germany due to resource efficiency interventions.

In moderate scenarios for GDP, no significant difference was found between CESs and BAU scenarios in 2030, with a median increase of 0.1% (IQR = [0.0 – 0.3] %). At the country level, Winning et al. (2017) assessed the macroeconomic impacts of moderate CESs in the iron and steel sectors of different nations, such as China (0.3%), Brazil (0.2%), Japan (0.1%), and the United States (0.0%). Furthermore, GDP change in moderate CESs for the EU region ranges from -0.0% to 0.4% (Cambridge Econometrics, European Commission, 2014; Rademaekers et al., 2017), and global GDP is estimated to increase by 0.02% (in Winning et al., 2017).

Regarding employment, the median value of increase in ambitious scenarios is 1.6% (IQR = [0.9 – 2.0] %). Employment in EU countries is expected to rise between 0.3% and 2.8% (CE, 2018; B. Meyer et al., 2015). Likewise, at the regional level, circularity interventions can contribute to an increase in employment by 0.0% to 2.8% (CE, 2018; Groothuis, 2016; Rademaekers et al., 2017). Nevertheless, the CESs explored by Wiebe et al. (2019) suggests that there could be a trade-off in job creation between regions. For instance, a CES resulting in 2.7% increase of jobs within the EU might lead to job creation in Asian economies ranging from -2.6% to 4.3%. Moreover, the overall effect of ambitious scenarios on job creation at the global scale is an increase of employment of 2.2% (Wiebe et al., 2019).

The impact of a moderate CESs on employment in 2030 is negligible, with a median of 0.1% (IQR = [0.0 – 0.4] %). The literature related to the impacts of moderate CESs on employment only reported on case studies in the EU. At the national level, moderate CESs could increase jobs by 0.0% to 0.7% (Distelkamp et al., 2010; Wijkman et al., 2015). In a similar way, the impacts of moderate CESs on job creation at the regional level vary between 0.0% and 0.8% (Beasley & Georgeson, 2014; Bosello et al., 2016; Cambridge Econometrics European Commission, 2014; Rademaekers et al., 2017).

Regarding CO_2 emissions, the median impact of ambitious CESs shows a reduction of -24.6% (IQR = - [34.0 – 8.2] %). A small number of studies reported on ambitious CESs in specific countries, with CO_2 emissions varying from -0.6% to -1.7% (Schandl et al., 2016; Tuladhar et al., 2016). In contrast, a larger number of studies modelled the CO_2 impacts of ambitious CESs on the regional scale, reporting reductions of -36.3% and -20.2% (Meyer et al., 2015; UNEP, 2017) for the EU and the Group of Seven (i.e. Canada, France, Germany, Italy, Japan, United Kingdom, and United States), respectively. The expected global impact of ambitious CESs on CO_2 emissions is to reduce emissions between -34.0% and -6.5% (Hatfield-Dodds et al., 2017; B. Meyer et al., 2015; Schandl et al., 2016).

The median value of the impact of moderate CESs on CO_2 emissions is -4.1% (IQR = - [10.2 – 0.3] %). At the country level, the impacts of moderate scenarios range between -5.4% and -0.3% (Wijkman et al., 2015; Xuan & Yue, 2017). Regional moderate CESs show that a -0.3% to -0.1% decrease of CO_2 emissions can be expected from circularity interventions in the EU (Beasley & Georgeson, 2014; Rademaekers et al., 2017). The expected impacts of moderate CESs on CO_2 emissions at the global level amount to a decrease of -14.0% (Hatfield-Dodds et al., 2017; M. Meyer et al., 2018; Winning et al., 2017).

It is important to notice that the results of CO_2 scenarios depend on the type of allocation used by the studies, and on whether the analysis is focused on production- or consumption-based CO_2 emissions. Most of the studies assessed production-based emissions, allocating the impacts to territorial emissions from economic activities. We found only one study related to carbon emissions from a consumption perspective. Schandl et al. (2016) presented their results as the direct and indirect CO_2 emissions (i.e. carbon footprint) in a country or region, and identified which carbon footprints were increased due to a circularity transition. For example, according to Schandl et al. (2016), the carbon footprints of Japan and the EU are expected to increase by 8.0% compared to the BAU scenarios resulting from the overall effect of circularity interventions up to 2030.

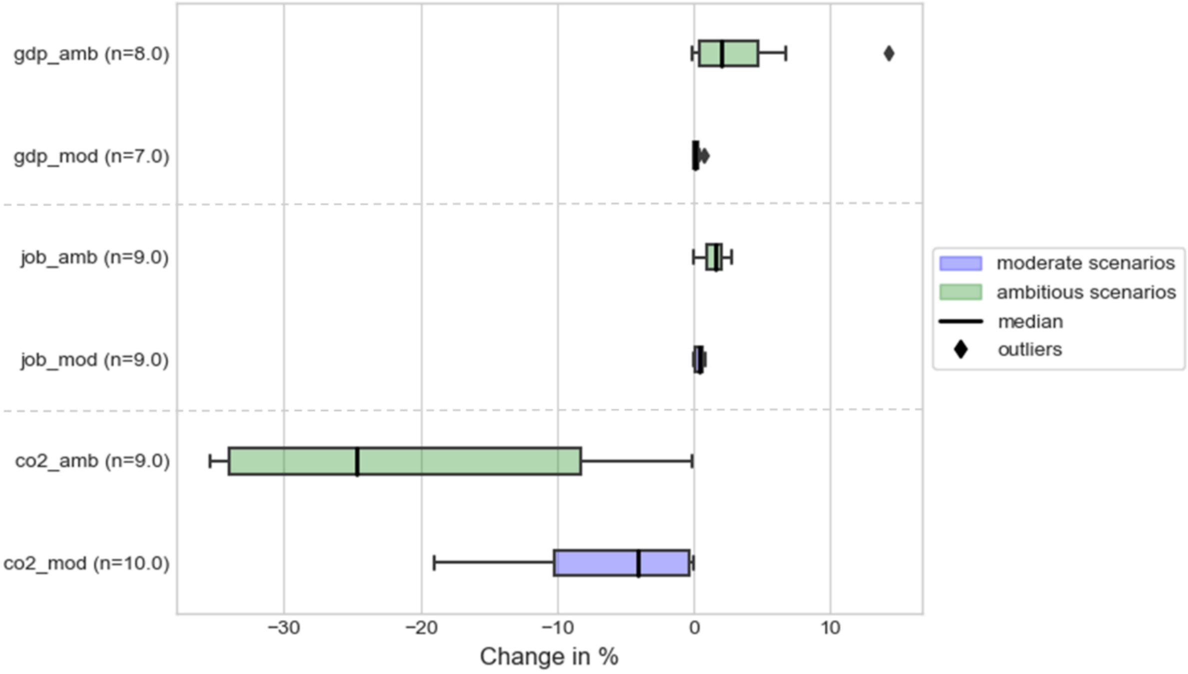

Figure 5.4. Boxplot of circular economy scenario impacts on GDP, job creation, and CO_2 emissions for 2030. gdp_amb and gdp_mod denote ambitious and moderate scenarios for GDP, respectively. job_amb and job_mod denote ambitious and moderate scenarios for job creation, respectively. co2_amb and co2_mod denote ambitious and moderate scenarios for CO_2 emissions, respectively. n indicates the number of studies in each category. Blue and green box indicate the range of moderate and ambitious scenarios, respectively. Diamond markers represent outliers, i.e. values which are away from 1.5 times the 1st or the 3rd quartile.

5.3.3. Does the circular economy lead to a ‘win-win-win’ situation?

Table 5.2 presents the correlation analysis of GDP increase, job creation, and CO_2 emissions in 2030. We use the Pearson correlation coefficient (r) as a measure of positive or negative relation between the indicators, and determine if a circularity transition could contribute to a ‘win-win-win’ situation in terms of macroeconomic, social and environmental impacts. Our findings show that there is a positive relation between GDP increase and job creation (r = 0.65), which means that if one CES leads to a higher GDP than another CES, then it is also expected to lead to more employment. CO_2 emissions are negatively related to GDP increase (r = -0.60) and job creation (r = -0.58), which means that if a CES leads to higher GDP or more jobs than another CES, it is expected to lead to less emissions. Thus, we observe that a circularity transition could lead to a ‘win-win-win’ situation for macroeconomic, social, and environmental impacts.

Table 5.2. Correlations between GDP, job creation, and CO_2 emissions in 2030

Correlated variables	**Pearson correlation coefficient (r)**	**Outcome**
GDP & Job	0.65	Win
GDP & CO_2	-0.60	Win
Job & CO_2	-0.58	Win

In order to better understand the relation between the indicators and whether a CES could drive a ‘win-win-win’ situation, we acknowledge that it is relevant to determine trade-offs across countries as well as to distinguish between specific circularity interventions. However, these aspects were not assessed due to the lack of information available in the CESs.

5.4. Discussion

Our meta-analysis showed that CESs are expected to increase GDP and employment while reducing CO_2 emissions. We focused on prospective studies that model exploratory scenarios. This means that CESs are not predictions, but rather a set of ‘what-if’ scenarios in which a circularity transition might change the impacts in comparison to a baseline scenario. Considering the exploratory nature of these studies, we now discuss the modelling features reported in the literature that yield the most favorable changes in GDP, job creation, and CO_2 emissions.

5.4.1. Key modelling features

A CES is developed by implementing multiple circularity interventions, whose general goal is to substitute primary materials with secondary materials and long-lasting products and which are modelled for specific features. For example, in the circular intervention of closing supply chains, the modelling feature can be changing the demand of resources for an economic activity, replacing the use of raw materials with the use of secondary materials. A detailed list of the modelling features used in each study is available in the worksheet selected_literature in file data_source.xlsx of the Supplementary Material. We now discuss the modelling features suggested by the literature that generate the larger changes in GDP, job creation, and CO_2 emissions. These key modelling features are resource taxes, technology change, and changes in consumption patterns.

Resource taxes (e.g. carbon tax, taxes on raw materials, such as metals and fossil fuels, and taxes on building materials) are used in the models to provide incentives for decreasing raw material extraction by increasing production costs and material/product prices. The revenues from the new taxes are usually allocated to material recovery activities (e.g. recycling activities) or reintroduced as R&D investment in material efficiency (Bosello et al., 2016; Cambridge Econometrics, European Commission, 2014; Hatfield-Dodds et al., 2017). As mentioned by McCarthy et al. (McCarthy et al., 2018), different studies apply resource taxes at multiple levels of the supply chain. Notice that there are no studies that apply resource taxes at the level of material extraction activities (e.g., extraction of coal in mining); instead, resource taxes are collected from the material outputs of such activities (e.g., the sale of coal).

Technological change, specifically improvements in resource use efficiency, are modelled through changes in unitary production costs. For instance, the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2015) modelled the improvement of resource use in the building sector by considering the cost of industrial and modular construction to be 50% lower than the cost of traditional building processes. In a similar way, many studies applied exogenous changes in production costs to reflect technological improvements (see, for example, Cambridge Econometrics, European Commission, 2014; M. Meyer et al., 2018; Wijkman et al., 2015). An aspect that limits the modelling of technological change is that the level of resolution in macroeconomic and structural models does not allow to model specific secondary and waste treatment activities. In other words, the high level of aggregation restricts the options of technological innovation (de Koning, 2018; McCarthy et al., 2018).

Another key modelling feature found in several studies is changing consumption patterns (or behavioral change). For example, consumers will require smaller numbers of certain goods resulting from product lifetime extension and more sharing, which means that less materials are required to satisfy specific societal needs. In many cases, behavioral changes develop from the intrinsic motivation of individuals, with bottom-up actions leading to societal transformation. For example, Hu et al. (2015) found that scenarios with active citizen participation would drive the largest reduction of CO_2 emissions, although they showed a trade-off between environmental and socioeconomic impacts, as the reduction of CO_2 emissions was associated with decreases in GDP and employment. On the other hand, governments can also contribute to changes in consumption patterns using a top-down approach. This is the case if governments encourage citizens to develop circular economy activities, for example, by promoting consumer information campaigns focusing on waste reduction and repairing activities (Vita et al., 2019; Woltjer, 2018). With proper policy schemes, these activities can create new job opportunities while reducing environmental impacts.

Regardless of which modelling feature is implemented in a particular CES, our statistical analysis shows that the circularity transition is likely to generate only marginal or incremental socioeconomic changes. For instance, our median results show that in ambitious CESs, we can expect increases of 2.0% of GDP and 1.6% of job creation relative to a BAU in the year 2030. In contrast, CO_2 emission reduction seems to be highly optimistic with a median of -24.6% for ambitious scenarios. Nevertheless, the ambitious scenarios for CO_2 emissions showed the largest spread of CES values (with interquartile ranges ranging from -34.0% to -8.2%), which means that results can vary significantly between studies.

We believe that a circularity transition will not yield a radical transformation of resource use and its impacts in the upcoming decade (as was also suggested by Tukker and Ekins, 2019). Thus, the implementation of circularity interventions could generate a 'win-win-win' situation with respect to GDP, job creation and CO_2 emissions, but these gains will be incremental.

5.4.2. Limitations and further research

Each approach to modeling the impacts of circularity interventions has specific strengths and weaknesses. However, we notice various modelling limitations that are recurrent across the literature: public investments, rebound effects, and policy interventions.

There is limited information about how much public investment is required to implement specific circularity interventions. Only a few studies modelled public investment to some degree, by using exogenous parameters related to capital stock, investments on R&D and consulting services (Best et al., 2018; McCarthy et al., 2018). Although there is no consensus about how much policy effort is required, we find that most studies acknowledge in a qualitative way that some degree of public investment is required. For example, Wijkman and Skånberg (2015) suggest that a circularity transition would require public investment on infrastructure involving a transitory increase of employment, material use and CO_2 emissions. We consider that further assessment of the impacts of circular economy policies can be improved by the explicit inclusion of a transition phase.

Secondly, current modelling of CESs is limited in terms of understanding rebound effects. The savings from a more resource-efficient and circular economy could result in more consumption, depending on how such savings are re-expended by consumers (Best et al., 2018; Zink & Geyer, 2017). According to some CESs, jobs and CO_2 emissions could shift between countries, affecting other regions and creating negative effects on society and the environment overall (Bosello et al., 2016; Wiebe et al., 2019). The rebound effect of CESs is discussed in some studies (European Commission, 2014; M. Meyer et al., 2018; UNEP, 2017). Nevertheless, there is still little quantitative analysis of the potential magnitude of rebound effects, and how to prevent their potential negative environmental impacts.

Thirdly, the modelling of circular economy policies has been focused on what-if future exploratory scenarios. However, it is still not clear which measures should be implemented at the present time to achieve the potential benefits of circular economy policies. Assessing circularity from the normative perspective could generate insights into which economic sectors are more relevant for implementing circularity interventions, thus supporting the decision-making process. Future studies might also use a backcasting approach, which makes it possible to assess current opportunities in order to achieve circularity targets in the middle and long term.

Finally, it is important to notice that the correlation analysis in this study does not differentiate between the studies' geographical scopes. We did not distinguish between specific countries or regions because there were not enough values per country or region to perform a proper correlation analysis.

As the majority of studies included in the present meta-analysis focused on one economy without considering the impacts on other countries or regions, the correlation analysis does not consider trade-offs between economies. For instance, an increase of jobs linked to repair activities in the EU would negatively impact primary production in other countries, which would imply a reduction of employment elsewhere. In this case, repair may increase the number of jobs in the country where products are repaired, but may lead to a greater reduction in jobs in countries where the primary production takes place. This type of trade-off between countries cannot be captured by the outcomes shown in table 2, which is a limitation of the present correlation analysis.

Moreover, we recognize that specific circularity interventions could lead to different results for the Pearson correlation coefficient (r). For example, the implementation of product lifetime extension might generate job losses (if more durable goods lead to a reduction in the demand for primary production) as well as reduce CO_2 emissions (if there are no high use-phase emissions), which would imply a 'lose-win' situation in terms of social and environmental impacts. However, we could not differentiate between circularity interventions in the correlation analysis because the results presented by the literature were highly aggregated in terms of circularity interventions. That is, sometimes a single CES outcome was reported that in fact resulted from multiple circularity interventions, whose individual impacts could not be isolated.

5.5. Conclusion

The purpose of this chapter was to perform a meta-analysis of CESs to establish a consensus regarding the potential macroeconomic, social, and environmental impacts of a circularity transition. Previous articles at macro level (i.e. on national and multinational scales) have shown the impacts of circularity interventions on GDP, job creation and CO_2 emissions, but these studies did not correlate the macroeconomic, social and environmental indicators to determine whether circularity interventions could generate a 'win-win-win' situation. We filled this research gap by performing a statistical analysis of 300 CESs.

Our study analyzed the changes in GDP, job creation and CO_2 emissions estimated by means of models that implement CESs for the period up to 2050. We identified the trajectories of more than 300 CESs compared to the business-as-usual scenarios from 2020 to 2050, and assessed the range of changes in GDP, job creation and CO_2 emissions up to 2030. Furthermore, we performed a correlation analysis between the indicators of changes that can be achieved by 2030 to evaluate if a circularity transition would provide a 'win-win-win' situation regarding macroeconomic, social, and environmental impacts.

We also discussed the three modelling features identified across the studies that yield the most favorable changes in the macro-economic indicators: resource taxes, technology changes, and adapting consumption patterns. A common view proposed in the selected literature is that a circularity transition requires some degree of policy intervention and that it will generate incremental macroeconomic and social benefits, as well as more considerable environmental benefits.

We consider that follow-up research should focus on the enhancement of modelling CESs. This modelling can be improved by incorporating public investments and rebound effects in the analysis. Moreover, in order to support decision making, we find it relevant to consider a normative approach on circularity assessments, i.e., to identify key measures in the present that contribute to a more cost-effective circularity transition.

As different circularity interventions are likely to have different trade-offs, we recommend that studies should differentiate between different types of circularity intervention when analyzing environmental and economic trade-offs. Furthermore, we suggest that studies focusing on a single country or region may miss trade-offs on the global scale and may hence suggest win-win effects that may exist on the national or regional scale, but are absent on the global scale. Thus, we suggest that future studies should include such trade-offs between regions and countries, which implies that they must consider the global scale and present region- or country-specific advantages and disadvantages of the implementation of circularity interventions.

This chapter contributes to understanding the macro-level implications of circular economy policies, which can support decision makers and practitioners in recognizing the macroeconomic, social, and environmental implications of a circularity transition. Moreover, our outcomes can help researchers that model the circularity interventions by identifying the main modelling features and indicating ways to enhance the analysis of circularity interventions.

5.6. References

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