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RESEARCH AND ANALYSIS

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Global environmental and socio-economic impacts of a transition to a circular economy in metal and electrical products

A Dutch case study

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Abstract

Shifting from a linear to a circular economy could decouple environmental footprints from an ever growing global GDP. As footprints are increasingly driven by international trade, such a shift in a national economy would have global implications. In this study, we explore the global environmental and socio-economic impacts of hypothetical circular policy interventions affecting the consumption of metal and electrical products in the Netherlands. We use environmentally extended multi regional input-output analysis and use repair activities as a proxy to model other circularity activities. Compared with a business-as-usual scenario of final demand for metal and electrical products in the Netherlands, we find that the considered interventions yield a decrease in global environmental and socio-economic impacts (average change −7%), and an increase in domestic employment (+13%) and value added (+2%), as well as a modest increase in most domestic environmental impacts (+1% on average). We explore whether these interventions would lead to resource decoupling (i.e., both economic activity and its associated environmental impacts grow, but the former more strongly than the latter) and/or impact decoupling (i.e., economic activity grows and impacts decrease). Domestically we observe resource decoupling while globally both environmental impacts and economic activity are reduced. Our findings thus challenge the assumption that the implantation of circular economy policies will lead to global resource decoupling, instead suggesting that the social and economic benefits of a circular transition are unequally distributed across regions. This article met the requirements for a gold-gold *JIE* data openness badge described at http://jie.click/badges.

KEYWORDS
circular economy, environmental footprint, industrial ecology, input–output analysis, policy, socio-economic footprint

1 | INTRODUCTION

Historically, the growth of global GDP has been accompanied by the increase of environmental footprints (Pothen & Schymura, 2015; Simas et al., 2017; Wiedmann et al., 2015). Moreover, due to globalization, these footprints are increasingly embodied in trade (Bruckner et al., 2012; Plank et al., 2018; Wood et al., 2018). It is not only the share of environmental footprints embodied in trade that is rising, but the same is also happening for socio-economic footprints, such as employment and value added (Arto et al., 2014; Simas et al., 2014; Wiedmann & Lenzen, 2018). To stay within planetary boundaries, it is vital to decouple environmental footprints from GDP growth (Steffen et al., 2015; Wiedmann et al., 2015) while minimizing negative impacts on the social foundation of human well-being (Raworth, 2017).

A popular framework to conceptualize this decoupling is the circular economy (CE) (Ellen MacArthur Foundation, 2019; European Commission, 2015; International Resource Panel, 2019), an idealized economy in which primary material use is reduced and the rates of reuse, refurbishing and recycling are increased and the service life of products is lengthened (Kirchherr et al., 2017).

While studies so far seem to be in agreement on the environmental benefits of a transition toward a CE, they have shown mixed results regarding the socio-economic effects. Ellen MacArthur Foundation and McKinsey Center for Business and Environment (2015) found that the implementation of CE policies would yield an increase in GDP of the 28 European member states (EU28) (7% by 2030 to 12% by 2050), compared to a business-as-usual (BAU) scenario. Moreover, they found decreases in CO_2 emissions (−25% to −56%) and in primary material consumption (−13% to −20%). While Wiebe et al. (2019) similarly found a decrease in global material extraction (−10%) in 2030 when CE policies are pursued globally, they found no significant effect in value added and an increase in employment (2%). Stronger still, Donati et al. (2020) also assessed the impacts of the global implementation of CE policies and reported decreases in global value added (−6.3%) and employment (−5.3%), combined with (on average) larger decreases in environmental footprints (carbon footprint: −10.1%, material use: −12.5%, land use: −4.3%, blue water withdrawal: −14.6%).

The objective of our study is to contribute to the debate on the benefits and drawbacks of the CE by calculating the global and domestic environmental and socio-economic impacts that would result from implementing CE policy interventions directed toward the Dutch final demand for metal and electrical products. We employ EXIOBASE 3, a state-of-the-art global environmentally extended multi regional input–output (EEMRIO) model with a high level of detail in product classification, and comprehensive coverage of environmental extensions like emissions, resource extraction, water extraction, and land use (Stadler et al., 2018). Unlike most of the aforementioned studies, we use detailed bottom-up sectoral data on CE interventions as input for our EEMRIO model. This data was gathered in an earlier study on CE opportunities for the Netherlands, with a focus on the electronics and metal sectors (TNO, 2013). These CE activities cover repair, refurbishment, recycling, and reuse. In this study we focus on repair activities and use these as a proxy for the other CE activities. These scenarios served as an exploration for the strategy of the Dutch government to realize a circular economy by 2050 (Ministry of Infrastructure and Water Management & Ministry of Economic Affairs, 2016).

2 | METHODS

Our study addresses the transition to a CE in Dutch metal and electrical products by considering two scenarios: baseline (or BAU) and CE (in which a set of hypothetical policy interventions has taken place). The source data that we will use to quantity these scenarios was obtained from a study which explored CE opportunities in NL in 2010 (TNO, 2013). That study identified a set of 17 product groups in CPA classification that is representative of the Dutch final demand for metal and electrical products and quantified Dutch final demand for primary products and 4 CE activities (repairs, reuse, refurbishments, and recycling) of these products, under both scenarios. The numerical values can be found in Supporting Information S1.

The baseline scenario of Dutch final demand for primary products was obtained through a combination of national statistics and data from trade organizations. The baseline scenario for each CE activity was obtained as follows. For the current situation, repairs were estimated based on European Commission (1999); reuse on national statistics and data from secondhand market platforms; refurbishments on reuse estimation in combination with Kimura et al. (2001); and recycling from Huisman et al. (2012).

The CE scenario was obtained by defining fractional changes to the baseline scenario, which were based on expert opinion. That is, stakeholders[1] were interviewed in focus groups regarding their perspective regarding shifts in CE activities of metal and electrical products. The CE scenario captures to what extent a higher level of the CE activities repairs, reuse, refurbishments, and recycling would be realistically possible, in combination with a corresponding lower demand for primary products due to longer service life times of existing products, or a higher use of secondary materials instead of primary materials. We refer to TNO (2013) for further details.

We assess the impacts of these scenarios on six footprints, namely carbon (CF), material use (MF), water consumption (WF), land use (LF), employment (EF), and value added (VF) (Tukker et al., 2016; Wiedmann & Lenzen, 2018; Wood et al., 2018). To assess the global effects of these scenarios,

[1] The full list of interviewees can be found in the background document of TNO (2013).

we implement them in an EEMRIO framework. For this purpose we employ the 2010 product-by-product representation of EXIOBASE v3.3 based on the industry technology assumption. This model contains data on 44 countries and 5 on rest of the continent regions. The EEMRIO has a sectoral resolution of 200 product groups in NACE1.1 classification.

In this study we want to explore the impact of circularity policies across multiple environmental and socio-economic dimensions for three regions, namely the Netherlands (NL), the EU28 excluding the Netherlands (RoE), and the rest of the world excluding EU28 (RoW). As a starting point we consider 426 different stressors (also called extensions, these can be emissions of specific gases, e.g.), which are aggregated to 6 footprints, using conversion factors to a common metric (e.g., different greenhouse gases [GHGs] are converted to CO_2 equivalent through multiplication by that gas' global warming), which are known as characterization factors. Seventy original stressors are combined to obtain the carbon footprint, 227 for materials, 103 for water, 14 for land, 6 for employment, and 6 for value added. The full list of extensions and corresponding characterization factors can be found in Supporting Information S2.

Within this framework, we implement each scenario as a final demand stimulus vector and calculate the associated environmental and socio-economic impacts *D*. Entry (i, j) of *D* represents the impact in category *i* (e.g., CF) in region *j* (e.g., RoW) that results from Dutch final demand for metal and electrical products. As such, our analysis is a type of hotspot analysis (Dawkins et al., 2019). *D* is calculated as follows (Miller & Blair, 2009):

$$D = \left(Q_{\mathrm{EB}} R_{\mathrm{EB}} \mathrm{diag}\left(\left(I_{\mathrm{RP(EB)}} - A_{\mathrm{RP(EB)}}\right)^{-1} y_{\mathrm{RP(EB)}}\right) + D_{\mathrm{DIRECT}}\right) G_{\mathrm{RP(EB),R}} \quad (1)$$

Where $y_{\mathrm{RP(EB)}}$ describes final demand for metal and electrical products in either the baseline or the CE scenario, in M€; $(I_{\mathrm{RP(EB)}} - A_{\mathrm{RP(EB)}})^{-1}$ is the Leontief inverse describing multiplier effects caused along supply chains driven by final demand; diag represents diagonal; R_{EB} contains the quantity of stressors per unit of output measured in each stressor's unit per M€; and Q_{EB} contains the characterization factors to map these stressors to the environmental and socio-economic footprints. Finally we use $G_{\mathrm{RP(EB),R}}$ to aggregate impacts of all products into the three regions of interest in order to obtain *D*.

Finally, D_{DIRECT} captures direct impacts on employment and value added of CE activities in NL. This term is added due to the fact that demand for CE activities in $y_{\mathrm{RP(EB)}}$ is modeled through their production recipe, as will be described shortly, and thus does not capture direct impacts. Lastly, we assume that direct environmental effects of repair activities are negligible.

The vector $y_{\mathrm{RP(EB)}}$ contains demand for primary products and demand for circularity activities. Demand for primary products is obtained by mapping this demand from CPA classification to EXIOBASE region and product classification. Demand for circularity activities is modeled through its production chain. The reason for this is that there is no obvious industry sector that supplies products or services corresponding to CE activities in EXIOBASE. In particular, the first step in the production chain of CE activities is modeled by three elements: demand for domestically sourced products and services; demand for imports; and trade and transport margins. The construction of each of these three elements is described below, as well as the construction of D_{DIRECT} . The full set of equations is found in Supporting Information S3. Moreover the matrices used to bridge between classifications are found in Supporting Information S4.

The domestically sourced demand for circularity activities is calculated as follows. First, this demand is mapped to repair sectors in the 2010 Dutch National Input–Output (IO) table. Next, this demand is disaggregated according to their respective production recipe. Finally, this disaggregated demand is mapped to EXIOBASE, and allocated to the Dutch sourcing block.

The imported demand for CE activities is calculated by multiplying the demand for repair activities in the Dutch IO table with their respective import coefficient. This coefficient is calculated by dividing imports by total intermediate demand of the repair sectors. The imported demand is then mapped to EXIOBASE and disaggregated according to its production recipe, and allocated to imported final demand.

Similarly, trade and transport margins are calculated by multiplying the demand for repair activities in the Dutch IO table with their respective margin coefficient. This coefficient is calculated by dividing the margins by total intermediate demand of the repair sectors. Finally these margins are allocated to the Dutch wholesale trade sector.

Lastly, we obtain the direct impacts of repair activities on value added and employment as follows. Similar to imports and margins, we calculate the value added coefficient by dividing value added of the repair sectors (reported by the Dutch table) by total demand. We obtain direct effects on value added by multiplying this coefficient with the final demand for repair activities. Lastly, we obtain employment statistics for the repair sectors from Dutch national statistics, and divide by total demand to obtain its coefficient. Again, by multiplying this coefficient with the final demand for repair activities we obtain direct effects.

Finally, we evaluate to what extend baseline Dutch final demand for metal and electrical products contribute to total Dutch final demand and its associated footprints. For this analysis we replace $y_{\mathrm{RP(EB)}}$ in Equation (1) with the Dutch final demand vector from EXIOBASE.

The analysis was carried out using Python 3.8.5. The scripts are available in https://doi.org/10.5281/zenodo.3878793. Moreover, this release contains the final demand vectors in EXIOBASE classification for the baseline and CE scenario, as well as the uncharacterized MRIO results—that is, the results from $R_{\mathrm{EB}}\mathrm{diag}((I_{\mathrm{RP(EB)}} - A_{\mathrm{RP(EB)}})^{-1} y_{\mathrm{RP(EB)}})$, as described in Equation (1).

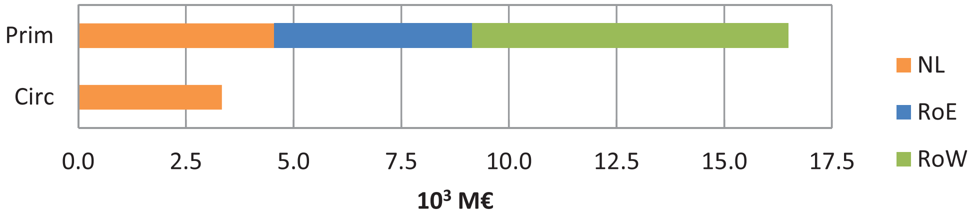

FIGURE 1 Baseline demand for metal and electrical products (prim), and associated circular activities (circ) in 2010, distinguishing the region supplying the product or service (NL in orange, RoE in blue, and RoW in green). Underlying data used to create this figure can be found in Supporting Information S5

TABLE 1 Total global impacts in environmental and socio-economic footprints caused by Dutch final demand for metal and electrical products and related CE activities in 2010

	NL		RoE		RoW			
Footprint	Circ	Prim	Circ	Prim	Circ	Prim	Total	Unit
Global warming	0.54	0.62	0.12	1.32	0.61	8.53	11.75	$TgCO_2eq$
Material use	0.09	0.20	0.11	1.23	1.03	16.96	19.63	Mt
Water consumption	0.8	4.5	0.5	5.2	9.4	129.6	150.0	Mm^3
Land use	1.0	2.6	32.2	247.7	603.1	7598.9	8485.5	10^3 km^2
Employment	48	27	4	66	43	662	850	k
Value added	2.5	3.3	0.3	4.3	0.4	7.6	18.4	10^3 M€

3 | RESULTS

In this section we describe the impact, in terms of environmental and socio-economic footprints, of both the baseline final demand for metal and electrical products in the Netherlands, and the changes that result from implementing various CE policy interventions.

3.1 | Baseline

We now describe the main features of the baseline scenario. The volume of Dutch final demand for metal and electrical products and associated CE activities in 2010 (the baseline scenario) was 16×10^3 M€ and 3.3×10^3 M€, respectively. Figure 1 distinguishes the regions where products and services are purchased from. This figure shows that the bulk of metal and electrical products are purchased from RoW (7.3×10^3 M€, or 45% of total), followed by RoE and NL (both 4.6×10^3 M€, 28%), while CE activities are supplied domestically (3.3×10^3 M€). This final demand represents 3% of all Dutch final demand for that year (578×10^3 M€), of which 85% is supplied domestically, 7% from RoE, and 8% from RoW.

Next, we calculate the impacts in environmental and socio-economic footprints occurring in different world regions caused by final demand for metal and electrical products and associated CE activities in NL in the baseline scenario. Note that both primary sales and CE activities in the Netherlands depend on a global supply chain, either directly from imports or because domestic sectors in turn also depend on imported supply. However, while we consider that final demand for primary products is supplied domestically as well by imports, we consider that final demand for CE activities on the other hand is only supplied domestically. We take this modeling option because CE services (e.g., repairs) are mostly provided domestically. As such, both primary sales and CE activities impact footprints globally. As shown in Table 1, we find that most of the impacts generally occur in RoW, followed by RoE and NL (except for value added an employment of circular activities, which occur primarily in NL).

Finally, we evaluate the contribution of Dutch final demand for metal and electrical products, including CE activities, to the footprints of all Dutch final demand, as shown in Table 2. We find that the total contribution ranges between 2.6% and 5.4%, and that highest values are found in RoW, followed by RoE, and finally NL.

TABLE 2 Fraction (in %) of the footprint, for different categories and impacts occurring in different world regions, associated with total Dutch final demand that results from consumption of metal and electrical products

Footprint	NL (%)	RoE (%)	RoW (%)	Total (%)
Global warming	1.2	5.5	8.4	5.0
Material use	0.4	2.9	6.8	5.0
Water consumption	1.2	1.8	2.8	2.6
Land use	0.1	1.0	2.9	2.7
Employment	1.4	8.1	7.5	5.4
Value added	1.4	8.8	10.2	3.4

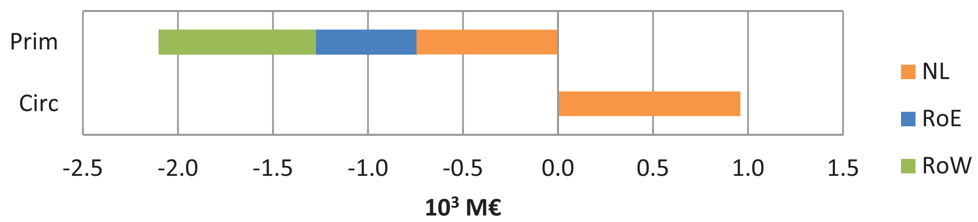

FIGURE 2 Difference in Dutch final demand of metal and electrical products and associated CE activities between the baseline and the CE scenario, showing the region from which products and services are purchased. Underlying data used to create this figure can be found in Supporting Information S5

3.2 | CE scenario

We next examine the demand shock of a transition to a CE as the difference in final demand compared to the baseline. We find that final demand for primary products decreases by 2.10×10^3 M€ (or −13%), and final demand for CE activities increases by 0.96×10^3 M€ (29%). Moreover, Figure 2 shows how these changes are distributed over regions of final sale. This figure shows that there is a decrease in purchases for final demand for metal and electrical products from all regions, but the change is most noticeable in products from RoW (-0.83×10^3 M€, or −11% of products purchased in the baseline scenario), followed by NL (-0.74×10^3 M€, −16%) and RoE (-0.53×10^3 M€, −12%). Lastly, increases in CE activities are fully allocated to NL.

Next, we assess the net changes in environmental and socio-economic footprints resulting from the shift from the baseline to the CE scenario across all footprint categories, as shown in Table 3. This table shows that the impact in all footprints decreased, primarily in RoW and RoE. Concurrently most impacts in NL increased, in particular EF (10k people, or a 13% increase compared to the baseline) and CF (0.07 $TgCO_2$eq., 0.6%).

TABLE 3 Changes in all footprints in the CE scenario (compared to baseline), distinguishing regions where impact occurs, and driving force (i.e., increase in circular activities and reduction in sales)

	NL		RoE		RoW			
Footprint	Circ	Prim	Circ	Prim	Circ	Prim	Total	Unit
Global warming	0.15	−0.09	0.03	−0.14	0.19	−0.92	−0.77	$TgCO_2eq$
Material use	0.03	−0.02	0.03	−0.13	0.30	−1.64	−1.45	Mt
Water consumption	0.2	−0.5	0.1	−0.5	3.1	−13.0	−10.5	Mm^3
Land use	0.3	−0.3	9.7	−27.3	178.6	−809.3	−648.3	km^2
Employment	14	−4	1	−7	14	−67	−49	k
Value added	0.7	−0.6	0.1	−0.5	0.1	−0.9	−1.1	10^3 M€

TABLE 4 Relative changes in footprints, both total and per region

Footprint	NL (%)	RoE (%)	RoW (%)	Total (%)
Global warming	6	−7	−8	−7
Material use	2	−8	−7	−7
Water consumption	−4	−7	−7	−7
Land use	−1	−6	−8	−8
Employment	13	−9	−8	−6
Value added	2	−10	−9	−6

Lastly, we evaluate the overall changes in footprints as shown in Table 4. We find that footprints decreased overall (−6% to −8%), with the largest decreases in RoE and RoW (−10% to −6%). Furthermore, we find a combination of increases in NL (2% to 13%) with modest decreases (−4% to −1%).

4 | DISCUSSION

The objective of this study was to contribute to the debate on the benefits and drawbacks of a transition toward a circular economy by offering insight into the global environmental and socio-economic impacts of a CE scenario in the case of metal and electrical product consumption in the Netherlands, compared to a baseline that corresponds to historical observations in the year 2010.

We found that the CE scenario yields more domestic value added and employment than the baseline scenario, combined with a modest increase in most domestic environmental footprints. In other words, domestically speaking we observe resource decoupling where economic activity grows stronger than its associated domestic environmental footprints. Stronger still, when only taking into account domestic growth in economic activity we observe impact decoupling as global environmental footprints are reduced (UNEP, 2011). However, from a global perspective we find that economic activity in terms of value added and employment is reduced as well.

As such, we find that defining the benefits and drawbacks of CE depends heavily on which perspective is taken (Wiebe et al., 2019). That is, our study is in line with Ellen MacArthur Foundation and McKinsey Center for Business and Environment (2015), Wiebe et al. (2019), and Donati et al. (2020), where we find global decreases in environmental footprints. At the same time, our study highlights that a transition to a circular economy increases domestic environmental impacts. Moreover, we find an increase in domestic economic activity (Ellen MacArthur Foundation & McKinsey Center for Business and Environment, 2015) and a decrease in global economic activity (Donati et al., 2020).

While EXIOBASE provided regional data which allowed us to offer a global perspective on the environmental and socio-economic impact of a national CE scenario, it did not provide sectoral data with enough detail to disaggregate CE activities of product groups. We overcame this limitation by modeling the CE scenario through the production chain of CE activities using national statistics. As our study highlights the importance of assessing the global implications of a transition toward CE on the one hand, and regional differences thereof on the other, we support the call for the development of EEMRIOs with a higher level of detail in product groups (de Koning et al., 2015).

Another possibility to increase the level of detail is through the use of Life Cycle Assessment (LCA). Product LCAs, however, even if done for all relevant products in our study and scaled up to total final Dutch demand, still do not create the inherent complete and consistent coverage of the global economy that can be realized with global EEMRIO. Moreover, LCA databases in general lack information on value added and use of labor in production processes, and usually do not give information specific by country. For these reasons we based ourselves on an EEMRIO approach. Hybrid approaches that combine LCA with EEMRIO and additional detail in value added and use of labor form an interesting avenue for future research improving upon our work.

Furthermore, this analysis is based on a static snapshot of the global economy in 2010. As such, we did not incorporate dynamic responses due to shifts in final demand and, for example, projected increased demand for materials, in particular metals. We chose to employ EEMRIO as opposed to, for example, a computable general equilibrium approach because of its linear and transparent behavior. Moreover, even though more recent national IO tables exist, these do not take into account global supply chains. Lastly, by modeling the CE scenario without projections regarding increased demand for materials, we could investigate its isolated effects.

Our findings can be interpreted in a number of ways. First, our analysis predicts that the implementation of a CE policy in a single country will decrease global environmental impacts, but raise domestic ones. This outcome is difficult to reconcile with territorial-based pledges as, for example, those enshrined in the Paris agreement (United Nations/Framework Convention on Climate Change, 2015), in which a country takes actions with the goal of reducing domestic emissions without taking into account footprints embodied in trade and emissions occurring abroad as a result of national policies. Counterintuitively, pursuing CE policies can make it more difficult for a nation to reach its territorial-based environmental goals, regardless of the fact that those policies promote domestic resource decoupling and the reduction of global impacts. As such, we advocate for the adoption of metrics which take into account the global decrease in environmental footprints, as proposed in the EU resource efficiency roadmap (European Commission, 2011).

Second, for the purpose of our analysis we aggregated our results into three regions. As such, our analysis does not consider the different local consequences of, for example, consuming water from a water-scarce or a water-rich region (Lutter et al., 2016). This is particularly true in the case of the aggregated Rest of World region, as this region contains many water-scarce regions. However, the development of a robust water-scarcity weighted water footprint has been problematic (Hoekstra, 2016). As such, we decided to employ environmental indicators which satisfy the RACER (Relevant, Accepted, Credible, Easy and Robust) criteria used to assess the policy relevance of indicators (Eisenmenger et al., 2016).

Moreover, our analysis showed that a CE scenario also yielded a domestic increase and global decrease in economic activity compared to the baseline. The often suggested environmental–economic win–win of a circularity transition hence seems not to hold at the global level. At the same time, one has to realize that our scenarios ended up with providing the same functionality of electrical and metal products for the final user (in the case of refurbishment and repair), despite a lower final consumption expenditure on these products (and a somewhat higher consumption of repair services). Overall, a circular economy is hence more efficient: the same functionality for the user, with less work (or more free time) and less environmental pressures.

So, finally, the remaining important question in a circular economy seems to be how to create a fair distribution of value added and income in an economy that shrinks in monetary terms. Our modeling shows added value and jobs are mainly lost in the Rest of World region due to reduced demand for primary products, which contains many low-income countries. This reflects the low domestic production/import ratio for such products in our IO database: countries like the Netherlands have outsourced most of the production of consumer goods abroad. At the same time, from a domestic perspective this scenario increases competitiveness in a rich country like the Netherlands (Ellen MacArthur Foundation & McKinsey Center for Business and Environment, 2015). Hence, it seems that a fair implementation of a circular economy should be based on a quite different narrative as the simple win–win discourse that currently is the main argument to create policy and business support for CE (Ellen MacArthur Foundation & McKinsey Center for Business and Environment, 2015; European Commission, 2011). In conclusion, our study brings forward a more nuanced perspective on the benefits of CE, by highlighting the heterogeneous shift in distribution of employment and value added across regions.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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