JOURNAL POST-PRINT CITE HTTPS://DOI.ORG/10.1016/J.EIAR.2023.107173.

Resource-use intensity and the labour market: more for less?

Andrew G Ross [a*], Kevin Connolly [b], Imke Rhoden [a,c], and Stefan Vögele [a]

[a] Institute of Energy and Climate Research (IEK), Systems Analysis and Technology Evaluation (IEK-STE), Forschungszentrum Jülich.

[b] Fraser of Allander Institute, Department of Economics, University of Strathclyde, Glasgow, Scotland.

[c] Center for Environmental Management, Resources and Energy (CURE), Faculty of Economics, Ruhr-Universität, 44801 Bochum, Germany.

* Corresponding author: Dr Andrew G Ross, a.ross@fz-juelich.de, Forschungszentrum Jülich, Forschungszentrum Jülich GmbH, IEK-STE, Wilhelm-Johnen-Straße, 52428 Jülich, Deutschland

JOURNAL POST-PRINT CITE PUBLISHED PAPER: ROSS, A. G., CONNOLLY, K., RHODEN, I., VÖGELE, S. (2023) RESOURCE-USE INTENSITY AND THE LABOUR MARKET: MORE FOR LESS?. ENVIRONMENTAL IMPACT ASSESSMENT REVIEW, 102, 107173. HTTPS://DOI.ORG/10.1016/J.EIAR.2023.107173

Keywords: labour market, circular economy, resource efficiency, computable general equilibrium

JEL codes: J01, J30, C30, C63, E27 [1]

JOURNAL POST-PRINT CITE HTTPS://DOI.ORG/10.1016/J.EIAR.2023.107173.

Abstract: Although the circular economy primarily focuses on closing supply chains, residual waste management, and product lifetime extensions, reducing resource use remains critical. This paper examines the system-wide impacts of reducing resource use using a multisectoral computable general equilibrium model. Although not strictly circular, the focus is on a costless 'technology shock' that reduces the consumption of intermediate goods in the construction sector and its system-wide effects. The results suggest that there is potential for reductions in CO_2 emissions, but this is accompanied with a fall in GDP and employment, with unskilled workers experiencing larger negative employment effects. However, the scale of these GDP and employment effects is small, despite relatively large reductions in resource use. This indicates that technology-induced reductions in resource use have the potential to support the transition towards an economy that uses fewer resources without causing significant disruptions at the macroeconomic level.

Acknowledgements: We are grateful for comments made by colleagues within the CIRCULAR FOAM (Systemic expansion of territorial CIRCULAR Ecosystems for end-of-life FOAM) project. This research draws on the analysis of Ross [2], which was jointly funded by the Economic and Social Research Council and the Scottish Government [ES/J500136/1]. We would like to express our gratitude to the two anonymous referees for their helpful comments. Their feedback has significantly improved the quality of our paper.

Funding: This paper is funded in part by the European Union under the Horizon 2020 research and innovation program under grant agreement No. 101036854.

Author contributions: AR: Conceptualization, Methodology, Software, Formal analysis, Writing - Original Draft, Writing - Review & Editing. KC: Formal analysis, Writing - Review & Editing. SV&IR: Funding acquisition.

Highlights

- 'More for less' is of importance in the transition towards a more circular economy
- Assess implications of an improvement in the resource-use intensity of construction
- Employ a dynamic, multi-sectoral computable general equilibrium model for Germany
- Identify a slight trade-off between the resource-use improvement and economic effects

1. Introduction

Improving resource-use intensity, i.e. decreasing the use of resources per unit produced [3], is a key pillar in moving towards a circular economy. This is in keeping with the overall notion of 'more with less' [4]. Whilst the circular economy is primarily concerned with closing supply chains, residual waste management, and product lifetime extensions, reducing the use of resources and materials remains crucially important [5]. This is reflected clearly in the ambitions set out in the circular economy action plan of the EU and the various directives adopted at the time of writing [6]. Substantial co-benefits, beyond the environmental impacts, are expected. The EU [7] Circular Economy Action Plan highlights the potential for positive net-effects on job creation. Specifically, 700 thousand new jobs could be created in the EU by 2030, along with an additional increase in EU GDP of 0.5%, by applying circular economy principles across the EU [7].

Many studies in this area focus on assessing the implications of resource use changes brought about by economic policy instruments, particularly material taxation. Note that scenario design in these ex-ante studies tends to be mainly stylised. For example: Chateau, et al. [8] assess the employment impacts of 'material fiscal reform' driven transition towards a more resource-efficient and circular economy. Hatfield-Dodds, et al. [9] consider, among other, the implications of the taxation of resource extraction. EC [10] examine the implications of a raw materials tax, and Distelkamp, et al. [11] assesses a material tax for building materials. Many more studies are summarised in Laubinger, et al. [12], McCarthy, et al. [13], Aguilar-Hernandez, et al. [14].

The scale of economic impacts, particularly these on employment, arising from taxation induced changes in resource-use depend on the redistribution of tax revenues [12]. Although, labour market (wage bargaining) responses might also affect outcomes e.g. workers could accept a lower pay in return for potential environmental improvements resulting in double dividend for the environment and the economy [15]. Many studies in this area – that employ computable general equilibrium (CGE) models - assume a homogeneous labour supply and that wages adjust to clear labour markets. As such, labour market imperfections and involuntary employment are often not considered.[1] Much of the academic

[1] Many CGE models either assume a market-clearing set up such that wages equilibrate demand and supply resulting in no involuntary unemployment, or a fixed wage set-up where labour supply and demand are determined given a fixed level of wages, and the resulting difference is interpreted as involuntary unemployment [16]. The former operates in a perfectly competitive labour market whilst the latter could be considered imperfect. These two options are limiting (extreme) cases and difficult to support with long-run empirical evidence [16]. An in-between modelling option, as employed in this paper, is

literature in the area of taxation driven transformation suggests that labour market effects will be either neutral or (marginally) positive [12, 14]. The stylised scenario design in the current literature and the focus on taxation as instrument to reduce intermediate-use intensity stems from the fact that it is challenging to translate 'soft policies', or behaviour changes and new business practices into quantifiable model scenarios [12].

The construction industry is a crucial component of many economies worldwide and the biggest consumer of raw materials [4, 18, 19]. However, it is also one of the most polluting industries, with a significant impact on the environment due to its large material and greenhouse gas emissions footprint. To achieve green goals in the future, significant changes are necessary in the current construction processes. The 'business-as-usual' projections suggest that urgent (and multi-pronged) action is necessary to reduce the environmental burden of the construction industry [18, 20]. One potential solution (and the focus of this paper) is to reduce the amount of resources required to produce the same output by implementing more efficient (technology driven) processes. However, this is just one avenue towards reducing resource-use, and it may not be the most environmentally friendly option. The pathway towards 'circular construction' involves reusing and recycling materials, particularly these from existing buildings. Although beyond the scope of this paper, a whole lifecycle approach is necessary, as also emphasised in the EU [7] Circular Economy Action Plan, to determine the most sustainable option.

Resource-use improvements in construction are crucial for transitioning towards a more resource-efficient economy due to the sector's economic importance and environmental impact [4, 18, 19, 21]. The Construction sector offers many avenues of resource-use improvements – beyond the use of policy instruments [22]. For example, automated prioritization of concrete mix design [23], data driven resource planning [24], textile reinforced concrete [25], converting waste plastics into construction applications [26], digital tools to enable design optimisation [27], optimised shapes [28], prefabricated buildings [29, 30], and so on, are among the many viable options to decrease resource-use in the Construction sector.

in the form of a 'wage curve' [17]. With this, an imperfect labour market is modelled that allows for involuntary unemployment such that 'equilibria' are not necessarily 'optimal'.

Overall, there are various ways in which resource-use intensity in the Construction sector can be improved and these are not necessarily 'circular', but certainly fall under the umbrella of the circular economy action plan of the EU where the notion of 'more for less' is the driving force. Given this, it is instructive to consider resource-use intensity improvements in general, rather than focusing solely on resource-use efficiency induced by taxation.[2] The analysis presented in this paper is mainly concerned with identifying the system-wide implications of (costless) improvements in production processes such that fewer intermediates (inputs) are used. Assessing such a costless 'technology shock' assists the analysis to focus on the impacts of the reduction in resource-use, rather than the impacts of e.g. R&D expenditures [31]. It could be argued that such stylised costless technology shock could arise due to nudging efforts underway to increase environmental and sustainability [4, 32-34], the various potential technology improvements outlined above, or any other environmental innovation [35].

This paper aims to identify the potential impacts of costless resource-use intensity improvements and considers in detail the labour market implications. That is, the system-wide impacts of an improvement in resource-use intensity, interpreted here as a reduction in the overall use of intermediates in the construction sector, are identified by employing an empirically founded multisectoral dynamic CGE model of Germany. While Germany is used as a case study in this analysis, the model and approach can be applied to other countries and regions, provided that the necessary data are available. However, the results presented in this paper are unique to Germany because they are heavily influenced by a range of key parameters and, more importantly, the industrial structure of the German economy. Second, the empirical analysis presented in this paper highlights the potential employment effects in a skill disaggregated labour market that allows for labour market imperfections and involuntary unemployment. This is of particular importance given that the analysis of resource-use intensity improvements on the labour market in general - and labour market subcategories specifically - is still lacking [12, 36, 37]. Appendix A gives a brief overview of the literature - to supplement the more detailed reviews outlined in [5, 8, 10, 12-14] - to again illustrate that much of the current literature concentrates on taxation as a means of reducing resource-use and/or employs models that only consider perfectly competitive and unified labour markets.

[2] Indeed, the German resource efficiency program [20] encompasses more than just taxation, as it includes several instruments to achieve its goals. Examples include the more typical policies that are considered 'circular, but also R&D-focused fiscal support, institutional support and education programs, extended product warranties, and most importantly for this paper, improved resource efficiency through digitalisation.

This paper is organised as follows. Section 2 discusses in more detail 'resource-use intensity' and illustrates the challenges of identifying system-wide impacts by using a simplified analytical framework. Sections 3 and 4 describes the model and the scenario considered. Section 5 outlines the simulation results, and Section 6 concludes.

2. Resource-use intensity and the labour market

There are various mechanisms by which resource-use intensity can be improved, particularly in the context of a circular economy. The focus of this paper is on assessing a costless 'technology shock', akin to an increase in efficiency, to the Construction sector such that it uses fewer intermediates in the production process – following the notion of 'more for less' [4]. Such changes in resource-use can be presented in a simplified analytical framework (as employed in the literature [38] in the context of improvements of energy efficiency, for example):

(1) $$\Lambda = (1+\psi)\,V$$

where intermediates in natural units are given as V, Λ are intermediates in efficiency units, and ψ is the intermediates change parameter. The subsequent price of intermediates in efficiency unts, p_{Λ}, is given by:

(2) $$p_{\Lambda} = \frac{p_V}{1+\psi} < p_V$$

With constant prices in natural units, p_V, an improvement in intermediates-use reduces the price of intermediates in efficiency units. Whether this reduces the use of intermediates in natural units depends on the general equilibrium own-price elasticity [38]. For example, in cases where this is greater than unity: substitution, income and output effects would dominate the effects of the intensity-use improvement so that the use of intermediates would increase. That is, the fall in the implicit price of intermediates will generate an increase in expenditure on intermediates, and thereby increase intermediates use [38]. This would act contrary to explicit target of a reduction in resource-use.

A similar complexity is present when seeking to identify the likely employment effects. Although, it can be expected that employment will mirror output, labour intensities, for example, become crucially important. It is evident that such simplified analytical framework is not sufficiently equipped to deal with such substitution, income and output effects at a multisectoral and economy-wide level [38]. Thus, there is the need for a more complex empirical model that is parameterised on a set of representative accounts of the economy. Such model is outlined in the next section.

3. The DEMACRO model

The model employed in this paper, DEMACRO, is a an intertemporal, dynamic, multi-sectoral CGE model for Germany. The DEMACRO model builds upon the macro-micro economic CGE simulation framework AMOS [15, 39-44]. A mathematical summary of the DEMACRO model is given in Appendix B and in Lecca, et al. [39]. The model is parameterised on a 2018 Social Accounting Matrix (SAM) for Germany. The 2018 EXIOBASE Input-Output (IO) tables [45] form the basis of the SAM.[3] The model has three domestic transactors: households, corporations, and government; four major components of final demand: consumption, investment, government, and exports; 25 industrial sectors; and two types of labour (skilled and unskilled). The demand for German exports (to the rest of the world) is determined via conventional export demand functions and imports are obtained through an Armington [48] link with trade substitution elasticities of 2.7 [49]. Financial flows are not explicitly modelled, and Germany is assumed to be a price-taker in financial markets. In the simulations presented in this paper real government expenditure is exogenous and remains fixed, although this assumption could be relaxed [15, 50].

Capital stock is fixed in the short run both in total and in its distribution across sectors. Capital stocks in individual sectors vary through period-by-period flows of net investment, and capital markets fully adjust in the long run models. Gross investment at time, t, is equal to depreciation, δ, plus some proportion τ, of the difference between the desired capital stock in the next time period, KST_{it}, and the actual capital stock, KS_{it}, so that:

(3) $$IND_{it} = \tau[KST_{it} - KS_{it}] + \delta KS_{it}$$

The desired capital stock in period t is determined by the output price, p^y, and cost of capital, UCK, value added Y_{JT} in time period t. Ek_{JT} are efficiency parameters calculated by industry with ρ elasticity parameters

[3] The multi-regional IO table is aggregated to Germany and the rest of the world (ROW). This aggregate German IO table is extended to a SAM using publicly available data [46], following the approach outlined in Emonts-Holley, et al. [47]. Given this, each period in the period-by-period simulations is interpreted as a year.

JOURNAL POST-PRINT CITE HTTPS://DOI.ORG/10.1016/J.EIAR.2023.107173.

(4) $$KST_{JT} = \left(\frac{EK_{JT}^{\rho_J^Y} \alpha_J P_{JT}^Y}{UCK_T}\right)^{\frac{1}{1-\rho_J^Y}} Y_{JT}$$

The industries investment decisions are based on their desired level of capital stock and in the last period $KS_{IT}\delta = IND_{IT}$. Note that a perfect foresight version is available, as outlined in detail Lecca, et al. [39].

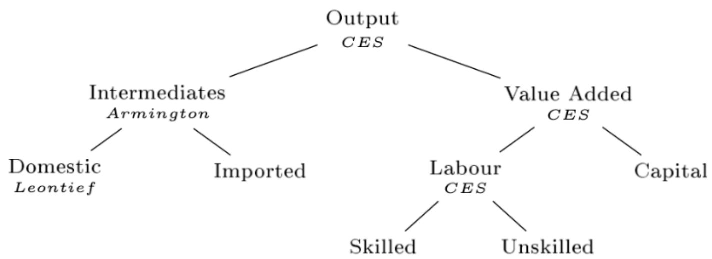
The production structure of each of the production sectors, as shown in Figure 1, is characterised by a capital and labour nested CES function. The combination of labour and capital forms value added, and intermediate inputs are determined via an Armington link [48] between domestic and imported. The combination of intermediates and value added in turn forms total output in each sector. Intermediate inputs in production, V_{ij}, are given as:

(5) $$VV_{ijt} = \psi_{ij}\, C_{ij}^{V\ \sigma_i} \left[\frac{P_{it}^X}{P_{it}^Q}\right]^{\sigma_i} X_{jt}$$

where C_{it}^V is the calibrated coefficient for intermediate inputs, P_{jt}^X and P_{it}^Q are the gross output price and the composite price respectively, X_{jt} is gross output, σ is a substitution parameter and ψ_{ij} is the intermediates change parameter.

In all simulations the labour force is fixed, but employment is variable over time, the unemployment rate can change, and labour is mobile across sectors. Natural demographic change is not modelled and there is no change in human capital formation.

Figure 1: DEMACRO production structure



The model allows for labour market imperfections and involuntary unemployment, implying that 'equilibria' are not necessarily 'optimal' [51]. The default model specification embodies a bargained real wage function (BRW) for each skill category represented in the labour market [17, 52, 53]. This is a positive empirical relationship between the real consumption wage and the bargaining power of workers, which is inversely to the unemployment rate:

$$(6) \qquad ln(rw_{zt}) = \beta - \epsilon_z \, ln(un_{zt})$$

where rw is the after-tax real wage, un is the unemployment rate (4% for the skilled and 6% for the unskilled), z is the skill category, ϵ is the unemployment rate elasticity which is set to 0.16 for the skilled and 0.15 for the unskilled [54-58], and β is a calibrated parameter so as to replicate base year data. While there is evidence in favour of this labour market wage specification, there exists some uncertainty about the way that the aggregate labour market currently operates, where real wages have been falling along with falling unemployment rates. This would suggest that there is some evidence of a degree of nominal wage inflexibility. This is illustrated by exploring the limiting case of a fixed nominal wage (FNW) were $w_{zt} = w_{zt=0}$.

4. The modelling scenario

Although reusing and recycling existing materials, such as these from the existing housing stock, is a more promising avenue for reducing resource usage, improving building practices, and utilising technological advancements can also contribute to long-term sustainable resource usage [18, 20]. Whilst it is feasible to incorporate modelling for material reuse and recycling within the framework used in this paper, the focus here is to enhance resource utilisation by improving technological efficiency. The Construction sector offers significant opportunities for efficiency improvements through the better use of technologies, as highlighted in the German resource efficiency program [20] and the illustrative examples outlined previously.

The analysis presented in this paper uses a stylised interpretation of an intermediate use-reduction in the Construction sector. That is, an exogenous large-scale (and costless) immediate and permanent 15% step improvement in resource-use improvement (i.e a reduction in the use of all intermediates) in the Construction sector is modelled.[4] For his, the intermediates change parameter, ψ, in Equation 5 is set to 0.85 for all purchases of the Construction sector. Note that this follows the same general approach

[4] A gradual improvement in resource-use would yield similar long-run effects. Adjustment paths, however, would be different such that impacts on employment and GDP, for example, would be less pronounced and distributed over a larger number of time periods.

that would be taken when employing an Input-Output model [59] – although the model employed in this paper considers in detail output, price, income, substitution, and competitiveness effects along with a more detailed representation of the labour market. Although a 15% improvement in resource usage is rather ambitious and likely not achievable without material reuse and recycling, it is nonetheless instructive to consider the economy-wide implications of such extreme structural changes to highlight potential growing pains that may be experienced in labour markets. A less pronounced increase in resource-use efficiency would not affect the qualitative results reported in the sections to follow.

The economy is taken to be in long-run equilibrium prior to the increase in resource-use in the Construction sector, and when the model is run forward without this exogenous disturbance it replicated the base-year dataset in each period [60]. The results reported in the following sections are percentage changes in the endogenous variables relative to this unchanging equilibrium and are directly attributable to the exogenous technology shock to resource-use in the Construction sector.

5. Simulation results

This section outlines the simulation results with focus is on two conceptual time periods. The first is the short run, the period immediately after the introduction of the change in intermediates use of the Construction sector. Capital stocks are fixed in the short run at industry level, but labour is perfectly flexible across sectors. The second period is the long run, where capital stocks fully adjust, across all sectors, and are again equal to their desired levels. Table 1 summarises the short- and long-run effects of a 15% decrease in intermediates-use in the Construction sector. The following sections outline these results in detail, starting with the long run, Section 5.3 gives the time path dynamics, and Section 5.4 considers the implications of changes to the openness of trade.

5.1 Long run results

Data columns 3 and 4 in Table 1 report the long-run results for the bargained real wage and the fixed nominal wage closures, labelled BRW and FNW respectively. There are some general effects that can be observed irrespective of the wage closure employed. As the decrease in resource-use of the Construction sector is effectively a negative demand shock to the sectors from which the Construction sector purchases, there is a fall in demands and so GDP, employment, investments, and household consumption all decrease. Domestic intermediates-use and territorial industrial CO_2 emissions decrease, indicating that the overall aim of a reduction in the use of resources is achieved. The scale of the impacts, however, critically depends on the wage closures.

In the FNW closure, the decrease in resource-use in the Construction sector results in a 0.98% fall in GDP. As there are no changes in prices, i.e. CPI and wages remain unchanged from base year levels, there are no competitiveness effects and exports remain unchanged. Only quantities change in this case since prices are invariant across long-run equilibria, and there is no crowding out/in. This corresponds closely to the behaviour of an Input-Output system with an entirely passive long-run supply side (although the labour force remains fixed here). As such, this gives the full effect of the fall in resource-use in the Construction sector. Overall economy wide intermediates decrease in the FNW closure by 2.19% (and domestic intermediates fall by 2.23%). Whilst there is no change in nominal and real wages, there is a fall in employment of 0.81% for the skilled, and 1.04% for the unskilled – leaving the unskilled worse off as compared to the skilled.

Table 1: Short- and long-run effects of a 15% decrease in intermediates-use in the Construction sector. Values are % changes from base year.

	Short run		Long run	
	BRW	FNW	BRW	FNW
GDP	-0.04	-0.21	-0.23	-0.98
CPI	-0.33	-0.27	-0.25	-
Unemployment rate	0.14	0.72	0.30	1.74
Skilled	0.07	0.31	0.14	0.76
Unskilled	0.08	0.40	0.16	0.98
Employment	-0.08	-0.38	-0.16	-0.93
Skilled	-0.07	-0.33	-0.15	-0.81
Unskilled	-0.08	-0.43	-0.17	-1.04
Nominal gross wage	-0.51	-	-0.64	-
Skilled	-0.51	-	-0.64	-
Unskilled	-0.52	-	-0.65	-
Real gross wage	-0.18	0.27	-0.39	-
Skilled	-0.18	0.27	-0.39	-
Unskilled	-0.19	0.27	-0.40	-
Total intermediates	-1.23	-1.41	-1.41	-2.19
Domestic intermediates	-0.84	-1.03	-1.18	-2.23
Territorial industrial CO_2 emissions	-0.42	-0.85	-0.59	-1.62
Household consumption	-0.02	-0.03	-0.09	-0.26
Investment	-0.32	-0.74	-0.33	-1.01
Exports	0.75	0.66	0.67	-

Note: BRW = bargained real wage; FNW = fixed nominal wage

It must be noted that the fall in GDP (and employment) is relatively small, despite the relatively large decrease in resource-use of the Construction sector. This, however, could be expected. According to the underlying IO tables [45], the Construction sector constitutes 6% of total national direct employment, and 5% of total national direct value added. Thus, a 15% decrease in intermediates-use of the Construction sector is not necessarily poised to generate large system-wide effects. It is therefore possible to absorb such changes in consumption patterns of the Construction sector in a system-wide context, particularly when competitiveness effects take effect (as illustrated in the BRW closure). Such rebound effects, however, might be counter to stated (energy policy) goals. This is discussed again in Section 5.4 where the openness to trade is considered.

Aggregate effects outlined above do not necessarily hold at the individual sector level (Appendix C and D give the long-run effects at the individual sector level for the two wage closures). Although sectoral results are not discussed in detail, the impacts depend on the proportion of the sectors' activities that are supported by the Construction sector, export and labour intensities of that sector, and other inter-sectoral and final demand effects. In the FNW closure, there are negative impacts across all sectors such that output and employment always fall. In the BRW closure, however, there is a stimulus to exports in all sectors. Sectors with strong export intensities and direct demand linkages to the Construction sector see an increase in demands for their outputs and thereby an increase in employment and investments, but correspondingly also resource-use. Thus, whilst economic activities fall at the aggregate level, this is not necessarily the case at the level of the individual sector. The following section outlined the short-run results, where capital restrictions exist.

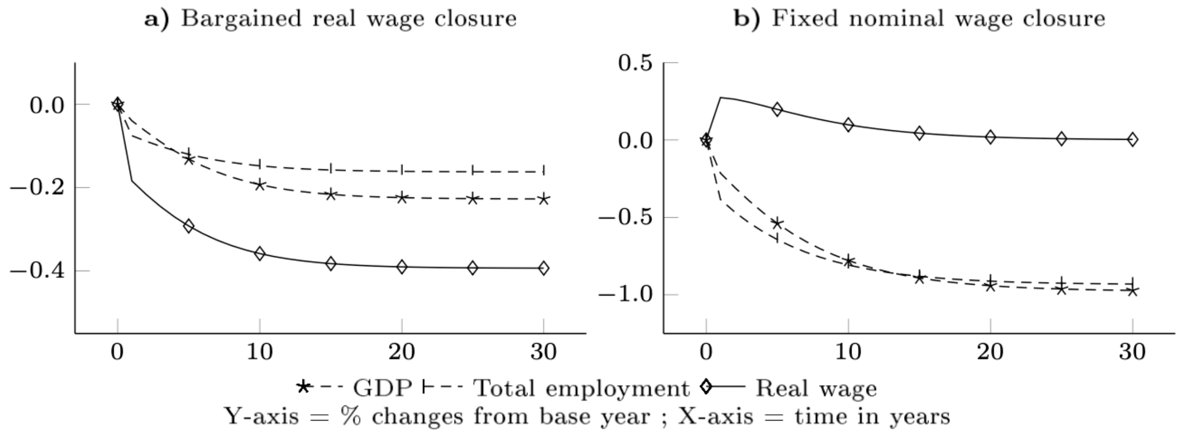
5.2 Short run results

The short-run results for the bargained real wage and the fixed nominal wage closures are reported in data columns 1 and 2 in Table 1. Recall that in the short run capital stocks are fixed at industry level. Aggregate effects are similar to those seen in the long run, but impacts are more muted as effects have not propagated fully through the system. GDP falls by only 0.04% in the BRW closure, and by 0.21% in the FNW closure. A key difference, however, in the FNW closure is that real gross wages increase (nominal wages being fixed along with falling prices). Moreover, as prices now also fall in the FNW closure, there are competitiveness effects at play that act as a buffer to the negative demand effects coming from the reduced intermediates demands from the Construction sector. Exports increase by 0.66% in the FNW closure. However, the comparatively large negative effects on employment act against this. This indicates that, as in the long run, there are negative economy wide effects from the fall in resource-use of the Construction sector. However, as outlined previously, the scale of the negative effects is small.

5.3 Time-path adjustments

Figure 2 gives the time-path adjustments for GDP, total employment, and aggregate real wages. Panel a of Figure 2 illustrates the period-by-period results for the bargained real wage closure, and panel b those for the nominal wage closure. Each period is one year. The difference in the way the labour market operates is highlighted here. Whilst real wages (for both skill categories) remain negative throughout all periods in the BRW case, the real wages are positive in the initial periods following the exogenous technology shock in the FNW closure. In both cases employment closely traces the impacts on GDP and is negative throughout all periods of the simulation. This illustrates again that effects are relatively small; that the most negative effects are confined to the long run; and that negative effects are cushioned in the BRW closure.

Figure 2: Aggregate transition paths of GDP, employment, and real wages of a 15% decrease in intermediates-use in the Construction sector. Values are % changes from base year.



5.4 Trade sensitivity

Table 2 gives the long run results for changes in the Armington trade elasticities, σ_v , for the bargained real wage closure. The elasticity is varied between 0.7 and 4.7 in increments of one, where the default value used in the model is taken to be 2.7 [49]. Note that changes to the Armington trade elasticity do not affect the results reported in Table 1 for the fixed nominal wage closure. This is because there are no changes in prices in the long run such that exports remain unchanged from base year values irrespective of Armington trade elasticities.

As the degree of openness of the economy is increased, with increasing values for the Armington elasticity, the system becomes more sensitive to competitiveness effects. That is, more is exported with higher Armington values so that GDP and employment take a smaller cut. However, this also implies that the resource-use decrease is smaller. With a relatively closed economy, as represented by an Armington elasticity of 0.7, there is a fall in GDP of 0.56% along with a fall in employment of around 0.4%, and a decreased use of intermediates of 1.78%. In contrast, a more open economy with an Armington elasticity of 4.7, GDP falls by 0.15%, but intermediates only decrease by 1.33%. Thus, the openness of the economy to trade is important in determining system-wide macroeconomic effects, and the corresponding resource-use levels.

Table 2: Long-run effects of a 15% decrease in intermediates-use in the Construction sector and changes to the Armington trade elasticity. Bargained real wage closure. Values are % changes from base year.

Armington σ_v	GDP	Employment skilled	Employment unskilled	Total intermediates	Domestic intermediates
0.7	-0.56	-0.41	-0.46	-1.78	-1.66
1.7	-0.32	-0.22	-0.25	-1.51	-1.31
2.7	-0.23	-0.15	-0.17	-1.41	-1.18
3.7	-0.18	-0.12	-0.13	-1.36	-1.11
4.7	-0.15	-0.09	-0.11	-1.33	-1.07

It is worth noting that not all construction materials will have the same Armington trade elasticity. High-volume but low-value materials may have limited competitiveness effects due to transport costs, reducing opportunities for trade and international competition. Sectors with high export intensities, such as Rubber and Plastics, Other Non-Metallic Minerals, and Basic Metals and Fabricated Metal, may exhibit a higher Armington trade elasticity [61, 62], with around 35% of each sector's output relying on trade. These sectors are also those from which the Construction sector directly purchases. In contrast, the Construction sector itself is not export-intensive, with only around 2% of output going to the external sector, such that a low trade elasticity can be expected for this sector.[5]

[5] To illustrate the potential effects, the Armington trade elasticities of Rubber and Plastics, Other Non-Metallic Minerals, and Basic Metals are increased to the extreme value of 4.7, while maintaining 2.7 for all other sectors. This results in a 0.21% long-run GDP fall, compared to 0.23% fall in GDP reported in Table 1, for the bargained real wage closure. Similarly, reducing the Construction sector's elasticity to 0.7, whilst maintaining the default value of 2.7 for all other sectors, results in a 0.24%

6 Discussion and conclusion

Whilst the circular economy is primarily concerned with closing supply chains, residual waste management, and product lifetime extensions, reducing the resource and material use remains crucially important in moving towards a more circular economy. Resource-use improvements in the Construction sector are a vital part in this given its emissions contents, for example. More importantly, the Construction sector holds substantial capacity to do so. Many studies focus on identifying the effects of taxation induced reductions in resource-use. However, there are other avenues that can be explored – beyond the use of (fiscal) policy instruments. This paper aims to analyse the system-wide implications of a reduction in resource-use of by using a dynamic multisectoral computable general equilibrium model of Germany. Specifically, the focus is on the macroeconomic implications of a costless 'technology shock' that reduces the intermediates used by the construction sector, and its possible effects on the labour market.

The large-scale decrease in resource-use of the Construction sector is effectively a negative demand shock to the sectors from which the Construction sector purchases. Thus, there is a fall in demands for these sectors and so GDP and employment, investments, and household consumption decrease. Both total and domestic intermediates-use decrease, indicating that the overall aim of a reduction in the use of resources is achieved. Many studies in this area - that employ computable general equilibrium models - assume a homogeneous labour supply and that wages adjust to clear labour markets. However, the analysis given in this paper illustrates that labour market imperfections and the consideration of involuntary employment substantially affect overall results.

In our preferred standard specification where workers have bargaining power over their wages, negative macroeconomic effects are cushioned (via competitiveness effects). This in turn, however, has contrary effects on resource-use and industrial CO_2 emissions as the use of overall intermediates increases. In contrast, in the case where nominal wages remain fixed, the use of intermediates decreases more substantially, but at the cost of lower GDP and employment. We note that results at the individual sector level might not follow these of the macroeconomy. Particularly in the case where workers have a bargained wage, there are winners and losers at the individual sector level. That is, there are sectors that experience a fall in output and employment (and resource-use), and there are sectors

fall in GDP. This is not significantly different from the results given in Table 1. Armington elasticities simply amplify existing trade intensities.

that experience the opposite. Sectoral export intensities play a key role here as competitiveness effects drive these results. Importantly, this implies that the stated aim of reductions in the use of resources might not be achieved fully in the presence of competitiveness effects. The scale of this competitiveness effect greatly depends on the economy's openness to trade (and corresponding sectoral export intensities). Higher openness means greater sensitivity to competitiveness effects, and this implies a smaller decrease in resource-use, but also smaller cuts in GDP and employment. Key inputs to the Construction sector, such as Other Non-Metallic Minerals, might be rather sensitive to competitiveness effects, so lower local demand could rebound via trade.

The primary goal of reducing resource-use is to mitigate the environmental impacts of industrial processes, rather than to achieve economic benefits. Although it would be desirable to have positive impacts on both the economy and environment, our modelling indicates that there is a small trade-off between the two. This is despite the relatively large-scale decrease in resource-use of the Construction sector of 15%. It is therefore possible to absorb such changes in sectoral consumption patterns in a system-wide context, particularly when competitiveness effects are taken into consideration. From a policy perspective, it is thus possible to concentrate on R&D investment and technologies that reduce the use of resources (this could also be within a more ‘circular’ setting) instead of solely using taxation to achieve policy goals. However, as shown in this paper, there is the potential for rebound effects acting contrary to stated goals of reducing resource-use.

The results presented in this paper cannot be generalised beyond the German economy due to the influence of various key parameters and, most importantly, the unique industrial structure of the German economy. However, this paper emphasises that it is important to take into consideration the system-wide effects - particularly the implications of different labour market specifications - and this holds universally.

The analysis presented in this paper could be expanded in several ways to provide further insight. First, comparing the aggregate effects of tax-induced changes to the use of intermediates with those presented here (or an extension that considers product-specific resource-use improvements) would be informative. This comparison would be useful for policy makers who are deciding whether to invest in R&D and technologies that reduce resource use (the carrot) or taxation (the stick). Second, it would be beneficial to extend the analysis to an interregional framework that considers trade effects in more detail. Last, a more detailed analysis of the Construction sector would be helpful. It is evident that such an analysis would benefit from a more disaggregated approach, and exploring the possibility of this in a multi-regional context could be useful.

Appendices

Appendix A: Brief overview of literature.

Paper	Region	Model	Policy / shock	Labour market segmentation	Labour market competition
[11]	Germany	ME	Resource efficiency = taxation	Unified	Perfect
[18]	Multiregional	CGE	Recycling + efficiency	Unified	Perfect
[63]	Spain	CGE	Tax on waste	Unified	Imperfect
[64]	China	CGE	Resource Tax	Unified	Imperfect
[65]	Belgium	CGE	Various taxes	Unified	Imperfect
[66]	China	CGE	Environmental taxes	Unified	Imperfect
[59]	Multiregional	IO	Product lifetime extension and other	Unified	Perfect
[67]	Multiregional	IO	Reuse of materials	Skill & Gender	Perfect
[68]	Multiregional	VCA	Reduction in production linked to reuse	Unified	Perfect
[69]	Multiregional	CGE	Innovation policy	Unified	Imperfect

Note: ME = Macro econometric, CGE = Computable General Equilibrium, IO = Input-Output, VCA = Value Chain Analysis. See [5, 8, 10, 12-14] for a more detailed review of the literature.

Appendix B: Mathematical summary of the DEMACRO model.

Production Technology

<u>CES production</u>

$$Y_{JT} = \psi_{IJ} C_J^{Y^{\sigma_J^Z}} \left[\frac{P_{JT}^X}{P_{JT}^Y}\right]^{\sigma_J^Z} X_{JT}$$

(B1)

$$VV_{IJT} = \psi_{IJ} C_{IJ}^{V^{\sigma_I^Z}} \left[\frac{P_{IT}^X}{P_{IT}^Q}\right]^{\sigma_I^Z} X_{JT}$$

(B2)

$$Y_{JT} = \left[\alpha_J \left(EK_{JT} KD_{JT}\right)^{\rho_J^Y} + \beta_J \left(EL_{JT} LD_{JT}\right)^{\rho_J^Y}\right]^{\frac{1}{\rho_J^Y}}$$

(B3)

$$LDU_{JT} = \left[ELU_{JT}{}^{\rho_J^Y} \beta U_J \frac{W}{W_U}\right]^{\frac{1}{1-\rho_J^Y}} LD_{JT}$$

(B4)

$$LDS_{JT} = \left[ELS_{JT}{}^{\rho_J^Y} \beta S_J \frac{W}{W_S}\right]^{\frac{1}{1-\rho_J^Y}} LD_{JT}$$

(B5)

$$LD_{JT} = \left[\beta S_J ELS_{JT} LDS_{JT}{}^{\rho_J^Y} + \beta U_J ELU_{JT} LDU_{JT}{}^{\rho_J^Y}\right]^{\frac{1}{1-\rho_J^Y}}$$

(B6)

$$RK_{JT} = P_{JT}^Y \alpha_J EK_{JT}{}^{\rho_J^Y} \left[\frac{Y_{JT}}{KD_{JT}}\right]^{1-\rho_J^Y}$$

(B7)

Y_{JT} – value added

P_{JT}^Y – value added price

C_J^Y – calibrated coefficient for unit of output

ψ_{IJ} - Intermediate change parameter

X_{JT} – gross output

$P_{I,J\,T}^X$ – gross output price

VV_{IJT} – intermediate inputs

P_{IT}^Q – composite price

C_{IJ}^V – calibrated coefficient for intermediate inputs I and J (Leontief)

EL_{JT} – labour augmenting technology

ELU_{JT} – labour augmenting technology unskilled

ELS_{JT} – labour augmenting technology skilled

EK_{JT} – capital augmenting technology

LD_{JT} – labour demand total

LDU_{JT} – labour demand unskilled

LDS_{JT} – labour demand skilled

W – firms' labour costs before tax

W_s – firms' labour costs before tax skilled

W_u – firms' labour costs before tax unskilled

KD_{JT} – capital demand

RK_{JT} – rate of return on capital

α_J – calibrated CES parameter for capital

β_J – calibrated CES parameter for labour

βU_J – calibrated CES parameter for unskilled labour

βS_J – calibrated CES parameter for skilled labour

$\sigma_{I,J}^Z$ – elasticity between value added and intermediate

	ρ_J^Y – substitution parameter for factors
Taxes on Production, Import and Production Subsidies	
$IBT_{IT} = BTAX_I X_{IT} P_{IT}^X$ (B8) $IMT_{JT} = \sum_I VM_{IJT} MTAX_J P_{JT}^M$ (B9) $SUBSY_{IT} = SUB_I X_{IT} P_{IT}^X$ (B10)	IBT_{IT} – indirect business tax $BTAX_I$ – indirect business tax rate X_{IT} – gross output P_{IT}^X – gross output price IMT_{JT} – indirect import tax $\sum_I VM_{IJT}$ – imported intermediate input from ROW $MTAX_J$ – import tax rate P_{JT}^M – import price $SUBSY_{IT}$ – production subsidy SUB_I – subsidy rate
Intermediate Demand	
$VV_{IJT} = \left(\delta_{IJ}^{VM}\left(\gamma_{IJ}^{VM} VM_{IJT}\right)^{\rho_I^V} + \delta_{IJ}^{VR}\left(\gamma_{IJ}^{VR} VR_{IJT}\right)^{\rho_I^V}\right)^{\frac{1}{\rho_I^V}}$ (B11) $VM_{IJT} = VV_{IJT}\left[\frac{\delta_{IJ}^{VM}}{\delta_{IJ}^{VR}}\frac{\gamma_{IJ}^{VM}}{\gamma_{IJ}^{VR}}\frac{P_{IT}^R}{P_{IT}^M}\right]^{\frac{1}{1-\rho_I^V}}$ (B12) $TV_{JT} = \sum_I VV_{IJT}$ (B13) $TVR_{JT} = \sum_I VR_{IJT}$ (B14) $TVM_{JT} = \sum_I VM_{IJT}$ (B15)	VV_{IJT} – intermediate inputs $\gamma_{IJ}^{VM}, \gamma_{IJ}^{VR}$ – shift parameters in Armington $\gamma_{IJ}^{TM}, \gamma_{IJ}^{TR}$ – shift parameters in Armington δ_{IJ}^{VM}, δ_{IJ}^{VR} – share parameters VR_{IJT} – Domestic input VM_{IJT} – ROW input P_{IT}^M – import price ρ_I^V – substitution parameter P_{IT}^R – domestic good price TV_{JT} – total intermediate inputs TVR_{JT} – total domestic intermediate input TVM_{JT} – total imported intermediate goods from ROW
Goods market balance	
$X_{IT} + M_{IT} = \sum_J VV_{IJT} + Q_{IT}^H + E_{IT}$ $+Q_{IT}^V + Q_{IT}^G + TUTOT_{IT} + STOCKTOT_I$	X_{IT} – gross output E_{IT} – exports

(B16)	M_{IT} – imports $\sum_J VV_{IJT}$ – total intermediate imports in sector i Q_{IT}^{H} – household consumption Q_{IT}^{V} – investment demand Q_{IT}^{G} – government consumption $TUTOT_{IT}$ – tourism consumption $STOCKTOT_I$ – total stock
Exports	
$X_{IT} = R_{IT} + E_{IT}$ (B17) $E_{IT} = SIMROW_{IT} E_{0I}^{INT} \left(\frac{P_{IT}^{E}}{P_{IT}^{Q}}\right)^{\sigma_I^X}$ (B18) $R_{IT} = \sum_J VR_{IJT} + Q_{IT}^{HR} + Q_{IT}^{VR}$ $+ Q_{IT}^{GR} + TURREG_{IT} + STOCKREG_I$ (B19)	X_{IT} – gross output E_{IT} – exports R_{IT} – domestic goods $SIMROW_{IT}$ – simulation variables E_{0I}^{INT} – exports to ROW in base year σ_I^X – export elasticity P_{IT}^{Q} – commodities price P_{IT}^{E} – export price $\sum_J VR_{IJT}$ – total domestic intermediate input in sector j Q_{IT}^{GR} – government domestic consumption Q_{IT}^{HR} – household domestic consumption Q_{IT}^{VR} – investment domestic demand $TURREG_{IT}$ – Tourists national consumption $STOCKREG_I$ – National stock
Income and Output	
$LY_T = \sum_J LD_{JT} WF_T$ (B20) $KY_T = \sum_J KD_{JT} RK_{JT}$ (B21) $GRP_T = C_T + \sum_I Q_{IT}^{G} + \sum_I Q_{IT}^{V}$ $+ \sum_I TUTOT_{IT} + \sum_I E_{IT} - \sum_I M_{IT}$	LY_T – labour income $\sum_J LD_{JT}$ – total labour demand WF_T – firms' labour costs before tax KY_T – capital income $\sum_J KD_{JT}$ – total capital demand

(B22) $TRSNG_{DNGINS,DNGINS,T}$ $= TRSNG_{0,DNGINS,DNGINSP} CPI_T$ (B23) $YNG^H_T = LY_T - HTAX^H_T + DSHR_{HH}KY_T$ $+ TRSNG_{HH,Firms,T} + TRH_{HH,Gov}CPI_T +$ $\sum_{FINS} SAM_{HH,FINS} * \varepsilon_T$ (B24) $YNG^F_T = DSHR_{Firms}KY_T + TRSNG_{Firms,HH,T} +$ $SAM_{Firms,Gov}CPI_T + NIEMPL_T + \sum_{FINS} SAM_{Firms,FINS}\varepsilon_T$ (B25)	RK_{JT} – rate of return on capital GRP_T – gross domestic product C_T – household consumption $\sum_I Q^G_{IT}$ – total government consumption $\sum_I Q^V_{IT}$ – total investment $\sum_I TUTOT_{IT}$ – total stock $\sum_I E_{IT}$ – total exports $\sum_I M_{IT}$ – total imports YNG^F_T – household income CPI_T – consumer price index ε_T – exchange rate YNG^F_T – firms' income $TRNSG_T$ – transfers TRH_T – Government transfers to households $DSHR$ – share of capital income $NIEMPL_T$ – Employer contribution SAM – values as given in the SAM $FINS$ – foreign institutions $HTAX^H_T$ – Household taxes $DNGINS$ – domestic non-government institutions
Household Taxes and Savings	
$SAV_T = (YNG^H_T - HTAX^H{}_T)MPSAV$ (B26) $HTAX^H_T = DTR^H * (EIRPEF_T + ESSCEE_T) * LY_T$ (B27)	SAV_T – household saving $MPSAV$ – household savings rate YNG^H_T – household income $HTAX^H_T$ – household tax paid LY_T – labour income DTR^H - Direct tax rate $EIRPEF_T$ – income tax rate $ESSCEE_T$ - Social security tax rate

Firm Taxes	
$ETAX_T = DTRE(YNG_T^F)$ (B28) $CTAX_{IT} = RK_{IT}KS_{IT}TKT_{IT}$ (B29) $CTAXTOT_T = \sum_I CTAX_{IT}$ (B30)	$ETAX_T$ – firm taxes (excluding corporation tax) YNG_T^H – firms' income $DTRE$ – effective firm tax rate (excluding CT) $CTAX_{IT}$ – corporation tax revenues by sector RK_{IT} – interest rate KS_{IT} – capital supply TKT_{IT} – effective corporation tax rate $CTAXTOT_T$ – total corporation tax revenue
Foreign Debt	
$DEBT_T = (1 + IR - GINT_0)DEBT_{T-1} + BALPAY_{T-1}$ (B31) <u>In first period only:</u> $DEBT_T = DEBT_0$ (B32) <u>In final period only:</u> $-(IR - GINT_0)DEBT_T = BALPAY_T$ (B33)	$DEBT_T$ – foreign debt IR – interest rate $GINT_0$ – variable in CALIB model $DEBT_0$ – base year debt $BALPAY_T$ – balance of payments
Prices, Wages and Balance of Payments	
$P_{IT}^M = \varepsilon_T P_I^{WM}(1 + MTAX_I)$ (B34) $P_{JT}^Y = \begin{bmatrix} P_{JT}^R(1 - BTAX_J - SUB_J) \\ -\sum_I P_{JT}^Q CV_{IJ}{}^{\sigma_J^Z} - P_{JT}^M CMT_J \end{bmatrix} \frac{1}{CY_J{}^{\sigma_J^Z}}$ (B35) $UCK_T = P_T^{INV}(IR + \delta)$ (B36) $P_T^{CON} = \frac{\sum_I P_{IT}^Q Q_{I0}^H}{\sum_I P_{I0}^Q Q_{I0}^H}$ (B37) $CPI_T = \frac{\sum_I P_{IT}^Q Q_{I0}^H}{\sum_I Q_{I0}^H}$	P_{IT}^M – import price P_I^{WM} – world import price $MTAX_I$ – import tax rate ε_T – exchange rate P_{JT}^Y – value added price CY_J – calibrated coefficient for a unit of output σ_J^Z – elasticity of substitution between value added and composite good P_{JT}^R – national output price P_{JT}^M – ROW output price

(B38) $WHG_T = \frac{WHN_T}{(1 - LABTAX_R)}$ (B39) $WF_T = WHG_T(1 + LABTAX_R)$ (B40) $P_{IT}^{E} = \varepsilon_T P_I^{WE}(1 - TE_I)$ (B41) $P_{IT}^{X} = \frac{P_{IT}^{R} R_{IT} + E_{IT} P_{IT}^{E}}{R_{IT} + E_{IT}}$ (B42) $P_{JT}^{Q} = \frac{R_{JT} P_{JT}^{R} + P_{JT}^{M} M_{JT}}{R_{JT} + M_{JT}}$ (B43) $BALPAY_T = \sum_{I} M_{IT} + SAM_{ROW,Firms}$ $+SAM_{ROW,Gov} - \left(\sum_{FINS} SAM_{Tur,FINS} + \sum_{I} E_{IT} + \sum_{FINS} SAM_{Gov,FINS} \varepsilon_T + \sum_{DNGINS,FINS} SAM_{DNGINS,FINS} \varepsilon_T \right)$ (B44)	Q_{IT}^{H} – household consumption P_{JT}^{Q} – composite good price CV_{IJ} – calibrated coefficient for intermediate inputs CMT_J – share of import tariffs of total production $BTAX_J$ – indirect business tax rate SUB_J – subsidy rate WF_T – firms' labour cost (before tax) CPI_T – consumer price index UCK_T – user cost of capital P_T^{INV} – price of investment good IR – interest rate δ – depreciation rate R_{JT} – domestic good P_{JT}^{R} – domestic good price R_{JT} – imports good P_{JT}^{M} – import good price P_T^{CON} – household consumption price Q_{IH}^{0H} – household consumption WHG_T – household gross wage WHN_T – household net wage $LABTAX_R$ – effective direct labour tax rates by type P_{IT}^{E} – export price P_I^{WE} – world export price TE_I – export tax rate (=0) P_{IT}^{X} – gross output price P_{IT}^{R} – domestic good price R_{IT} – domestic good E_{IT} – export P_{IT}^{E} – price of export

	$BALPAY_T$ – balance of payments SAM – values as given in the SAM $FINS$ – foreign institutions TUR – tourism $DNGINS$ – domestic non-government institutions
Household Consumption	
$U = \sum_{t=0}^{\infty}\left(\frac{1}{1+\rho}\right)^t \frac{C_T{}^{1-\sigma}-1}{1-\sigma}$ (B45) $\frac{C_T}{C_{T+1}} = \left[\frac{P_T^{CON}(1+\rho)}{P_{T+1}^{CON}(1+r)}\right]^{-\left(\frac{1}{\sigma}\right)}$ (B46) $Q_{IT}^H = HDEL_I\left[\frac{P_T^{CON}}{P_{IT}^Q}\right]^{SIGINV} C_T$ (B47) $Q_{IT}^H = \gamma_I^{QH}\left[\delta_I^{QHR} Q_{IT}^{HR\,\rho_I^H} + \delta_I^{QHM} Q_{IT}^{HM\,\rho_I^H}\right]^{\frac{1}{\rho_I^H}}$ (B48) $Q_{IT}^{HR} = Q_{IT}^{HI}\left[\frac{\delta_I^{QHR}}{\delta_I^{QHI}}\right]^{\frac{1}{1-\rho_I^H}}$ (B49)	U – household and other domestic institutions ρ – rate of time preference r – interest rate σ – Constant elasticity of marginal utility Q_{IT}^H – household consumption by sector $HDEL_I$- consumption share P_T^{CON} – consumption price P_{IT}^Q – composite price $SIGINV$ – elasticity of substitution (0.3) C_T – total household consumption γ_I^{QH} – shift parameter δ_I^{QHM}, δ_I^{QHI}, δ_I^{QHR} – share parameters Q_{IT}^{HM} – household consumption of imports ρ_I^H – elasticity Q_{IT}^{HR} – domestic household consumption
Government Expenditure and Revenues	
$GEXP_T = GEXP_0$ (B50) $GOVBAL_T = (GEXP_T P_T^{Gov} + SAM_{Firms,Gov} CPI_T + TRH_T CPI_T + SAM_{KFOR,Gov} + SAM_{ROW,Gov}) - (DSHR_{GOV} KY_T + \sum_I IBT_{IT} + \sum_I IMT_{IT} + HTAX_T + ETAX_T + CTAXTOT_T + \sum_I SUBSY_{IT})$ (B51) $P_T^{GOV} BF_T = \left[1 + IR - DIN + \left(\frac{CPI_T}{CPI_{T-1}} - 1\right)\right] P_{T-1}^{GOV} BF_{T-1} + GOVBAL_{T-1}$	$DHSR_{GOV}$– capital share of government KY_T – capital income $\sum_I IBT_{IT}$ – indirect business tax revenues CPI_T – consumer price index $\sum_I IMT_{IT}$ – import tax revenues (= 0) $HTAX_T$– household tax revenues $ETAX_T$ – firm tax revenues (excl. CT)

(B52) <u>In first period only:</u> $BF_T = BF_0$ (B53) <u>In final period only:</u> $-(IR - DIN)BF_T = GOVBAL_T$ (B54) $Q^G_{IT} = GDEL_I GEXP_T$ (B55) $Q^{GM}_{IT} = Q^{GM}_{I0}$ (B56) $Q^{GR}_{IT} = Q^G_{I0} - Q^{GM}_{I0}$ (B57) $P^{GOV}_T = \frac{\sum_I P^Q_{IT} Q^G_{I0}}{\sum_I P^Q_{I0} Q^G_{I0}}$ (B58)	$CTAXTOT_T$ – CT revenues $\sum_I SUBSY_{IT}$ – subsidies $GOVBAL_T$ – government deficit SAM – values as given in the SAM $GEXP$ – current government spending P^{GOV}_T – government price index TRH - *transfers to households* BF_T – gov. borrowing IR – interest rate DIN – calibrated variable Q^G_{IT} – government consumption Q^{GR}_{IT} – government domestic consumption $GDEL_I$ – consumption share Q^{GM}_{IT} - imports by government (= 0) P^Q_{IT} – composite price SAM – values as given in the SAM Q^{GM}_{I0}– imports by government Q^G_{I0}– government consumption
Investment "Demand" (investment by sector of origin)	
$Q^V_{IT} = \sum_J KMATRIX_{IJ} JINV_{JT}$ (B59) $Q^V_{IT} = \gamma_I^{QV}\left[\delta_I^{QM}(Q^{VM}_{IT})^{\rho_I^V} + \delta_I^{QVR}(Q^{VR}_{IT})^{\rho_I^V}\right]^{\frac{1}{\rho_I^V}}$ (B60) $Q^{VM}_{IT} = Q^{VR}_{IT}\left[\frac{\delta_I^{QM}}{\delta_I^{QVR}}\frac{P^R_{IT}}{P^M_{IT}}\right]^{\frac{1}{1-\rho_I^V}}$ (B61) $Q^{VR}_{IT} = Q^{VI}_{IT}\left(\frac{\delta_I^{QVR}}{\delta_I^{QVI}}\frac{P^R_{0I}}{P^X_{IT}}\right)^{\frac{1}{1-\rho_I^V}}$ (B62)	Q^V_{IT} – investment demand by sector $KMATRIX_{IJ}$ – parameter linking investment by destination and origin $JINV_{JT}$ – Investment by destination (incl. adjustment costs and tax credits) γ_I^{QV} – shift parameter δ_I^{QM} δ_I^{QVR} – share parameters Q^{VM}_{IT} – imported investment P^R_{IT} – domestic price P^M_{IT} – export price Q^{VR}_{IT} – domestic investment

	P_{IT}^X – gross output price δ_I^{QV} – share parameter ρ_I^V – share parameter
Investment and Capital Accumulation	
$KST_{JT} = \left(\frac{EK_{JT}^{\rho_J^Y}\alpha_J P_{JT}^Y}{UCK_T}\right)^{\frac{1}{1-\rho_J^Y}} Y_{JT}$ (B63) $JINV_{IT} = IND_{IT}(1 - BOP_{0I} + COP_{0I} - TAXC_I + \frac{ADJ}{2}\frac{IND_{IT}^2}{KS_{IT}})$ (B64) $PINV_T = \frac{\sum_{IJ} PQ_{JT}(1-TKT_{IT})^{-1}KMATRIX_{IJ}}{\sum_{IJ} PQ_{J0}(1-TK_I)^{-1}KMATRIX_{IJ}}$ (B65)	IND_{IT} - (net) investment KS_{IT} – capital supply KST_{IT} – desired level of capital stock $JINV_{JT}$ – investment by destination BOP_{0I} – calibrated parameter (rate of distortion or incentive to invest) COP_{0I} – calibrated parameter $TAXC_I$ – rate of tax credit to investment ADJ – cost parameter PQ_{JT} – composite price $KMATRIX_{IJ}$ – parameter linking investment by destination and origin $PINV_T$ – price of investment TKT_{IT}, TK_I – effective CT rate EK_{IT} – capital augmenting technical change α_J – CES parameter for capital ρ_J^Y – elasticity of substitution between labour and capital P_{JT}^Y – value added price UCK_T – user cost of capital Y_{JT} – value added
Labour Market Closures	
Bargained real wage: $ln(rw_{zt}) = \beta - \epsilon_z ln(un_{zt})$ (B66) Fixed nominal wage:	WHN_T – household wage after tax CPI_T – price level β – calibrated parameter (based on real wage and unemployment in base) WHG_T – gross household wage

$WHG_T = WHG_0$ (B67) <u>Real Wage Resistance:</u> $\frac{WHN_T}{CPI_T} = \frac{WHN_0}{CPI_0}$ (B68)	ε_z – unemployment rate elasticity rw_{zt} – Real wage after tax by labour type z un_{zt} - Unemployment rate by labour type
Capital Market Equilibrium	
$KS_{IT} = KD_{IT}$ (B69) <u>In first period only:</u> $KS_{IT} = KS_{0I}$ (B70) <u>In final period only:</u> $KS_{IT}\delta = IND_{IT}$ (B71) $IND_{IT} = \tau[KST_{IT} - KS_{IT}] + \delta KS_{IT}$ (B72)	KS_{IT} – capital supply KD_{IT} – capital demand δ – depreciation of physical capital IND_{IT} – investment by sector of destination KST_{IT} – desired level of capital stock τ – Speed of adjustment parameter
Labour Supply	
$LSU_T(1 - UNU_T) = \sum_J LDU_{JT}$ (B73) $LSS_T(1 - UNS_T) = \sum_J LDS_{JT}$ (B74) $LSU_T = LSU_{T=0}$ (B75) $LSS_T = LSS_{T=0}$ (B76) $LS_T = LSU_T + LSS_T$ (B76)	LSU_T – labour supply unskilled LDU_{JT} – labour demand unskilled UNU_T – unemployment rate unskilled LSS_T – labour supply skilled LDS_{JT} – labour demand skilled UNS_T – unemployment rate skilled LS_T – labour supply total

Appendix C: Long-run effects at the individual sector level of a 15% decrease in intermediates-use in the Construction sector. Bargained real wage closure. Values are % changes from base year.

	Output	Invest-ment	Total employ-ment	Employ-ment skilled	Employ-ment Unskilled	Exports
Agriculture, Forestry & Fishing	0.39	1.49	0.51	0.43	0.52	0.59
Mining	-1.25	-2.78	-1.23	-1.26	-1.22	0.62
Food, Beverages and Tobacco	0.37	1.84	0.51	0.49	0.53	0.61
Textiles, Wood, Paper & Printing	-0.14	0.39	-0.02	-0.04	0.00	0.65
Chemicals	0.40	1.31	0.54	0.52	0.55	0.58
Rubber & Plastics	-0.47	-0.97	-0.37	-0.39	-0.36	0.72
Other Non-Metallic Mineral	-3.09	-7.06	-3.03	-3.06	-3.02	0.67
Metals	-1.61	-4.23	-1.52	-1.54	-1.50	0.70
Machinery	0.67	2.27	0.79	0.77	0.81	0.74
Electrical Equipment	0.09	1.08	0.21	0.18	0.22	0.67
Transport Equipment	0.81	3.52	0.96	0.94	0.97	0.59
Manufacturing	0.21	1.03	0.34	0.31	0.35	0.65
Electricity, Gas & Water Supply	-1.01	-3.96	-0.93	-0.94	-0.91	0.60
Construction	-1.34	-6.40	-1.23	-1.28	-1.22	0.49
Wholesale & Retail Trade	-0.32	-0.69	-0.23	-0.25	-0.22	0.91
Hotels & Restaurants	0.19	0.90	0.31	0.28	0.33	0.71
Transport	-0.19	0.46	-0.08	-0.11	-0.07	0.73
Post and Telecommunications	-0.07	0.42	0.04	0.02	0.06	0.74
Financial Intermediation	-0.38	-0.59	-0.28	-0.29	-0.26	0.71
Real Estate Activities	-0.43	-1.29	-0.30	-0.31	-0.29	0.45
Other Business Activities	-0.50	-1.97	-0.40	-0.41	-0.38	0.72
Public Admin and Defence	-0.26	-1.15	-0.19	-0.20	-0.17	1.09
Education	0.01	0.14	0.07	0.06	0.08	1.12
Health & Social Work	-0.03	-0.02	0.06	0.05	0.07	0.96
Social & Personal Services	0.10	1.39	0.22	0.20	0.24	0.69

Appendix D: Long-run effects at the individual sector level of a 15% decrease in intermediates-use in the Construction sector. Fixed nominal wage closure. Values are % changes from base year.

	Output	Invest-ment	Total employ-ment	Employ-ment skilled	Employ-ment Unskilled	Exports
Agriculture, Forestry & Fishing	-0.22	1.26	-0.21	-0.21	-0.21	-
Mining	-1.90	-3.15	-2.06	-2.06	-2.06	-
Food, Beverages and Tobacco	-0.17	1.42	-0.18	-0.18	-0.18	-
Textiles, Wood, Paper & Printing	-0.93	-0.33	-0.96	-0.96	-0.96	-
Chemicals	-0.40	1.09	-0.41	-0.41	-0.41	-
Rubber & Plastics	-1.06	-1.41	-1.10	-1.10	-1.10	-
Other Non-Metallic Mineral	-4.10	-7.74	-4.19	-4.19	-4.19	-
Metals	-2.68	-5.12	-2.72	-2.72	-2.72	-
Machinery	-0.33	1.54	-0.34	-0.34	-0.34	-
Electrical Equipment	-0.83	0.09	-0.85	-0.85	-0.85	-
Transport Equipment	-0.07	2.72	-0.07	-0.07	-0.07	-
Manufacturing	-0.51	0.42	-0.53	-0.53	-0.53	-
Electricity, Gas & Water Supply	-1.65	-4.52	-1.72	-1.72	-1.72	-
Construction	-2.64	-9.61	-2.70	-2.70	-2.70	-
Wholesale & Retail Trade	-1.16	-1.78	-1.17	-1.17	-1.17	-
Hotels and Restaurants	-0.37	0.41	-0.39	-0.39	-0.39	-
Transport	-1.00	-0.50	-1.03	-1.03	-1.03	-
Post and Telecommunications	-0.71	-0.11	-0.74	-0.74	-0.74	-
Financial Intermediation	-0.99	-1.06	-1.02	-1.02	-1.02	-
Real Estate Activities	-0.90	-1.75	-0.94	-0.94	-0.94	-
Other Business Activities	-1.56	-5.28	-1.59	-1.59	-1.59	-
Public Admin & Defence	-0.39	-0.94	-0.40	-0.40	-0.40	-
Education	-0.12	0.39	-0.12	-0.12	-0.12	-
Health & Social Work	-0.07	0.62	-0.07	-0.07	-0.07	-
Social & Personal Services	-0.40	0.72	-0.41	-0.41	-0.41	-

References

[1] A.G. Ross, K. Connolly, I. Rhoden, S. Vögele, Resource-use intensity and the labour market: More for less?, Environmental Impact Assessment Review 102 (2023) 107173. https://doi.org/10.1016/j.eiar.2023.107173
[2] A.G. Ross, Household and skill disaggregation in multi-sectoral models of the Scottish economy, (2017). https://doi.org/10.48730/8z7f-g850
[3] J. Kirchherr, D. Reike, M. Hekkert, Conceptualizing the circular economy: An analysis of 114 definitions, Resources, Conservation and Recycling 127 (2017) 221-232. https://doi.org/10.1016/j.resconrec.2017.09.005
[4] EEA, Resource efficiency and the circular economy in Europe 2019 : even more from less : An overview of the policies, approaches and targets of 32 European countries, Publications Office, 2020. https://doi.org/10.2800/331070
[5] G.A. Aguilar-Hernandez, C.P. Sigüenza-Sanchez, F. Donati, J.F.D. Rodrigues, A. Tukker, Assessing circularity interventions: a review of EEIOA-based studies, Journal of Economic Structures 7(1) (2018) 14. https://doi.org/10.1186/s40008-018-0113-3
[6] E. Mazur-Wierzbicka, Circular economy: advancement of European Union countries, Environmental Sciences Europe 33(1) (2021) 111. https://doi.org/10.1186/s12302-021-00549-0
[7] EU, A new Circular Economy Action Plan, The Europen Parliament and the Council of the European Union, 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2020:98:FIN
[8] J. Chateau, E. Mavroeidi, The jobs potential of a transition towards a resource efficient and circular economy, OECD Environment Working Papers 167 (2020). https://doi.org/10.1787/28e768df-en
[9] S. Hatfield-Dodds, H. Schandl, D. Newth, M. Obersteiner, Y. Cai, T. Baynes, J. West, P. Havlik, Assessing global resource use and greenhouse emissions to 2050, with ambitious resource efficiency and climate mitigation policies, Journal of Cleaner Production 144 (2017) 403-414. https://doi.org/10.1016/j.jclepro.2016.12.170
[10] EC, Study on modelling of the economic and environmental impacts of raw material consumption : final report, European, Commission Publications Office, 2014. https://doi.org/10.2779/77904
[11] M. Distelkamp, B. Meyer, M. Meyer, Quantitative and qualitative effects of a forced resource efficiency strategy: summary report of task 5 within the framework of the" Material efficiency and resource conservation"(MaRess) project, Wuppertal Institut für Klima, Umwelt, Energie, 2010.
[12] F. Laubinger, E. Lanzi, J. Chateau, Labour market consequences of a transition to a circular economy, OECD Environment Working Papers 162 (2020). https://doi.org/10.1787/e57a300a-en
[13] A. McCarthy, R. Dellink, R. Bibas, The Macroeconomics of the Circular Economy Transition: A Critical Review of Modelling Approaches, OECD Environment Working Papers 130 (2018). http://dx.doi.org/10.1787/af983f9a-en
[14] G.A. Aguilar-Hernandez, J.F. Dias Rodrigues, A. Tukker, Macroeconomic, social and environmental impacts of a circular economy up to 2050: A meta-analysis of prospective studies, Journal of Cleaner Production 278 (2021) 123421. https://doi.org/10.1016/j.jclepro.2020.123421
[15] P.G. McGregor, A.G. Ross, J.K. Swales, How fiscal policies affect energy systems: the importance of an 'environmental social wage', Regional Studies 55(8) (2021) 1354-1364. https://doi.org/10.1080/00343404.2021.1893895
[16] S. Boeters, L. Savard, Chapter 26 - The Labor Market in Computable General Equilibrium Models, in: P.B. Dixon, D.W. Jorgenson (Eds.), Handbook of Computable General Equilibrium Modeling, Elsevier, 2013, 1645-1718. https://doi.org/10.1016/B978-0-444-59568-3.00026-2
[17] D.G. Blanchflower, A.J. Oswald, An Introduction to the Wage Curve, Journal of Economic Perspectives 9(3) (1995) 153-167. https://doi.org/10.1257/jep.9.3.153

[18] OECD., Global Material Resources Outlook to 2060 Economic Drivers and Environmental Consequences, OECD publishing, 2019. https://doi.org/10.1787/9789264307452-en
[19] IEA, Material efficiency in clean energy transitions, International Energy Agency (IEA) Vienna, 2019.
[20] BMUV, Deutsches Ressourceneffizienzprogramm III – 2020 bis 2023 (2020) Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (BMUV). https://www.bmuv.de/publikation/deutsches-ressourceneffizienzprogramm-iii-2020-bis-2023.
[21] Y. Wu, K.W. Chau, W. Lu, L. Shen, C. Shuai, J. Chen, Decoupling relationship between economic output and carbon emission in the Chinese construction industry, Environmental Impact Assessment Review 71 (2018) 60-69. https://doi.org/10.1016/j.eiar.2018.04.001
[22] D. Guo, H. Hou, J. Long, X. Guo, H. Xu, Underestimated environmental benefits of tailings resource utilization: Evidence from a life cycle perspective, Environmental Impact Assessment Review 96 (2022) 106832. https://doi.org/10.1016/j.eiar.2022.106832
[23] K. Rashid, S. Farooq, A. Mahmood, S. Iftikhar, A. Ahmad, Moving towards resource conservation by automated prioritization of concrete mix design, Construction and Building Materials 236 (2020) 117586. https://doi.org/10.1016/j.conbuildmat.2019.117586
[24] L. Wu, W. Ji, B. Feng, U. Hermann, S. AbouRizk, Intelligent data-driven approach for enhancing preliminary resource planning in industrial construction, Automation in Construction 130 (2021) 103846. https://doi.org/10.1016/j.autcon.2021.103846
[25] R. Ortlepp, S. Ortlepp, Textile reinforced concrete for strengthening of RC columns: A contribution to resource conservation through the preservation of structures, Construction and Building Materials 132 (2017) 150-160. https://doi.org/10.1016/j.conbuildmat.2016.11.133
[26] L. Li, J. Zuo, X. Duan, S. Wang, R. Chang, Converting waste plastics into construction applications: A business perspective, Environmental Impact Assessment Review 96 (2022) 106814. https://doi.org/10.1016/j.eiar.2022.106814
[27] W.J. Hawkins, M. Herrmann, T.J. Ibell, B. Kromoser, A. Michaelski, J.J. Orr, R. Pedreschi, A. Pronk, H.R. Schipper, P. Shepherd, D. Veenendaal, R. Wansdronk, M. West, Flexible formwork technologies – a state of the art review, Structural Concrete 17(6) (2016) 911-935. https://doi.org/10.1002/suco.201600117
[28] S.J.G. Cooper, J. Giesekam, G.P. Hammond, J.B. Norman, A. Owen, J.G. Rogers, K. Scott, Thermodynamic insights and assessment of the ‘circular economy’, Journal of Cleaner Production 162 (2017) 1356-1367. https://doi.org/10.1016/j.jclepro.2017.06.169
[29] Y. Ji, S. Chang, Y. Qi, Y. Li, H.X. Li, K. Qi, A BIM-Based Study on the Comprehensive Benefit Analysis for Prefabricated Building Projects in China, Advances in Civil Engineering 2019 (2019) 3720191. https://doi.org/10.1155/2019/3720191
[30] S. Aghasizadeh, A. Tabadkani, A. Hajirasouli, S. Banihashemi, Environmental and economic performance of prefabricated construction: A review, Environmental Impact Assessment Review 97 (2022) 106897. https://doi.org/10.1016/j.eiar.2022.106897
[31] G. Figus, K. Swales, A Child's Guide to Energy Intensity and Energy Efficiency, Discussion paper in economics 22(1) (2022) 1-26. https://doi.org/10.17868/strath.00080661
[32] C. Isensee, F. Teuteberg, K.-M. Griese, How can corporate culture contribute to emission reduction in the construction sector? An SME case study on beliefs, actions, and outcomes, Corporate Social Responsibility and Environmental Management 1(18) (2022). https://doi.org/10.1002/csr.2368
[33] M. Lehner, O. Mont, E. Heiskanen, Nudging – A promising tool for sustainable consumption behaviour?, Journal of Cleaner Production 134 (2016) 166-177. https://doi.org/10.1016/j.jclepro.2015.11.086
[34] M. Santos Silva, Nudging and Other Behaviourally Based Policies as Enablers for Environmental Sustainability, Laws, 2022. 10.3390/laws11010009
[35] F. Flachenecker, M. Kornejew, M.L. Janiri, The effects of publicly supported environmental innovations on firm growth in the European Union, Journal of Cleaner Production 372 (2022) 133429. https://doi.org/10.1016/j.jclepro.2022.133429

[36] M. Burger, S. Stavropoulos, S. Ramkumar, J. Dufourmont, F. van Oort, The heterogeneous skill-base of circular economy employment, Research Policy 48(1) (2019) 248-261. https://doi.org/10.1016/j.respol.2018.08.015
[37] L.J. Llorente-González, X. Vence, How labour-intensive is the circular economy? A policy-orientated structural analysis of the repair, reuse and recycling activities in the European Union, Resources, Conservation and Recycling 162 (2020) 105033. https://doi.org/10.1016/j.resconrec.2020.105033
[38] G. Allan, N. Hanley, P. McGregor, K. Swales, K. Turner, The impact of increased efficiency in the industrial use of energy: A computable general equilibrium analysis for the United Kingdom, Energy Economics 29(4) (2007) 779-798. https://doi.org/10.1016/j.eneco.2006.12.006
[39] P. Lecca, P.G. McGregor, J.K. Swales, Forward-looking and myopic regional Computable General Equilibrium models: How significant is the distinction?, Economic Modelling 31 (2013) 160-176. https://doi.org/10.1016/j.econmod.2012.11.010
[40] K. Lisenkova, A. Greig, P.G. McGregor, G. Roy, J.K. Swales, Growth incentives and devolved fiscal systems, Regional Studies 56(10) (2022) 1744-1756. https://doi.org/10.1080/00343404.2021.2006172
[41] G. Allan, G. Figus, P.G. McGregor, J.K. Swales, Resilience in a behavioural/Keynesian regional model, Environment and Planning A: Economy and Space 53(4) (2020) 858-876. https://doi.org/10.1177/0308518X20941775
[42] G. Figus, P.G. McGregor, J.K. Swales, K. Turner, Do sticky energy prices impact the time paths of rebound effects associated with energy efficiency actions?, Energy Economics 86 (2020) 104657. https://doi.org/10.1016/j.eneco.2019.104657
[43] G. Allan, D. Comerford, P. McGregor, The system-wide impact of healthy eating: Assessing emissions and economic impacts at the regional level, Food Policy 86 (2019) 101725. https://doi.org/10.1016/j.foodpol.2019.05.008
[44] P. Lecca, P.G. McGregor, K.J. Swales, M. Tamba, The Importance of Learning for Achieving the UK's Targets for Offshore Wind, Ecological Economics 135 (2017) 259-268. https://doi.org/10.1016/j.ecolecon.2017.01.021
[45] K. Stadler, R. Wood, T. Bulavskaya, C.-J. Södersten, M. Simas, S. Schmidt, A. Usubiaga, J. Acosta-Fernández, J. Kuenen, M. Bruckner, S. Giljum, S. Lutter, S. Merciai, J.H. Schmidt, M.C. Theurl, C. Plutzar, T. Kastner, N. Eisenmenger, K.-H. Erb, A. de Koning, A. Tukker, EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables, Journal of Industrial Ecology 22(3) (2018) 502-515. https://doi.org/10.1111/jiec.12715
[46] G. Elshof, J. Luckmann, K. Siddig, A 2018 Social Accounting Matrix for Germany depicting waste and recycling accounts for a circular economy, Working Paper 102 (2022). http://doi.org/10.22004/ag.econ.320879
[47] T. Emonts-Holley, A. Ross, J. Swales, A social accounting matrix for Scotland, Fraser of Allander Economic Commentary 38(1) (2014) 84-93. https://strathprints.strath.ac.uk/id/eprint/48626
[48] P.S. Armington, A theory of demand for products distinguished by place of production, Staff Papers 16(1) (1969) 159-178. https://doi.org/10.2307/3866403
[49] J. Bajzik, T. Havranek, Z. Irsova, J. Schwarz, Estimating the Armington elasticity: The importance of study design and publication bias, Journal of International Economics 127 (2020) 103383. https://doi.org/10.1016/j.jinteco.2020.103383
[50] T. Emonts-Holley, A. Greig, P. Lecca, K. Lisenkova, P.G. McGregor, J.K. Swales, A Scandinavian 'high-tax, high-spend' model for regions? The impact of enhanced regional fiscal autonomy, Spatial Economic Analysis 14(3) (2019) 321-338. https://doi.org/10.1080/17421772.2019.1568536
[51] M.D. Partridge, D.S. Rickman, Computable General Equilibrium (CGE) Modelling for Regional Economic Development Analysis, Regional Studies 44(10) (2010) 1311-1328. https://doi.org/10.1080/00343400701654236

[52] P.R.G. Layard, R. Layard, S.J. Nickell, R. Jackman, Unemployment: macroeconomic performance and the labour market, Oxford University Press on Demand, 2005. https://doi.org/10.1093/acprof:oso/9780199279166.001.0001
[53] S. Nickell, B. Bell, The collapse in demand for the unskilled and unemployment across the OECD, Oxford Review of Economic Policy 11(1) (1995) 40-62. https://doi.org/10.1093/oxrep/11.1.40
[54] H. Brücker, E.J. Jahn, Migration and Wage-setting: Reassessing the Labor Market Effects of Migration, The Scandinavian Journal of Economics 113(2) (2011) 286-317. https://doi.org/10.1111/j.1467-9442.2010.01634.x
[55] H. Brücker, A. Hauptmann, E.J. Jahn, R. Upward, Migration and imperfect labor markets: Theory and cross-country evidence from Denmark, Germany and the UK, European Economic Review 66 (2014) 205-225. https://doi.org/10.1016/j.euroecorev.2013.11.007
[56] B.H. Baltagi, U. Blien, K. Wolf, A dynamic spatial panel data approach to the German wage curve, Economic Modelling 29(1) (2012) 12-21. https://doi.org/10.1016/j.econmod.2010.08.019
[57] S. Longhi, P. Nijkamp, J. Poot, Spatial heterogeneity and the wage curve revisited, Journal of Regional Science 46(4) (2006) 707-731. https://doi.org/10.1111/j.1467-9787.2006.00474.x
[58] U. Blien, W. Dauth, T. Schank, C. Schnabel, The Institutional Context of an 'Empirical Law': The Wage Curve under Different Regimes of Collective Bargaining, British Journal of Industrial Relations 51(1) (2013) 59-79. https://doi.org/10.1111/j.1467-8543.2011.00883.x
[59] F. Donati, G.A. Aguilar-Hernandez, C.P. Sigüenza-Sánchez, A. de Koning, J.F.D. Rodrigues, A. Tukker, Modeling the circular economy in environmentally extended input-output tables: Methods, software and case study, Resources, Conservation and Recycling 152 (2020) 104508. https://doi.org/10.1016/j.resconrec.2019.104508
[60] P.G. McGregor, J.K. Swales, Y.P. Yin, A long-run interpretation of regional input-output analysis, Journal of Regional Science 36(3) (1996) 479-501. https://doi.org/10.1111/j.1467-9787.1996.tb01113.x
[61] Z. Olekseyuk, H. Schürenberg-Frosch, Are Armington elasticities different across countries and sectors? A European study, Economic Modelling 55 (2016) 328-342. https://doi.org/10.1016/j.econmod.2016.02.018
[62] H. Welsch, Armington elasticities for energy policy modeling: Evidence from four European countries, Energy Economics 30(5) (2008) 2252-2264. https://doi.org/10.1016/j.eneco.2007.07.007
[63] J. Freire-González, V. Martinez-Sanchez, I. Puig-Ventosa, Tools for a circular economy: Assessing waste taxation in a CGE multi-pollutant framework, Waste Management 139 (2022) 50-59. https://doi.org/10.1016/j.wasman.2021.12.016
[64] H. Hu, W. Dong, Q. Zhou, A comparative study on the environmental and economic effects of a resource tax and carbon tax in China: Analysis based on the computable general equilibrium model, Energy Policy 156 (2021) 112460. https://doi.org/10.1016/j.enpol.2021.112460
[65] J. Brusselaers, K. Breemersch, T. Geerken, M. Christis, B. Lahcen, Y. Dams, Macroeconomic and environmental consequences of circular economy measures in a small open economy, The Annals of Regional Science 68(2) (2022) 283-306. https://doi.org/10.1007/s00168-021-01079-6
[66] G. Li, T. Masui, Assessing the impacts of China's environmental tax using a dynamic computable general equilibrium model, Journal of Cleaner Production 208 (2019) 316-324. https://doi.org/10.1016/j.jclepro.2018.10.016
[67] K.S. Wiebe, M. Harsdorff, G. Montt, M.S. Simas, R. Wood, Global Circular Economy Scenario in a Multiregional Input–Output Framework, Environmental Science & Technology 53(11) (2019) 6362-6373. http://doi.org/10.1021/acs.est.9b01208
[68] L. Repp, M. Hekkert, J. Kirchherr, Circular economy-induced global employment shifts in apparel value chains: Job reduction in apparel production activities, job growth in reuse and recycling activities, Resources, Conservation and Recycling 171 (2021) 105621. https://doi.org/10.1016/j.resconrec.2021.105621

[69] H. Boonman, P. Verstraten, A.H. van der Weijde, Macroeconomic and environmental impacts of circular economy innovation policy, Sustainable Production and Consumption 35 (2023) 216-228. https://doi.org/10.1016/j.spc.2022.10.025