Circular economy innovations in a 2-area input-output stock-flow consistent dynamic model

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European Commission Grant, Project 101003491: "A Just Transition to the Circular Economy"

WP5 - JUST2CE

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A Just Transition to Circular Economy

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Introduction: what is just2ce?

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- It is a EU-funded project proposing an alternative way to looking at CE

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- Most projects have focused on how to produce circularity. JUST2CE focuses on what (democracy, participation, gender, global justice)

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  - a systematic review of current literature on macroeconomic models for assessing the transition towards a CE
  - a formal model (or set of models) to simulate and compare alternative CE policies and transition scenarios

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Macro-modelling the transition

– Main tools in (theory-to-data) macroeconomics:

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- In principle, we can disaggregate SFC models by crossbreeding them with IO models... (Hardt and O'Neill 2017)

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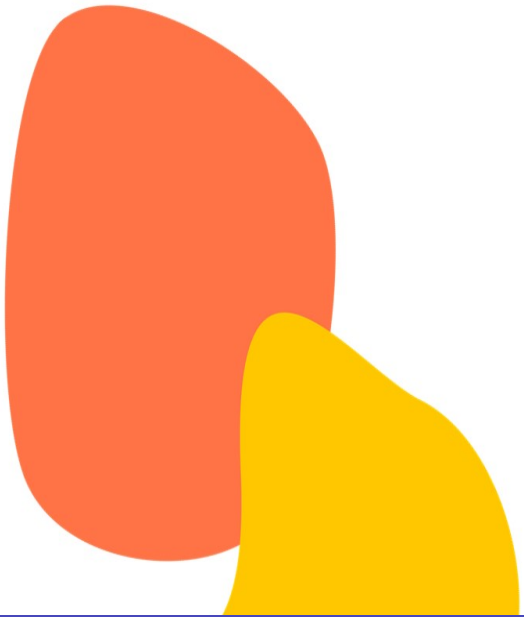
Aim / Research questions

– However, just a few papers use IO-SFC models:



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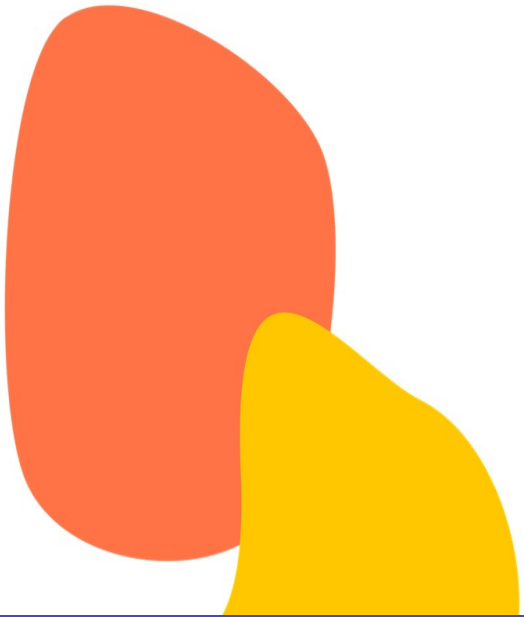

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  2) To assess the impact of a variety of CE innovations on the economy, the society and the ecosystem

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c) Identification: *Exiobase* (EU vs RoW) / literature / calibration (steady state)

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Assets and liabilities

Table 1: Balance-sheet matrix in period 20 (curr. p., EU currency)

	EU						RoW					
	H	F	G	B	CB	*xr*	H	F	G	B	CB	Tot
Money	83.13	0	0	0	-83.13	1	270.40	0	0	0	-270.4	0
Advances	0	0	0	0	0	1	0	0	0	0	0	0
Deposits	554.25	0	0	-554.25	0	1	2163.29	0	0	-2163.29	0	0
Loans	-110.50	-371.11	0	481.61	0	1	-424.54	-1658.9	0	2083.44	0	0
EU bills	87.81	0	-255.42	72.64	66.27	1	28.70	0	0	0	0	0
RoW bills	26.34	0	0	0	16.86	1	287.02	0	-680.47	79.85	270.4	0
EU shares	219.53	-248.23	0	0	0	1	28.70	0	0	0	0	0
RoW shares	17.56	0	0	0	0	1	516.64	-534.2	0	0	0	0
Capital stock	0	619.34	0	0	0	1	0	2193.1	0	0	0	2812.45
Net financial wealth	-878.13	0	255.42	0	0	1	-2870.21	0	680.47	0	0	-2812.45
Total	0	0	0	0	0		0	0	0	0	0	0

Transactions and Δ in stocks

Table 2: Transactions-flow matrix in period 20 (curr. p., EU currency)

	EU							RoW						
	H	F (y)	F (k)	G	B	CB	*xr*	H	F (y)	F (k)	G	B	CB	Tot
Consumption	-831.32	831.32	0	0	0	0	1	-2703.96	2703.96	0	0	0	0	0
Investment	0	212.26	-154.84	-57.42	0	0	1	0	923.48	-657.93	-265.55	0	0	0
Government spending	0	269.91	0	-269.91	0	0	1	0	766.98	0	-766.98	0	0	0
Export of EU	0	217.08	0	0	0	0	1	0	-217.08	0	0	0	0	0
Import of EU	0	-213	0	0	0	0	1	0	213	0	0	0	0	0
[Value added]	0	[1195.75]	0	0	0	0	1	0	[4018.28]	0	0	0	0	0
Wage bill	614.74	-614.74	0	0	0	0	1	1976.22	-1976.22	0	0	0	0	0
Corporate profit	414.20	-418.75	0	0	0	0	1	1338.91	-1334.36	0	0	0	0	0
Amortization	0	-154.84	154.84	0	0	0	1	0	-657.93	657.93	0	0	0	0
Bank profit	4.81	0	0	0	-4.81	0	1	42.45	0	0	0	-42.45	0	0
CB profit	0	0	0	1.00	0	-1.00	1	0	0	0	5.41	0	-5.41	0
Income tax revenue	-207.18	0	0	207.18	0	0	1	-668.56	0	0	668.56	0	0	0
VAT revenue	0	-102.09	0	102.09	0	0	1	0	-352.69	0	352.69	0	0	0
Tariffs revenue	0	-19.73	0	19.36	0	0	1	0	-19.36	0	19.73	0	0	0
Interests on deposits	5.54	0	0	0	-5.54	0	1	21.62	0	0	0	-21.62	0	0
Interests on loans	-2.20	-7.42	0	0	9.63	0	1	-12.71	-49.77	0	0	62.48	0	0
Interests on EU bills	0.88	0	0	-2.55	0.73	0.66	1	0.29	0	0	0	0	0	0
Interests on RoW bills	0.53	0	0	0	0	0.34	1	5.74	0	0	-13.61	1.60	5.41	0
Change in money stock	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Change in advances	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Change in deposits	-0.31	0	0	0	0.31	0	1	-0.94	0	0	0	0.94	0	0
Change in loans	0.31	0	0	0	-0.31	0	1	0.94	0	0	0	-0.94	0	0
Change in EU bills	0	0	0	0.25	0	-0.25	1	0	0	0	0	0	0	0
Change in RoW bills	0	0	0	0	0	0.25	1	0	0	0	-0.25	0	0	0
Change in EU shares	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Change in RoW shares	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Revaluation effects							1							0
Total	0	0	0	0	0	0		0	0	0	0	0	0	0

Cross-industry interdependencies

Table 3: Baseline: IO matrix in period 20 (curr. p., EU currency)

	A in EU	M in EU	S in EU	W in EU	R in EU	A in RoW	M in RoW	S in RoW	W in RoW	R in RoW	Final demand	Output
Agriculture in EU	5.03	22.86	2.43	0.01	0.05	0.24	1.03	0.45	0.01	0	28.04	60.14
Manufacturing in EU	11.38	305.85	98.08	1.22	7.42	1.65	45.32	16.6	0.14	0.29	480.15	968.11
Services in EU	8.63	167.66	387.89	2.36	6.28	0.76	13.59	28.67	0.16	0.1	891.13	1507.23
Waste manag. in EU	0.25	3.56	4.17	1.28	0.37	0.07	0.23	0.21	0.01	0	0	10.16
Recycling in EU	0.13	18	1.92	0.09	1.91	0.01	2.48	0.22	0	0.04	0	24.78
Agriculture in RoW	0.98	2.71	0.67	0	0.03	49.5	156.01	26.02	0.21	0.12	169.45	3934
Manufacturing in RoW	1.96	75.84	14.96	0.14	2.62	51.04	1761.35	455.15	5.33	5.22	1560.39	405.69
Services in RoW	0.39	12.49	31.17	0.15	0.4	54.46	577	1244.55	7.22	3.54	2826.04	4757.39
Waste manag. in RoW	0.02	0.22	0.09	0.02	0.01	2.84	11.88	20.57	2.05	0.1	0	37.8
Recycling in RoW	0	0.29	0.02	0	0.02	0.87	11.67	0.49	0.02	1.1	0	14.48
Value added												
˜ Compensation of employees	5.73	163.52	462.92	1.9	4.05	111.89	507.12	1433.5	11.09	2.84		2704.57
˜ G.O. surplus and mixed inc.s	25.63	195.13	502.9	2.99	1.61	132.37	846.32	1530.98	11.55	1.14		3250.63
Taxes on production	0	0	0	0	0	0	0	0	0	0		
Output	60.14	968.11	1507.23	10.16	24.78	405.69	3934	4757.39	37.8	14.48	5955.19	

Area-specific physical flows

Table 4: Physical flow matrix in period 20 (matter = Gt, energy = EJ)

	EU matter	RoW matter	Global matter	EU energy	RoW energy	Global energy
Inputs						
Extracted matter	317.86	2141.84	2459.7			
Recycled matter	7.72	55.3	63.03			
Renewable energy			0	1176.34	1461.97	2638.31
Non-renewable energy	17.37	23.33	40.7	7204.01	8980.65	16184.66
Oxygen	46.37	62.3	108.66			
Outputs						
Industrial CO_2 emissions	-63.73	-85.63	-149.36			
Discarded stock	-28.34	-276.51	-304.84			
Dissipated energy				-8380.36	-10442.61	-16760.72
Δ in socio-economic stock	297.24	1920.64	2217.88			
Difference	0	0	0	0	0	0

Global physical stocks and related changes

Table 5: Physical stock-flow matrix in period 20 (matter = Gt, energy = EJ)

	Material reserves	Energy reserves	CO_2 concentration	Socio-economic stock
Initial stock	9451266.99	-201040.39	2101.05	40831.85
Resources converted into reserves	193156.73	1536.04		
CO_2 emissions			149.36	
Production of material goods				2522.72
Extraction/use of matter/energy	-2459.7	-16184.66		
Distruction of socio-ec. stock				-304.84
Final stock	9647311.66	-197232.48	2442.4	37174.38
Difference	0	0	0	0

Selected equations: households

- Total "real" consumption in each area is:

$$c^z = \alpha_1^z \cdot \frac{YD_w^z}{E(p_A^z)} + \alpha_2^z \cdot \frac{YD_c^z}{E(p_A^z)} + \alpha_3^z \cdot \frac{V_{-1}^z}{p_{A,-1}^z} \quad (1)$$

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- Households' total disposable income in each area is:

$$\begin{aligned} YD^z = {} & WB^z + DIV^z + FB^z + \\ & + r_{m,-1}^z \cdot M_{h,-1}^z + r_{b,-1}^z \cdot B_{s,z,-1}^z + xr_{-1}^f \cdot r_{b,-1}^f \cdot B_{s,z,-1}^f + \\ & + \Delta xr^f \cdot (B_{s,z,-1}^f + E_{s,z,-1}^f) - r_{h,-1}^z \cdot L_{h,-1}^z - T^z \end{aligned} \tag{2}$$

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where the apex indicates the origin of the security, while the subscript indicates its destination.

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Selected equations: households

- Total "real" consumption in each area is:

$$c^z = \alpha_1^z \cdot \frac{YD_w^z}{E(p_A^z)} + \alpha_2^z \cdot \frac{YD_c^z}{E(p_A^z)} + \alpha_3^z \cdot \frac{V_{-1}^z}{p_{A,-1}^z} \tag{1}$$

- Households' total disposable income in each area is:

$$\begin{aligned} YD^z = {} & WB^z + DIV^z + FB^z + \\ & + r_{m,-1}^z \cdot M_{h,-1}^z + r_{b,-1}^z \cdot B_{s,z,-1}^z + xr_{-1}^f \cdot r_{b,-1}^f \cdot B_{s,z,-1}^f + \\ & + \Delta xr^f \cdot (B_{s,z,-1}^f + E_{s,z,-1}^f) - r_{h,-1}^z \cdot L_{h,-1}^z - T^z \end{aligned} \tag{2}$$

where the apex indicates the origin of the security, while the subscript indicates its destination.

- Households' net wealth is:

$$V^z = V_{-1}^z + YD^z - c^z \cdot p_A^z \tag{3}$$

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Selected equations: firms (current)

- Let us consider a 10×10 global production. The final demand vector of EU is:

$$\mathbf{d}^z = \begin{pmatrix} \beta_1^z \\ \vdots \\ \beta_{10}^z \end{pmatrix} \cdot c^z + \begin{pmatrix} \iota_1^z \\ \vdots \\ \iota_{10}^z \end{pmatrix} \cdot i_d^z + \begin{pmatrix} \sigma_1^z \\ \vdots \\ \sigma_{10}^z \end{pmatrix} \cdot gov^z + \begin{pmatrix} \eta_{1,z}^f \\ \vdots \\ \eta_{10,z}^f \end{pmatrix} \cdot exp^z - \begin{pmatrix} \eta_1^z \\ \vdots \\ \eta_{10}^z \end{pmatrix} \cdot imp^z \tag{4}$$

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- The gross output vector is:

$$\mathbf{x}^z = \mathbf{A} \cdot \mathbf{x}^z + \mathbf{d}^z = (\mathbf{I} - \mathbf{A})^{-1} \cdot \mathbf{d}^z, \; with : \mathbf{A} = \begin{pmatrix} a_{1,1} & \cdots & a_{1,10} \\ \dots & \ddots & \dots \\ a_{10,1} & \cdots & a_{10,10} \end{pmatrix} \tag{5}$$

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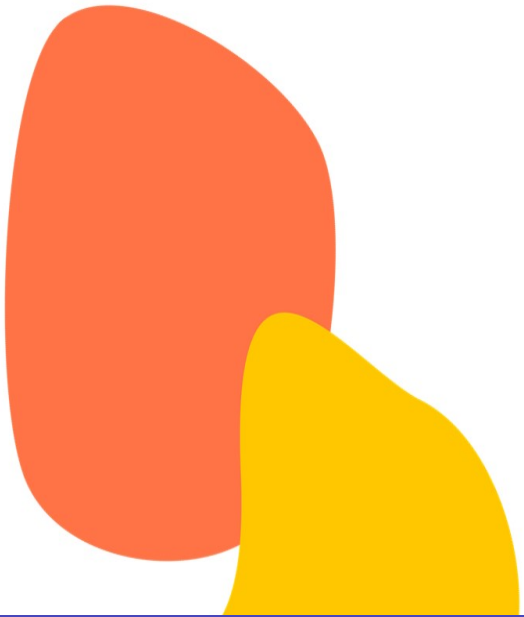
Selected equations: consumer choices

- The share of manufacturing products to total consumption is stable:

$$\beta_1^z = \bar{\beta}_1^z \tag{6}$$



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Selected equations: consumer choices

- The share of manufacturing products to total consumption is stable:

$$\beta_1^z = \bar{\beta}_1^z \tag{6}$$

- The share of services to total consumption increases as disposable incomes (expressed in real terms, using the price of services) increase:

$$\beta_3^z = \beta_{3,-1}^z + \beta_{31}^z \cdot \frac{YD_{w,-1}^z}{p_{3,-1}^z} + \beta_{32}^z \cdot \frac{YD_{c,-1}^z}{p_{3,-1}^z} \tag{7}$$

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- The share of agricultural products is calculated residually, and tends to decline as the economy grows:

$$\beta_2^z = 1 - \beta_1^z - \beta_3^z \tag{8}$$

with $\beta_2^z \geq 0$.

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Selected equations: firms (capital)

- The target stock of fixed capital depends on industry-specific target capital to output ratios:

$$k^{z*} = \mathbf{p}_{-1}^{zT} \cdot \left[\mathbf{h}^{z} \odot (\mathbf{x}_{-1}^{z} + \mathbf{x}_{-1}^{f})\right] \cdot \frac{1}{p_{I,-1}^{z}} \tag{9}$$

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The real gross investment is:

$$i_{d}^{z} = \gamma^{z} \cdot (k^{z*} - k_{-1}^{z}) + \delta^{z} \cdot k_{-1}^{z} \tag{10}$$

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The real gross investment is:

$$i_d^z = \gamma^z \cdot (k^{z*} - k_{-1}^z) + \delta^z \cdot k_{-1}^z \tag{10}$$

- The end-of-period stock of bank loans is defined residually:

$$L_F^z = L_{F,-1}^z + i_d^z \cdot p_I^z - AF^z - FF_u^z - \Delta E_s^z \tag{11}$$

where:

$$AF^z = \delta^z \cdot k_{-1}^z \cdot p_I^z - k^z \cdot \Delta p_I^z$$

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Selected equations: commercial banks

- The supply of bank loans is:

$$L_s^z = L_F^z + L_h^z \tag{12}$$

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Selected equations: commercial banks

- The supply of bank loans is:

$$L_s^z = L_F^z + L_h^z \tag{12}$$

- where the demand for personal loans is defined as:

$$L_h^z = L_{h,-1}^z \cdot (1 - \psi_1^z) + \max\left[c^z \cdot p_A^z - YD^z, \psi_2^z \cdot \Delta(\mathbf{p}^{zT} \cdot \mathbf{dc}^z)\right] \tag{13}$$

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- The supply of bank deposits is:

$$M_s^z = M_h^z \tag{14}$$

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Selected equations: labour market and popul.

- The employment generated by demand of (domestic and foreign) industries is:

$$N^z = \mathbf{x}^{zT} \cdot \mathbf{l}^z = \sum N_j^z \tag{15}$$

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- The available labour force in each area is:

$$\mathbf{POP}^z = \mathbf{POP}^z_{-1} \odot (I + \mathbf{g}^z_{pop}) + \mathbf{IMM}^z - \mathbf{IMM}^f \tag{16}$$

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- Immigration inflow in each area is:

$$\mathbf{IMM}^z = \gamma^z_{imm,0} \odot \mathbf{POP}^f_{-1} + \gamma^z_{imm,1} \odot \mathbf{un}^f_{-1} + \gamma^z_{imm,2} \odot (\mathbf{w}^z_{-1} - \mathbf{w}^f_{-1}) \tag{17}$$

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- In each industry, the percentage of female workers (gender segregation) is:

$$\rho_j^z = \rho_{0j}^z - \rho_{1j}^z \cdot (w_j^z - w_{j,-1}^z) \tag{18}$$

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Selected equations: government and CB

- The government budget deficit in each area is:

$$DEF_g^z = gov^z \cdot p_G^z + r_{b,-1}^z \cdot B_{s,-1}^z - F_{cb}^z - T^z - VAT^z - TAR^z \qquad (19)$$

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- Therefore, the supply of government bills is:

$$B_s^z = B_{s,-1}^z + DEF_g^z \tag{20}$$

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- Therefore, the supply of government bills is:

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- The amount of domestic bills held by the central bank of the first area is:

$$B_{cb,z}^z = \Delta H_s^z - \Delta A_s^z - xr^f \cdot \Delta B_{cb,s,z}^f \tag{21}$$

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- Cash supply adjusts to households' demand:

$$H_s^z = H_h^z \tag{22}$$

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Selected equations: prices

- Firms use a mark-up rule. The unit price of production vector is:

$$\mathbf{p}^{z*} = \mathbf{w}^{z} \odot \mathbf{l}^{z} + \mathbf{p}^{z*} \cdot \mathbf{A} \odot \mathbf{m}^{z*} \odot \mathbf{h}_{d}^{z} \tag{23}$$

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- However, market prices also depend on labour-constrained potential output, vat and tariffs:

$$\mathbf{p}^{z} = \left[\mathbf{p}^{z*} + \Gamma_{x}^{z} \odot \left(\mathbf{x}_{-1}^{z} - \mathbf{x}_{-1}^{z*}\right)\right] \odot \left[\begin{pmatrix} 1 \\ \vdots \\ 1 \end{pmatrix} + \tau_{vat}^{z} + \tau_{tar}^{f}\right] \tag{24}$$

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- The consumer price index or average price of consumption is:

$$p_{A}^{z} = \mathbf{p}^{zT} \cdot \beta^{z} \tag{25}$$

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Selected equations: portfolio choices

- Households' demand for domestic bills is:

$$\frac{B^z_{h,z}}{V^z} = \lambda_{10} + \lambda_{11} \cdot r^z_{b,-1} - \lambda_{12} \cdot \left(r^f_{b,-1} + \frac{\Delta x r^f}{x r^f} \right) - \lambda_{13} \cdot r^z_{m,-1} - \lambda_{14} \cdot \frac{YD^z}{V^z} + \\ - \lambda_{15} \cdot r^z_{e,-1} - \lambda_{16} \cdot \left(r^f_{e,-1} + \frac{\Delta x r^f}{x r^f} \right) \tag{26}$$

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$$H^z_h = \lambda^z_c \cdot c^z_{-1} \cdot p^z_{A,-1} \tag{27}$$

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- Bank deposits are the buffer stock:

$$M^z_h = V^z + L^z_h - H^z_h - B^z_{h,z} - B^f_{h,z} - E^z_{h,z} - E^f_{h,z} \tag{28}$$

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- The redundant equation is:

$$B^z_{cb,z} = B^z_s - B^z_{s,z} - B^z_{s,f} - B^z_b$$

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Figure 1. Sankey diagram of transactions (in $t = 20$)

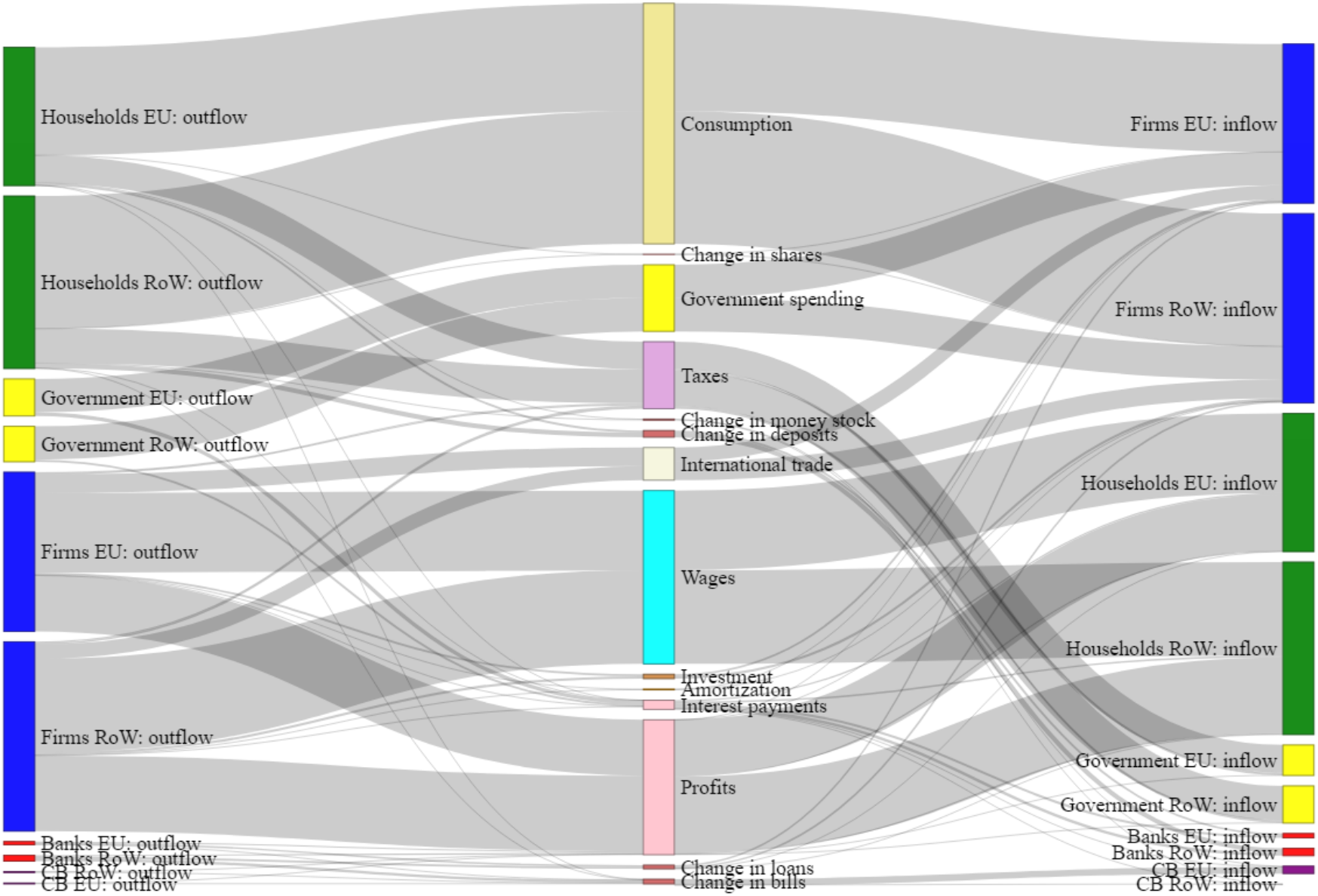


Figure 2. Cross-industry input-output flows (in $t = 20$)

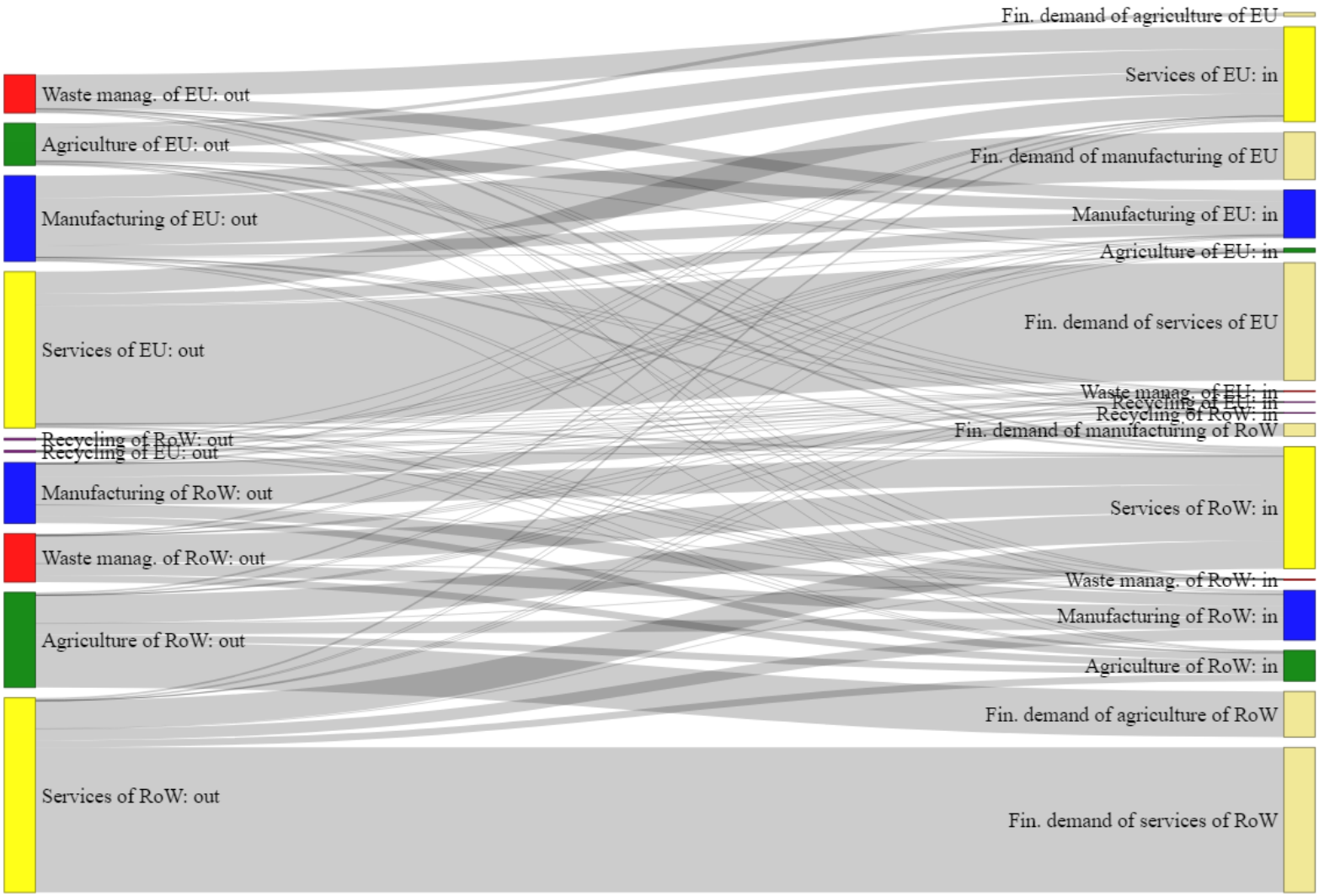


Figure 3. Physical flows of matter and energy (in $t = 20$)

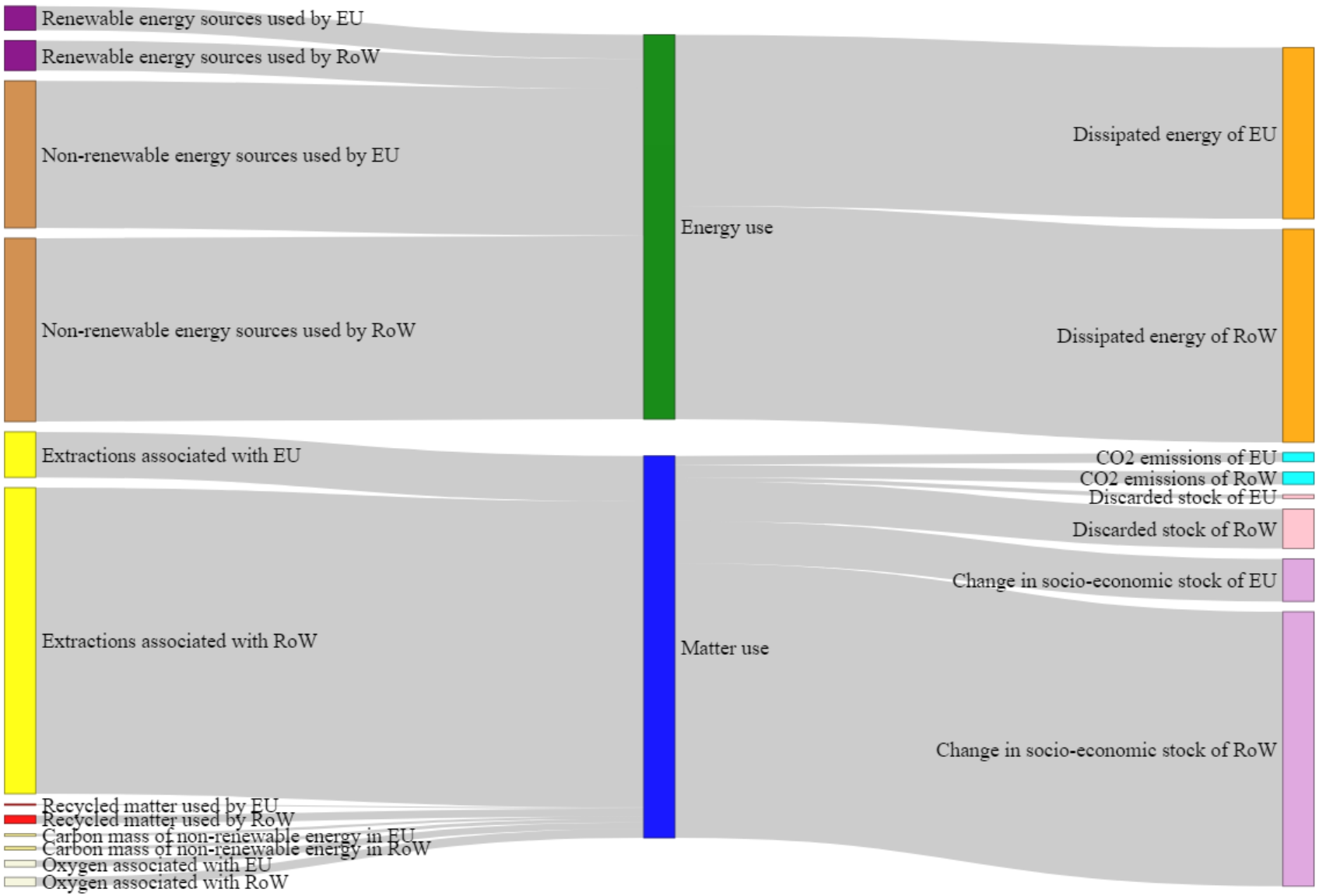


Figure 4. Product Life Extension

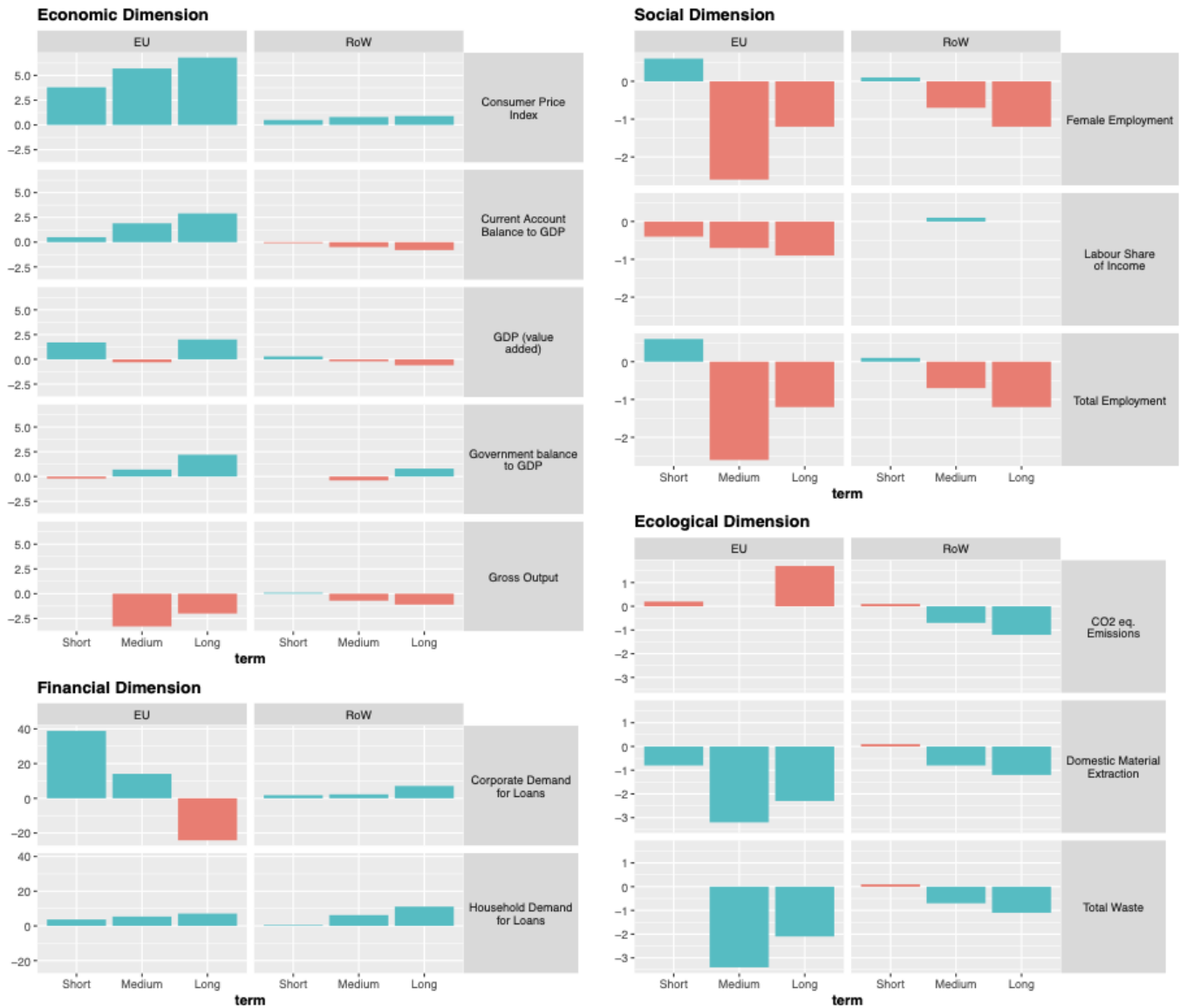
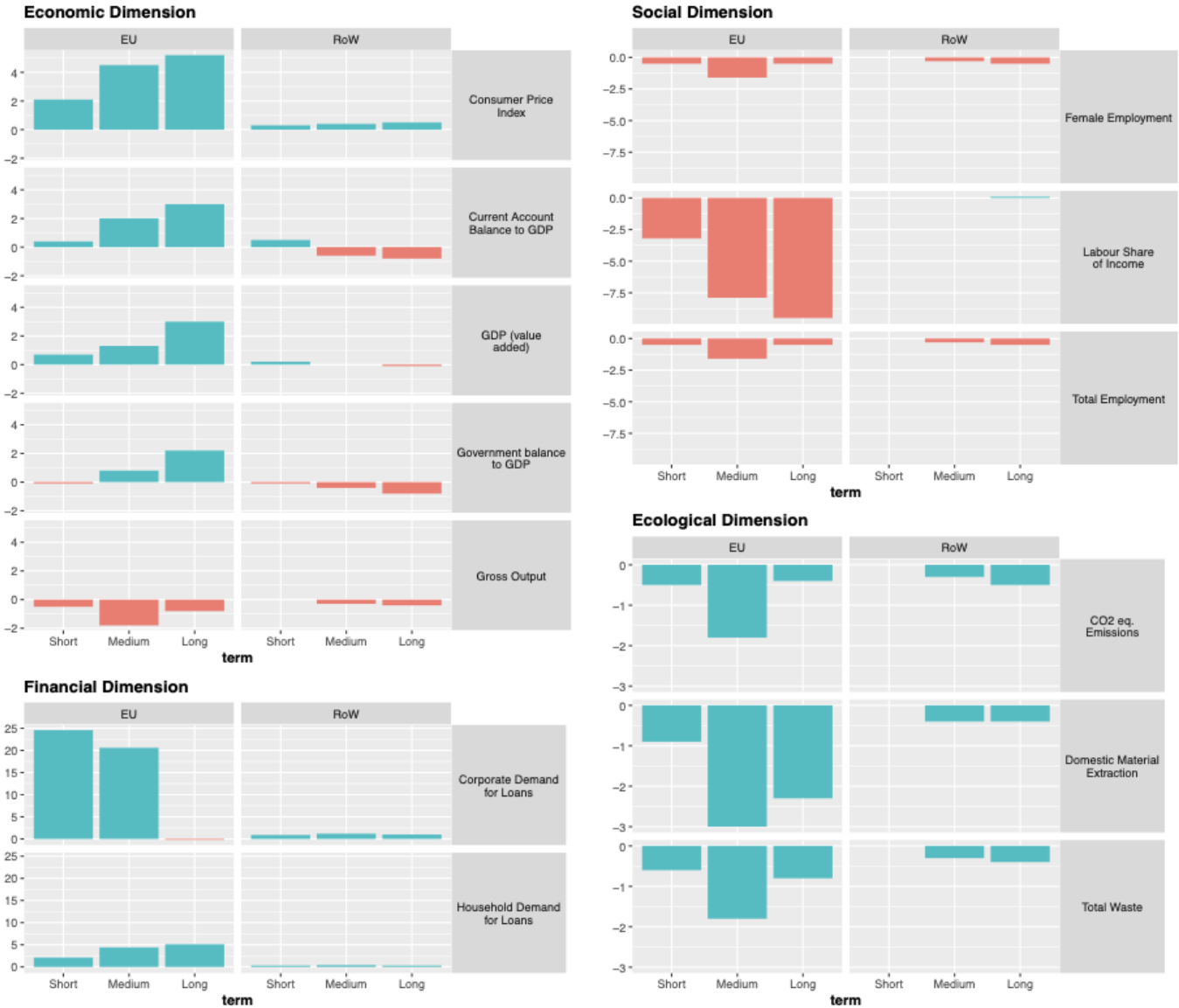


Figure 5. Closing the Supply Chain



Final remarks

- The model provides a benchmark for other MA-IO-SFC models

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Final remarks

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  b) Make additional experiments
  c) Introduce other financial, social and ecological variables

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Final remarks

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  c) Introduce other financial, social and ecological variables
  d) Explore other world-economy partitions

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