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Environmental Research Communications

LETTER

Material circularity and environmental quality in the EU: what causes what and where?

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Abstract

Although the green and blue dividends associated with circular economy have been widely advocated, whether circular economy necessarily guarantee environmental quality remains unclear. To provide a more precise insight, in this case for a novel case of all the European Union countries, environmental effect of the share of used material resources from the reuse of waste materials is examined over the period 2010–2021. The results reveal that the reuse of waste materials statistically (i) increase CO_2 emissions in most quantiles in Austria, Belgium, Denmark, France, Greece, Hungary, Lithuania, Malta, Netherlands, Poland, and Slovenia, (ii) mitigate CO_2 emissions in most quantiles in Bulgaria, Croatia, Cyprus, Estonia, Finland, Italy, Portugal, Romania, Slovak Republic, Spain, and Ireland, and (iii) either increasing or reducing CO_2 emissions depending on the quantile of material circularity use rate and CO_2 emissions in Czech Republic, Germany, Luxembourg, Sweden, and Latvia. This result points to a more policy driven approach.

1. Introduction

By providing new growth strategy with overarching vision alongside the 50 outlined actions toward 2030 Sustainable Development Goals (SDGs), European Green Deal is central to European Union (EU)'s SDG and 2050 carbon neutral targets. Importantly, the goal to attain '*Responsible Consumption and Production*' (i.e., SDG #12) is both central to the global goal of carbon neutral future and the EU's circular economy drive (European Commission 2023a). Moreover, as reported by the European Commission (EC), a circular EU economy translates to reduction of material (including biomass, metal ores, non-metallic minerals, and fossil energy resources) extractions and utilizations, thus providing channels for new job opportunities and improving sustainable growth alongside critically driving EU's 2050 net zero emission. However, while the EU's commitment toward a circular economy is commendable, pathway to a circular EU economy remained a herculean endeavour. As evidently indicated by the EC report, the EU's share of used material resources from the reuse of waste materials i.e., circularity rate was only 11.5 percent in 2022 (European Commission 2023b).

Given the EU's circularity rate report, it is natural to ponder whether material circularity necessarily improve environmental quality in the present scenario, thus increasing the expectation of an EU 2050 net zero emission. Therefore, with the objective of unveiling the environmental effect of material circularity, this study attempts to define and establish the nature of relationship between material circularity and carbon dioxide (CO_2) emission for each of the 27 EU member states. While previously related studies have mostly being on the pollution effect of specific resources such as reuse of washing machine, used fires, organic waste, food systems (Cobo *et al* 2018, Lonca *et al* 2018, Boldoczki *et al* 2021, Hailemariam and Erdiaw-Kwasie 2023, van Selm *et al* 2023), there is

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Table 1. Countries descriptive statistics and stationarity test for CE and CMUR.

	Mean	Std. Dev.	Skew.	Kur.	J-B	P-value	KPSS
Panel A: CE							
Austria	0.000	0.004	−0.591	5.580	15.767***	0.000	0.123
Belgium	−0.001	0.005	−0.237	5.017	8.406**	0.015	0.290
Bulgaria	0.000	0.009	0.026	3.311	0.195	0.907	0.088
Cyprus	0.000	0.004	−0.193	5.489	12.418***	0.002	0.354
Czechia	−0.001	0.003	0.114	7.931	47.718***	0.000	0.119
Germany	−0.001	0.004	0.061	6.128	19.196***	0.000	0.083
Denmark	−0.003	0.006	0.778	3.863	6.197**	0.045	0.179
Spain	−0.001	0.007	−0.373	6.115	20.091***	0.000	0.070
Estonia	−0.002	0.013	−0.550	3.865	3.836	0.147	0.095
Finland	−0.003	0.006	0.825	4.147	7.914**	0.019	0.206
France	−0.001	0.006	−0.189	6.223	20.628***	0.000	0.160
Greece	−0.003	0.005	−0.419	6.493	25.264***	0.000	0.060
Croatia	−0.001	0.004	−0.236	4.021	2.478	0.290	0.252
Hungary	0.000	0.003	0.214	3.270	0.501	0.779	0.271
Ireland	−0.001	0.004	0.027	3.238	0.117	0.943	0.262
Italy	−0.001	0.005	0.295	7.149	34.392***	0.000	0.210
Lithuania	0.000	0.002	−2.118	9.618	120.906***	0.000	0.123
Luxembourg	−0.001	0.006	−1.955	13.460	244.198***	0.000	0.067
Latvia	−0.001	0.004	0.402	5.148	10.301***	0.006	0.326
Malta	−0.002	0.011	−0.853	5.493	17.877***	0.000	0.206
Netherland	−0.001	0.004	−0.464	5.417	13.126***	0.001	0.134
Poland	0.000	0.003	0.734	4.810	10.640***	0.005	0.147
Portugal	−0.001	0.005	0.809	6.295	26.389***	0.000	0.159
Romania	0.000	0.005	−0.769	5.850	20.538***	0.000	0.108
Slovakia	0.000	0.005	0.921	5.955	23.749***	0.000	0.200
Slovenia	−0.001	0.003	−1.011	6.480	31.730***	0.000	0.078
Sweden	−0.002	0.003	−1.516	8.535	78.003***	0.000	0.160
Panel B: CMUR							
Austria	0.004	0.005	−0.452	5.241	11.438***	0.003	0.115
Belgium	0.002	0.007	0.775	6.833	33.478***	0.000	0.061
Bulgaria	0.002	0.031	1.806	10.531	136.623***	0.000	0.053
Cyprus	0.000	0.014	−0.313	5.877	16.975***	0.000	0.105
Czechia	0.004	0.005	0.886	3.940	7.885**	0.019	0.113
Germany	0.000	0.003	−0.257	4.153	3.120	0.210	0.115
Denmark	0.000	0.007	0.690	4.482	8.035**	0.018	0.082
Spain	−0.003	0.012	−1.053	6.668	35.026***	0.000	0.140
Estonia	0.004	0.016	0.052	3.634	0.810	0.667	0.122
Finland	−0.013	0.029	−1.805	6.321	47.128***	0.000	0.130
France	0.001	0.003	−0.793	4.466	9.132**	0.010	0.120
Greece	0.000	0.014	0.085	4.841	6.694**	0.035	0.187
Croatia	0.007	0.012	0.612	2.768	3.041	0.219	0.159
Hungary	0.002	0.015	−0.906	9.843	98.147***	0.000	0.064
Ireland	0.002	0.011	0.416	4.294	4.639*	0.098	0.131
Italia	0.002	0.006	−0.209	4.169	3.017	0.221	0.093
Lithuania	0.000	0.010	−0.553	7.698	45.618***	0.000	0.094
Luxembourg	−0.013	0.028	−0.855	6.041	23.837***	0.000	0.155
Latvia	0.013	0.049	−0.289	9.979	96.027***	0.000	0.064
Malta	0.003	0.026	0.921	4.887	13.624***	0.001	0.062
Netherland	0.002	0.005	0.564	3.735	3.554	0.169	0.074
Poland	−0.001	0.014	−0.614	6.777	30.900***	0.000	0.079
Portugal	0.002	0.008	0.296	3.813	1.979	0.372	0.075
Romania	−0.006	0.012	−0.037	4.812	6.438**	0.040	0.063
Slovakia	0.001	0.017	0.548	7.811	47.676***	0.000	0.075
Slovenia	0.004	0.010	−0.587	4.605	7.747**	0.021	0.125
Sweden	−0.001	0.005	−0.385	5.223	10.842***	0.004	0.071

***$p \leqslant 0.01$, **$p \leqslant 0.05$, and *$p \leqslant 0.10$.

The KPSS critical value of the 5% significance levels is 0.463. Std. Dev., Skew., Kur., J-B, P-value, and KPSS are respectively standard deviation, skewness, kurtosis, Jarque-Bera, probability statistics, and Kwiatkowski-Phillips-Schmidt-Shin. The EU countries include 27 countries from Austria to Sweden.

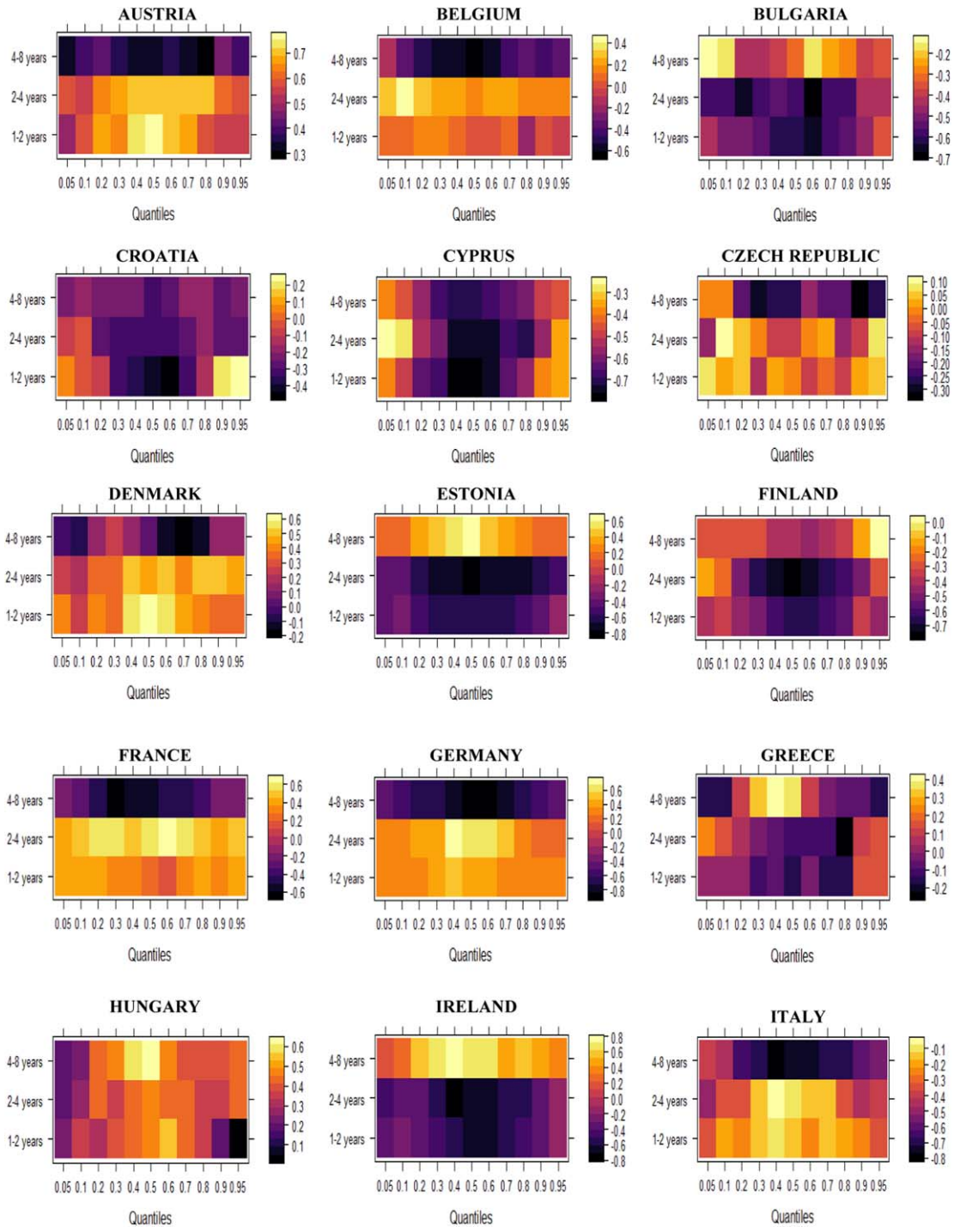

Figure 1. Wavelet quantile correlation results.

sparse literature for the EU countries, especially in the perspective of aggregate material circularity and carbon neutrality. Moreover, the outcome of the examination via an econometric approach offers deeper policy insight on the environmental relevance of circular economy. In the succeeding section (2), the dataset and empirical approaches are outlined. In sections 3 and 4, discussion of the empirical results and concluding remark are respectively presented.

2. Data and method

The share of used material resources from recycled waste materials vis-à-vis circular material use rate (measured in percentage, herewith named CMUR) and carbon dioxide (CO_2) emission (measured in tonnes, herewith named CE) dataset was collect for 27 EU countries. The CE comprises of all emissions (excluding land-use

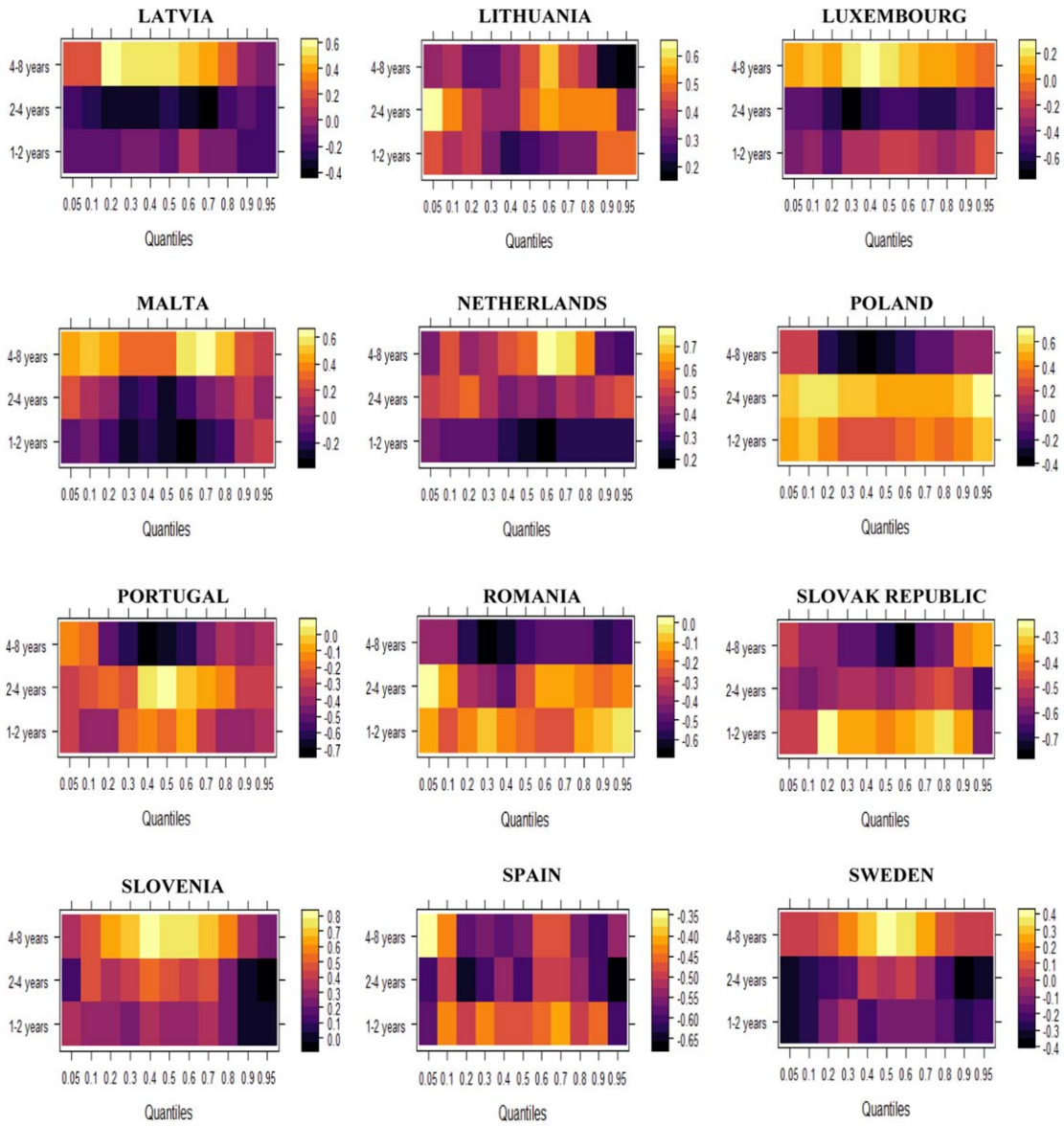

Figure 1. (Continued.)

change) from the burning of fossil fuels, or cement production within a country's borders (i.e., production or territorial emissions). These indicators i.e., CMUR and CE that cover the period 2010–2021 are respectively retrieved freely from the databases of European Commission (EC) and Our World in Data.

The descriptive statistics of the dataset alongside the stationarity test result for all the countries are presented in table 1. To meet the stationarity condition, the first difference of the quarterly logarithmic series was employed. Given that the mean and standard deviation values for CMUR and CE are within the same range in most of the countries, it suggests that there is a relatively uniform changes in the two indicators over the examined period. Contrarily, the CMUR in Bulgaria, Finland, Latvia, and Malta are relatively higher than rest of the countries, thus indicating that the rate of utilizing material resources in the countries have significantly changes over time. While the statistical distributions of these indicators are positively and negatively skewed across the countries, they values are also largely normally distributed. Moreover, with the Kwiatkowski *et al* (1992) stationarity test result (herewith referred as KPSS) illustrated in the last column of table 1, CMUR and CE are stationary across the countries.

2.1. Method

With the rejection of null hypothesis of normality given the probability values of the Jarque-Bera statistics, linearity test is performed by using the Broock *et al* (1996) (herewith referred as BDS). Following the hypothesis of the investigation i.e. '*establishing the environmental effect of material circularity*', the wavelet correlation method is employed to examine the correlations between CMUR and CE at various time frequencies. The result

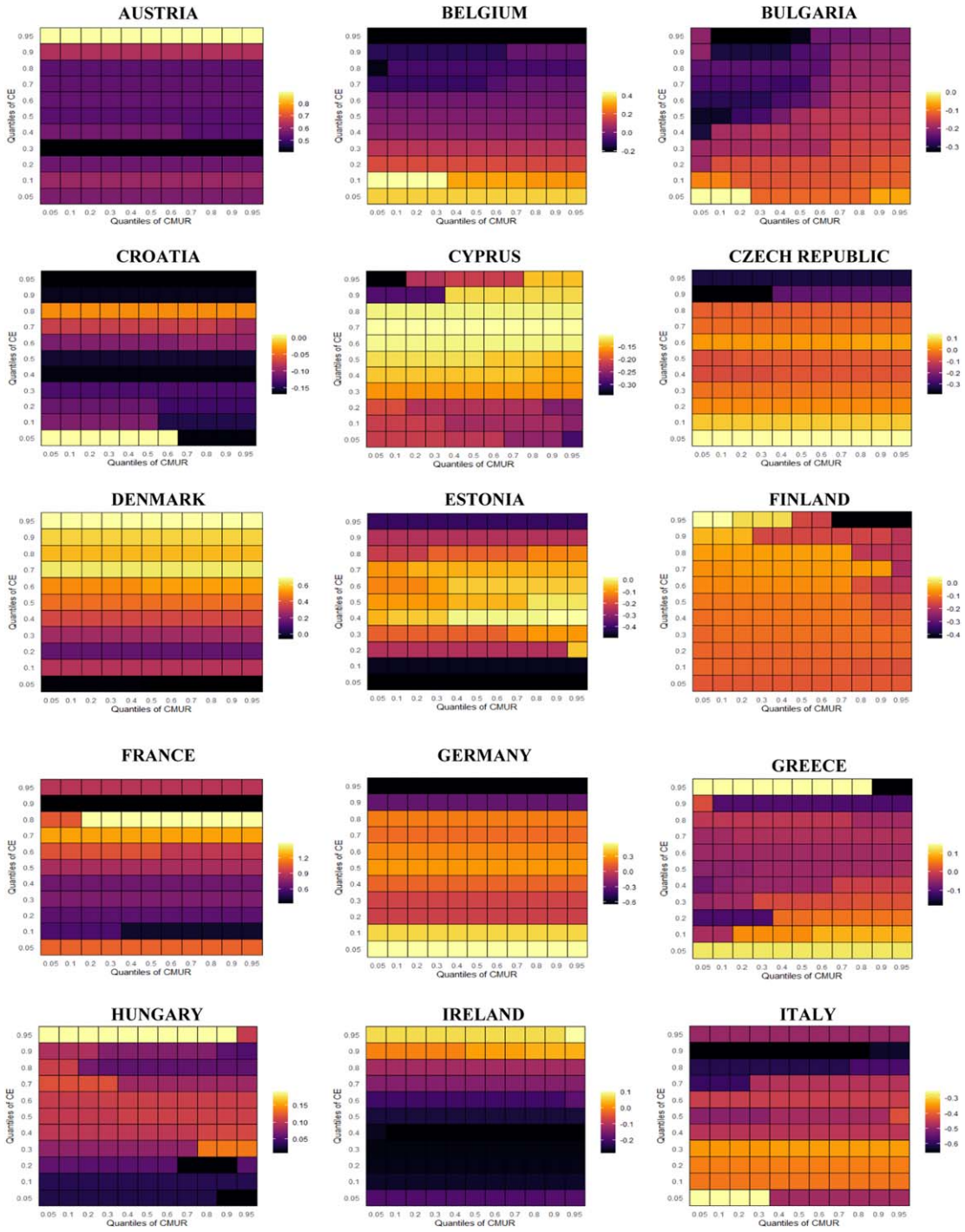

Figure 2. Quantile on quantile regression results.

of the wavelet correlation reveals statistically significant evidence of correlation between CMUR and CE across the countries (see figure 1). Importantly, the impact of the conditional quantiles of CMUR on the conditional quantiles of CE is examined by employing the Quantile-on-Quantile Regression (QQR) constructed by Sim and Zhou (2015). The results of the QQR for the countries are displayed in figure 2. For robustness purpose, we compare the validity of the QQR results with the estimates of the Quantile Regression (QR) of Koenker and Bassett (1978) and Koenker (1981) and the results for the countries are indicated in figure 3.

3. Findings and discussion

The QQR results show the causality from the quantiles of CMUR to the quantiles of CE for the countries as presented in figure 2. In most of the EU countries, the nexus between CMUR and CE is largely divided between

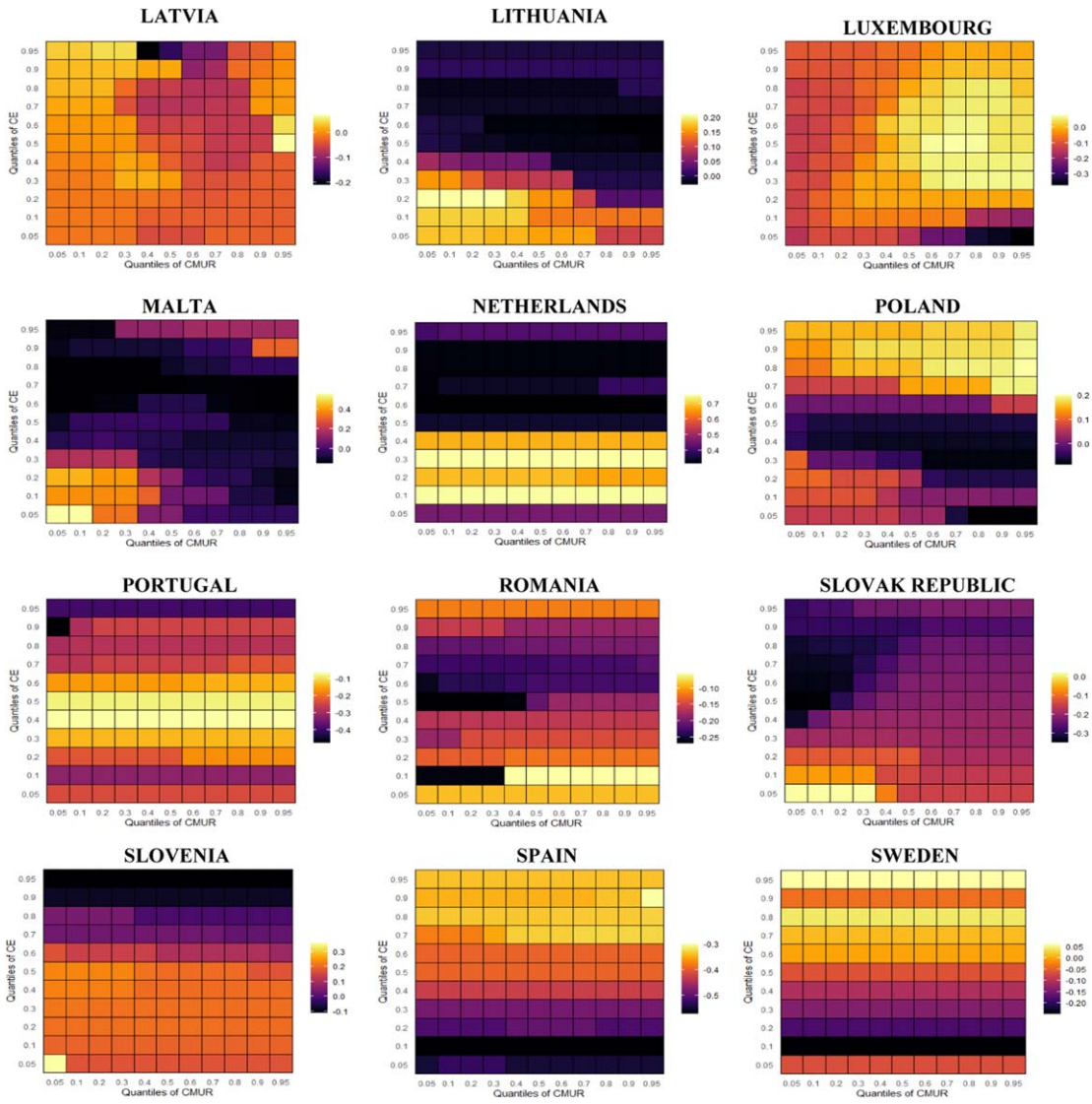

Figure 2. (Continued.)

positive and negative association. Specifically, in 11 EU countries i.e., Austria, Belgium, Denmark, France, Greece, Hungary, Lithuania, Malta, Netherlands, Poland, and Slovenia, material, carbon dioxide emission responds positively to the share of used material resources from the reuse of waste materials. This indicates that the share of material resources utilization from the reuse of waste materials in these countries is not sufficient to induce environmental quality by mitigating CO_2 emissions. This outcome is not out of place given that material consumption or material use rate does not necessarily translate to high use rate of recycled material. However, this observation aligns with the outcomes in Lonca *et al* (2018) and Cobo *et al* (2018). Specifically, Cobo *et al* (2018) found that nutrient circularity arising from organic waste increases the systems carbon footprint, thus worsen environmental quality.

Contrarily, the share of used material resources from the reuse of waste materials improves environmental quality by mitigating CO_2 emissions in another 11 EU states i.e., Bulgaria, Croatia, Cyprus, Estonia, Finland, Italy, Portugal, Romania, Slovak Republic, Spain, and Ireland. The implication is that the current trend and practice of material reuse in these countries is already yielding green dividend. This outcome reflects the evidence provided in van Selm *et al* (2023). Specifically, van Selm *et al* (2023) establishes the capability of reducing land use and greenhouse gas (GHG) emissions through the introduction of circularity interventions to the food system, thus improving sustainable ecosystem. Additionally, Hailemariam and Erdiaw-Kwasie (2023) found that recycling of municipal waste, bio-waste, and packaging waste mitigate emissions of CO_2 and GHG in the panel of 29 selected European countries. Meanwhile, in the last 5 EU countries i.e., Czech Republic, Germany, Luxembourg, Sweden, and Latvia, the impact of CMUR on CE clearly cut across positive and negative thresholds depending on the quantiles of the examined indicators.

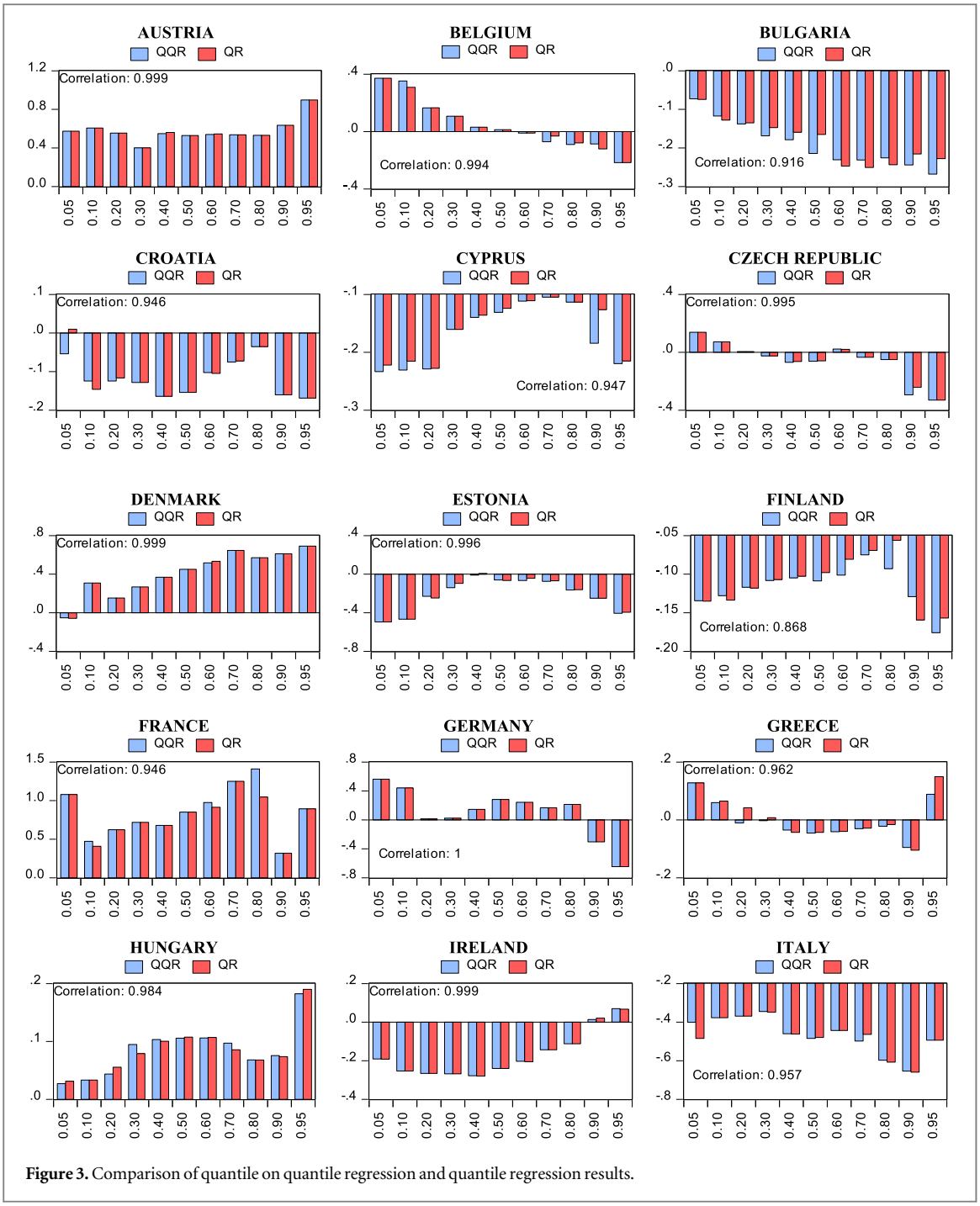

Figure 3. Comparison of quantile on quantile regression and quantile regression results.

As a robustness, and by comparing the two quantile regression approaches, the outcomes of the relationship between CMUR and CE for the countries are clearly presented in figure 3. These illustrations clearly support the description of the QQR evidence indicating that the impact of the share of used material resources from the reuse of waste materials on CO_2 emissions in the countries is largely divided between positive and negative effect.

4. Conclusion and policy recommendation

By employing the Quantile-on-Quantile Regression approach by Sim and Zhou (2015) and comparing the outcome with the traditional Quantile Regression (QR) of Koenker and Bassett (1978), the relationship between material circularity and CO_2 emissions was examined in all the 27 EU member states over the period 2010–2021. The outcomes reveal that the share of used material resources from the reuse of waste materials statistically influence environmental quality by (i) largely increasing CO_2 emissions across the quantiles in Austria, Belgium, Denmark, France, Greece, Hungary, Lithuania, Malta, Netherlands, Poland, and Slovenia, (ii) largely reducing CO_2 emissions across the quantiles in Bulgaria, Croatia, Cyprus, Estonia, Finland, Italy, Portugal, Romania,

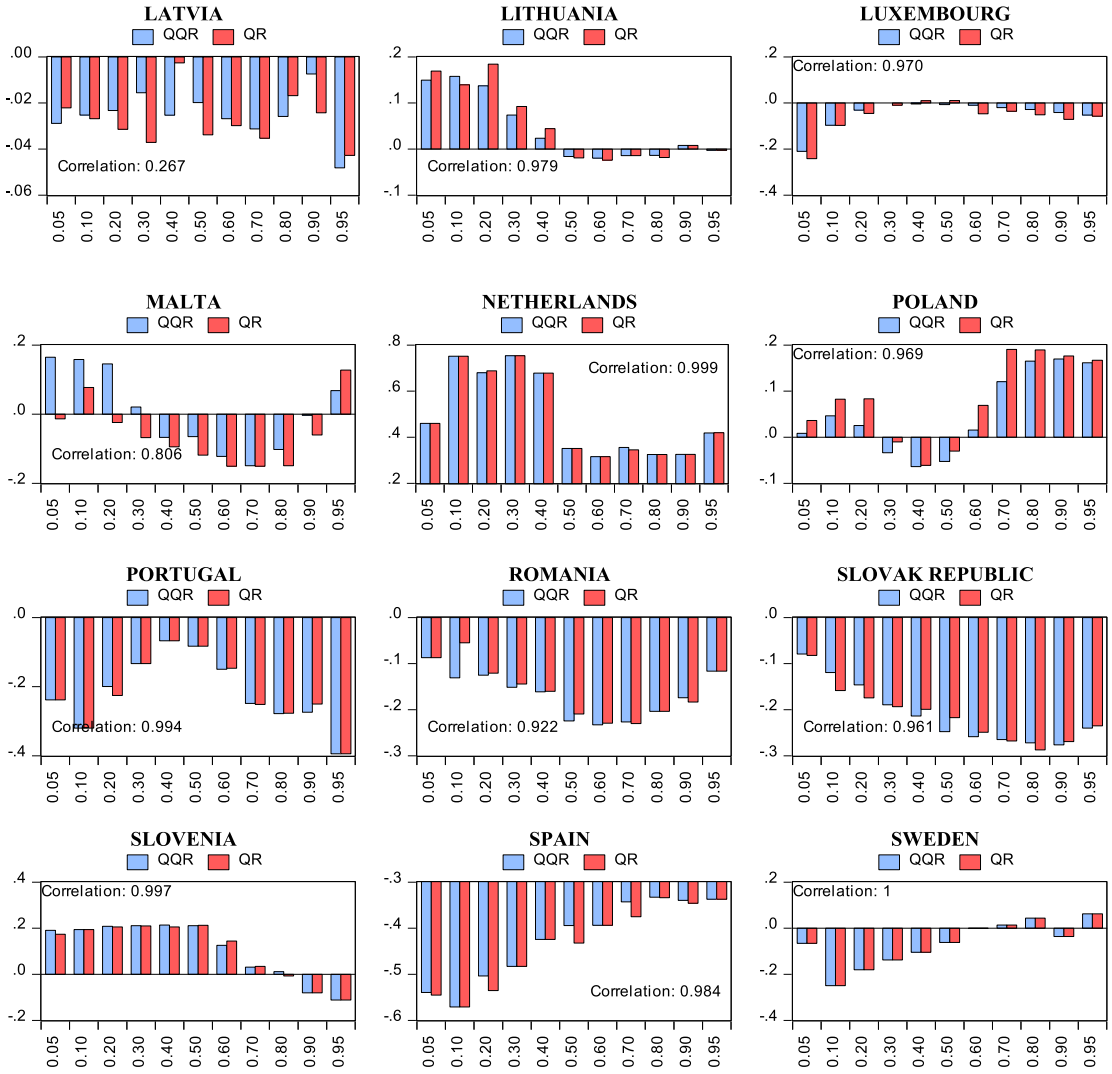

Figure 3. (Continued.)

Slovak Republic, Spain, and Ireland, and (iii) either increasing or reducing CO_2 emissions depending on the quantile of CMUR and CE in Czech Republic, Germany, Luxembourg, Sweden, and Latvia.

4.1. Recommendations: future study and policy

There is no doubt that the current investigation is limited in the scope of quantifying the impact of the relationship between the disaggregate circular material use rates and environmental indicator. Specifically, there is lack of evidence in term of the effect of each component of material resources i.e., biomass, metal ores, non-metallic minerals, and fossil energy resources. Moreover, a sectoral analysis of the current framework especially for the same case of the EU countries will also provide significant policy relevance, thus providing motivation for a future study.

However, there are policy insights from these outcomes. With the current share of used material resources from the reuse of waste materials in the EU put at 11.5 percent in 2022 (European Commission (2023b), more deliberate effort is needed to ensure a green benefit of circularity practices in these countries. Specifically, there should be more realistic and resource specific approach to the implementation of circularity practices across the spheres of human activities. In essence, more attention and awareness should be geared toward production and reuse of environmentally friendly products and achieving hazard-free end-of-life of product. To achieve this, where necessary, more stricter measures should be implemented to preserve and encourage the re-use or recycling of resources that are mostly in demand or highly utilized. Moreover, investment in research and development by private and public institutions should not only target discovery of sustainable material resources, but there should be more knowledge and innovative way of improving resource efficiency in the process of product design, use, and re-use.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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