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Assessment of the urban circular economy in Sweden

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ABSTRACT

This study proposes a general standard for the circular economy (CE), and estimates a multidimensional parametric index composed of eight components which is in line with the principles of a circular economy. The concept and index are used for evaluating the practices of a circular economy at the municipality level. The index is regressed on a number of indicators influencing the level and development of circular economy. The empirical analysis is based on data from 273 municipalities in Sweden observed 2012–18. The results suggest that there are significant differences between the municipalities in the CE index and its sub-components. Variations in the index's level are mainly attributed to their regional location, population size and density, concentration of industries, and investment programs in the circular economy's infrastructure. At a disaggregate level, the municipalities of Gotland, Härjedalen, and Mörbylånga performed well in the CE index. In contrast, Stockholm, Uppsala, and Burlöv municipalities had the lowest ranks in the CE index. The index had a growth rate of 9.7 percent over 7 years at an average annual growth rate of 1.3 percent. One policy implication of these results is that each municipality should implement a policy adapted to the sectorial structure of its economy and availability of resources. The central government should apply strict environmental regulations and provide necessary incentives for achieving environmental quality objectives. Incentive programs can target a wider application of technologies and policies used by the best performing municipalities and provide support in transferring knowledge and resources for strengthening the weak performing municipalities.

1. Introduction

By focusing strictly on firms' objectives of cost minimization and profit maximization and households' objectives of utility maximization, economies have neglected the environmental effects of industrialization, economic growth, and consumerism. The Schumpeterian constructive destruction (Schumpeter, 1942) which assigns a strong role to entrepreneurs and innovations in the process of economic development has contributed to the development of material saving technologies and also led simultaneously to the expansion of production capacity and speeding up environmental destruction.

The rapid degradation of the environment led to the development of sustainable development strategies. Countries and organizations have developed diverse environmental strategies and policies. To mention a few, the Swedish Government Office's, Ministry of Environment (GO-, 2002) describes Sweden's national strategy for sustainable development. Lehtinen (2007) provides a Nordic view of environmental justice. Ministry of Economy, Trade, and Industry in Japan (METI, 2004) has published a handbook on resource recycling legislation and 3R (reduce, reuse, and recycling) initiatives. The World Bank has reported on circular economy related practices and policy trends (Heck, 2006). China has embarked on investments in the circular economy and its large-scale implementation (Zhu et al., 2019; Ren, 2007; Geng et al., 2009; Geng, 2011). OECD (2014) has also introduced green growth indicators. These developments were followed by the United Nations Report (UN, 2019) on sustainable development goals with strong reference to environmental degradation and climate change.

Today, cities or municipalities consume close to two-third of the global energy, account for about 80 percent of the global greenhouse gas (GHG) emissions, and produce more than 50 percent of the global waste. The rapid growth of the urban population has led to several environmental problems and challenges such as pollution, resource scarcity, and limiting aging infrastructure. Urban areas are often acknowledged as growth engines and are recognized as productive places for experimenting with alternative modes of service provision and public governance. However, if cities' environmental policies, practices, and

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performance are not properly assessed it can easily lead to unsustainable development (see Fratini et al., 2019). Altvater (2009) views the world economy, the financial crisis, and ecological sustainability a trilemma. Lehtinen (2007) discuss green waves' and globalization with a Nordic view on environmental justice.

The path of industrialization has been material and energy intensive. Profit maximization, fierce competition in the market, and a policy of a 'race to the bottom' combined with limited knowledge about environmental consequences have led to unsustainable development of production, distribution, and consumption. To solve this problem, sustainable development strategies, policies, and standards are being developing at the regional, national, and international levels. Their target is reducing the level of emissions to the 1990 level by 2030. Given the rapid population increases, biased fossil energy-based technology development, and a dominant focus on increased productivity, these goals are seen as coming late and merely cosmetic aimed at only partially greening the market economy. Their development is thus unsustainable. Efforts are being made to cooperate for developing standards, policies, and evaluation methods for achieving true sustainable development. A number of the UN initiated sustainable development goals (SDG) are related to environment and climate change (United Nations, 2019).

The World Commission on Environment and Development (WCED, 1987), coined the concept of our common future. Pearce and Turner (1990) followed with influential research on economics of natural resources and environment which led to growing interest on environmental economics. Leontief (1928, 1991) and Samuelson (1991) viewed the economy as a circular, flow. A circular economy (CE) is a sustainable solution for current linear economic systems' problems as it treats the environment as a waste reservoir. Reducing the resources used and the waste and leakages thus generated enables conservation of resources and helps reduce environmental pollution and degradation. CE is an economic system that is based on the principles of reducing, reusing, and recycling material. In contrast to the traditional linear economy, the CE is regenerative. It minimizes resource inputs, waste, emissions, and energy use and leakages through design, maintenance, repair, reuse, and recycling of material; clean and closed loop production; and responsible consumption. Compliance with the circular economy's principles in managing resources is necessary regardless of the level of development. It is expected that developed countries will lead the transformation from a linear to a circular economy through their access to finances, technologies, and management.

A circular economy has major benefits in four areas —— environmental benefits, economic benefits, resource benefits, and social aspects. CE can result in significant cost savings for different industries (EMF, 2013) and increase in net benefits for businesses (AMEC, 2013). A circular economy can reduce demand for raw materials hence increasing the efficiency of primary resources. According to the European Commission (EC), a circular economy is expected to create up to 178,000 new direct jobs by 2030 (EC, 2015). As estimated by EC, different combinations of municipal recycling, packaging waste, and reducing landfills could reduce greenhouse gas emissions of about 424–617 million tons of carbon dioxide equivalent over 2015–35 (EC, 2015; EEA, 2016).

This research focuses on Sweden, a country which has well-built environmental ambitions and policies. Sweden's main energy source is bioenergy which accounts for about 36 percent of the country's total energy consumption. Over 99 percent of Swedish household waste and 53 percent of plastic material are recycled but only 50 percent of the construction sector's waste is recycled. The construction sector is responsible for most of the waste in the country. Sweden has a high rate of recycling compared to other European countries. However, the per capita resource use in Sweden is above the EU average (EEA, 2011) and waste generated per capita is growing fast (SEPA, 2013). Sweden has introduced various incentive programs for CE's effective implementation. It has tried to improve conditions for productive growth through treating solid waste and wastewater and recycling through public education and various incentive programs. Sweden, like many other OECD countries, has incorporated green political parties in its decision-making process and the political system which has motivated its transition towards a circular economy (OECD, 2014). In 2016, the Swedish government appointed a special investigator for CE who had the role of proposing and analyzing instruments for promoting the utilization and reuse of products in reducing waste generation. The investigation led to the government setting up a Circular Economy Delegation in 2018. Its intention was facilitating a transition to a circular, resource-efficient, and bio-based economy at the national and regional levels.

Our research interest is in assessing the current state of CE's development in Sweden. This research has several objectives. First, it introduces a standard for a circular economy that is multidimensional and covers different aspects of material use, reuse, and recycle at the municipality level. The index is composed of eight components covering the areas of waste collection, waste recycling and utilization, emission of air pollutants, infrastructure and mechanism, waste tax, investments and waste management costs, clean transport, and renewable energy. Second, it estimates a composite index that is in line with the principles of a circular economy. Third, the index is used for evaluating the practices of a circular economy at the municipality level including the management of residues in both urban and rural areas and covering agriculture, industry, household, and public services sectors. More specifically, it includes managing residues in both urban and rural areas and covering all sectors of the economy. The empirical analysis is based on 273 municipalities in Sweden observed during the period 2012–18. Fourth, municipalities are ranked by their performance in adapting a circular economy. The temporal development of their performance is also analyzed. Finally, in a separate stage the circular economy index is regressed on a number of indicators that influence the level and development of the circular economy.

In this study we wanted to find out which municipalities performed better environmentally in a circular economy and with a sustainable perspective. We characterized different determinants/drivers of the circular economy in Sweden and investigated how the general environmental and circular economy conditions have developed during recent years. The empirical results suggest that municipalities' effectiveness in applying a circular economy differ significantly. Variations in the index are mainly attributed to regional location, population size and density, concentration of industries, and investment programs in a circular economy's infrastructure. An analysis of the circular economy leads to various implications for public policy and the results of this research will be helpful in formulation of future CE development programs. This will help municipalities recognize the barriers to local CE development in different urban areas helping them to formulate appropriate standard policies by considering their local environmental realities. The composite index and its decomposition will help develop effective environmental standards both locally and nationally. One policy implication of these results is that each municipality should implement a policy adapted to the sectorial structure of its economy and the local resources available. The central government should introduce strict environmental regulations and improve distribution of public resources through CE based resources reallocation and public investment programs and through providing incentives for achieving environmental objectives and equality in environment quality among municipalities.

The rest of this paper is organized as follows. Section 2 reviews literature on a circular economy. Section 3 presents the state of the circular economy and its sustainability in Sweden. The data and estimation of the composite circular economy index and its determinants are discussed in Section 4. The results are analyzed in Section 5. After discussing the findings, this paper summarizes the results and gives a conclusion by providing policy recommendations for decision-makers.

2. Literature review

The Bruntland report (WCED, 1987) attracted attention to our common future. The economics of natural resources and environment was first mentioned in Pearce and Turner (1990). Leontief (1991) viewed the economy as a circular flow and Samuelson (1991) provided an introduction to Leontief's circular flow. A review of the literature and the taxonomy of industrial symbiosis is provided by Chertow (2000). Altvater (2009) considers the world economy, the financial crisis, and ecological sustainability as a trilemma. The urgency in transitioning from a linear economy to a circular economy has led to rapid development of literature in the last two decades.

In this section, we summarize literature other than that listed earlier on the implications of a circular economy (CE) worldwide. Published academic studies exist at three different planes of macro (countries, provinces, large cities), meso (eco-industrial parks), and micro (consumers and companies) levels. In Europe, Germany is the forerunner CE as it started implementing it with its Waste Disposal Act in early 1976 (Heshmati, 2017). CE on a larger scale was first applied in Japan with the Law for Effective Utilization of Recyclables in 1991 (METI, 2004; IES, 2015; UNEP, 2013). The third country that has implemented CE on a large scale is China.

Korea (by issuing the Waste Management Act in 2007) and Vietnam (by issuing the Environmental Protection Law and the National Strategy on Integrated Solid Waste Management in 2005) have also promoted important 3R policies (Ghisellini et al., 2016). According to the Sustainable Business Network (SBN, 2015) and Jewell (2015), New Zealand and Australia have accelerated access and action agenda for the circular economy. Over the last decade, a body of academic research has been devoted to evaluating CE and its implications.

Heshmati (2017, 2018) reviewed literature on CE and green economy, the concepts, practices, and implementations. His study presented the concept of CE and compared it with the current linear economy. Su et al. (2013), Geng (2011), Geng et al. (2009) and Zhu et al. (2019) are among studies assessing the performance of CE in China after studying relevant policies. These authors compared the changes in Dalian with three other pilot cities of Tianjin, Shanghai, and Beijing. Their study found that the Dalian municipality had achieved its target of developing CE in 2010. It performed well in waste management but lagged behind in terms of energy efficiency. Wu et al. (2014) assessed the efficiency of CE in China's 30 regions during the period 2005–10 using a super-efficiency window data envelopment analysis (DEA). Their results showed that China's CE efficiency increased slightly showing notable policy effects of CE in China. Their study also provided evidence of significant heterogeneity among Chinese cities. Guo et al. (2017) evaluated CE's development in China's four megacities of Chongqing, Beijing, Urumqi, and Shanghai during the period 2006-15 by creating a CE assessment indicator system. Their results showed that CE development improved significantly in all these megacities. The megacities in eastern China performed better than the megacities located in southeastern China.

Wang et al. (2018) evaluated an index system for a circular economy by using the entropy methodology and combining entropy and expert weightings. They calculated the index for 40 cities in China which were part of China's pilot CE cities program during the period 2012–16. They found that CE increased significantly over the study period and there was a certain relationship between the CE index, economic development, and urban systems. Prendeville et al. (2018) investigated the performance of different European cities in developing CE strategies. More recently, Sánchez-Levoso et al. (2020) presented a methodological structure to facilitate an understanding and the implications of CE strategies in urban systems. By proposing a four-step methodology their study identified the capabilities of areas with sizable CE potential.

Another group of studies analyzes the adoption of circular economy policies. Ekvall et al. (2016) suggest a policy mix to boost resource efficiency focusing on both primary and supplementary policy instruments (such as taxing material, expanded producer obligations, and technical requirements). Nuβholz et al. (2019) and Zhu et al. (2019) focus on quality standards. Franco-García (2019) studied the market mechanisms and Milios (2018) created a map of current policies linked to life-cycle stages that, when combined, makes CE easier.

An extensive body of literature also addresses the methodologies used for analyzing the performance of the different policies that have been adopted for improving the circularity of the economy. Wu et al. (2014) used the super-efficiency DEA window analysis approach to dynamically test CE efficiency in 30 Chinese regions from 2005 to 2010. They assessed the basic efficiency of three sub-systems – resource saving and pollutant reduction, waste reusing and resource recycling, and pollution controlling and waste disposal – in accordance with CE's features. Previous studies have used the following methods to assess CE (Sassanelli et al., 2019): Data Envelopment Analysis and Input-Output (Park et al., 2016); Design for X (Grimaud et al., 2017); Guidelines, Life Cycle Assessment (Laso et al., 2016); Life Cycle Inventory (Petit et al., 2018); Life Cycle Impact Assessment (Gbededo et al., 2018); Multi-Criteria Decision Methods (Petit et al., 2018); EMergy Approach (Huysman et al., 2017); Discrete Event Simulation (Gbededo et al., 2018); Material Flow Analysis (Grimaud et al., 2017); Material Cost Analysis and Material Flow Cost Accounting (Pauliuk, 2018).

A review of literature shows that most of the studies address the implications of urban CE development in China. China is attracted by CE because of human health and the social and environmental troubles caused by its fast and constant economic growth and development. The rapid progress of CE in China may be attributed to local development of technologies that can be easily adapted to local markets and conditions. The centralized industrial policy has also eased the development of environmentally progressive standards and policies which are applied through decrees. However, no study to date has examined CE's development on a smaller scale and in Sweden. In this background, this research fills this gap by using an index-based methodology to evaluate CE's development in different municipalities/counties in Sweden. Hence, this research will be practically helpful in guiding Sweden's future circular economy policy and for its development and evaluation standards.

3. Circular economy and sustainability in Sweden

Sweden and many other European countries have managed to incorporate green political parties in their political systems and decision-making processes that has encouraged and facilitated a shift to CE. Sweden has also successively introduced various incentive programs for creating optimal conditions for a gradual and effective increase in the rate of recycling through public education and participation. The market economy and product and process innovations have also reduced use of materials and substitutions possible. However, behavior for reusing materials has not developed enough to catch up with CE's recycling and reduction elements. In general, a circular economy is considered as a development strategy which eases tensions between environmental concerns and economic development. CE can also help consider pollution problems and resource scarcity and it enables green competitiveness.

According to the report, 'Sweden's national strategy for sustainable development' (GO-, 2002) published by the Swedish government's office, sustainable development is defined as the overall aim of the government's policy. Sweden's national sustainable development strategy (GO-, 2002) is a complex strategy that aims at bringing together economic, cultural, social, and environmental priorities in a shift towards more sustainable development.

In 2018, the Swedish government set up a Delegation for a Circular Economy with the aim of strengthening Swedish society's national and regional transition to a resource-efficient, circular, and bio-based economy. Initially, the Delegation focused on three areas: a design for circularity, plastic materials, and public procurements. By choosing a design for circularity, the Delegation wanted to contribute to new business models in which circularity was an integral part of the design for both products and production systems. Plastic is a typical material with great potential for increased recycling and longer material life. In a welfare society like Sweden with a large public sector, public procurement generates huge volumes of goods and services every year. Thus, procurement has a major impact on resource flows which the Delegation believes can be steered towards both increased reuse and longer material life.

The main tasks of the Swedish Delegation for Circular Economy include[1]: developing a strategy for a shift to a bio-based and circular economy at various levels in society; contacting relevant actors for inclusive participation; identifying barriers, needs for education, and advising and proposing cost-effective measures to the government; gathering and sharing knowledge about ongoing initiatives and facilitating collaboration between them; designating reference groups for supporting the Delegation's work; creating an innovative, competitive, and sustainable business environment at the national and regional levels; and creating a transition process that can contribute to national environmental goals, strengthening Sweden's competitiveness, and increasing its contribution to the implementation of United Nations sustainable development agenda 2030. At least seven of the 17 sustainable development goals are related to environment: clean water and sanitation; affordable and clean energy; sustainable cities and consumption; responsible consumption and production; climate action; life below water; and life on land.[2]

4. Data and measurement of the circular economy index

4.1. The data

Sweden is divided into 21 counties/regions and 290 municipalities. No hierarchical relation between the municipalities and regions exists since all of them have their own self-governing local authorities with responsibility for different activities allocated to each. Municipalities are legally responsible for water supply and sewerage collection, rescue services, and waste disposal systems. Caring services for the elderly, children, refugees, disabled people, basic schooling, and cultural and recreational activities are among the important concerns of municipalities in Sweden.[3] Counties/regions are responsible for within region, cross-regional, and national common services. The two administrative levels of services provision are financed through direct municipality tax revenues and distribution of state taxes.

To investigate and compare CE in different municipalities in Sweden (Fig. 1), we use data obtained from Kolada. Kolada is a database that has indicators for activities by county and municipality councils which is managed by the Council for the Promotion of Local Analyses (RKA) owned by the Swedish State (50 percent) and the Swedish Association of Local Authorities and Regions (SALAR) (50 percent). Kolada provides comprehensive key figures on resources, volumes, and quality of services in municipalities and regions. These key figures are often based on national statistics from the statistical authorities, but are complemented with data from other sources (Kolada, 2019). More than 2000 indicators are provided by Kolada which are considered as a base for analyses and comparisons. The indicators reported in Kolada come directly from county councils and municipalities.

Kolada sourced data used in this research is a balanced panel covering 273 municipalities in Sweden observed for the period 2012–18. Data availability determined the sample size and period studied. Due to missing data, 17 of these municipalities are not listed in the database files and the sample studied. An aggregate circular economy index (CEI) is estimated by using 40 indicators, which are categorized into eight groups or components. Missing units are imputed using the Stata imputation command. The distribution of the variables before and after imputation was very similar. Most of the indicators correspond to the reduce, reuse, and recycle principles of materials. The index is used for comparing the municipalities' circular economy performance. A list and description of these variables and the index's components are given in Table 1.

Part A of Table 1 describes the indicators that are used for measuring the CE index. The first component, collected waste (CW), uses four indicators covering different waste types. The second component, waste recycling and utilization (WR), consists of eight indicators. The third component, emission of air pollutants (EAP), has three key indicators of total emissions. The fourth component, infrastructure and mechanism and culture (IMC), has seven indicators. The fifth index, waste tax (WT), is constructed using five indicators. The sixth index, investments and waste management cost (IWM), is associated with investment expenditure on waste management and investment expenditure on energy, water, and waste. The seventh index captures the clean transportation aspects of CE. It is constructed by using three indicators. Finally, the last index, renewable energy (RE), employs five indicators. We estimated an overall composite CE index in which all these 40 indicators and eight index components were accounted for.

Part B of Table 1 describes the determinants of variations in levels and temporal patterns in the circular economy index. The variables include unemployment rate (UNEMP), gross regional product (GRP), commuting to/from the municipality (COMM), revenue from tourism business (REVE), total investment expenditure of the municipality (TINV), population density (RESID), cost of educational activities (EDUCO), consumer and energy costs (ENER), asylum seekers (ASYL), most common waste tax total for single and two-family houses (WTAX), and charge for waste collection for type of property according to the Nils Holgersson model (WCOL).

A high and costly unemployment rate is expected to reduce investments in the circular economy. A high gross regional economy not only increases the waste volume but also tax revenues enabling municipalities to invest in CE. The labor market, education, housing, and healthcare are spatial markets involving commuting which is negative for a circular economy. High revenues from tourism is a source of employment and it encourages investments in a clean environment for increasing tourist inflows. A high level of municipal expenditure can be a source for allocating funds to environment friendly projects. High population density per square kilometer in urban areas is negative for environmental quality. Municipalities' investments in education and training are expected to positively affect households and firms' production, consumption, and waste management. Asylum seekers are arriving from developing countries experiencing long periods of war and destruction with lower education and training in considering environment and as such their large numbers and high costs can be negative for green investments and thus the implementation of the circular economy. Ivlevs (2020) investigated how emigrations affect pro-environmental behavior back home. A high rate of waste tax and waste collection charges are expected to induce reduction in the quantity of waste thus leading to higher environmental quality.

4.2. Measurement of the circular economy index

Researchers and organizations are looking at measuring the circular economy as a way of improving the long-term sustainability of economic systems. A review of existing studies shows that scholars have used different index-based methodologies for measuring the adoption of the CE paradigm (Herva et al., 2011; Galli et al., 2012; Angelakoglou and Gaidajis, 2015). Elia et al., 2017) used the following techniques which are based on a life-cycle approach: (i) Index-based methods focused on

[1] https://tillvaxtverket.se/amnesomraden/affarsutveckling/delegationen-for-cirkular-ekonomi.html.

[2] https://sustainabledevelopment.un.org/?menu=1300.

[3] See https://skr.se/tjanster/englishpages/municipalitiesandregions.1088.html.

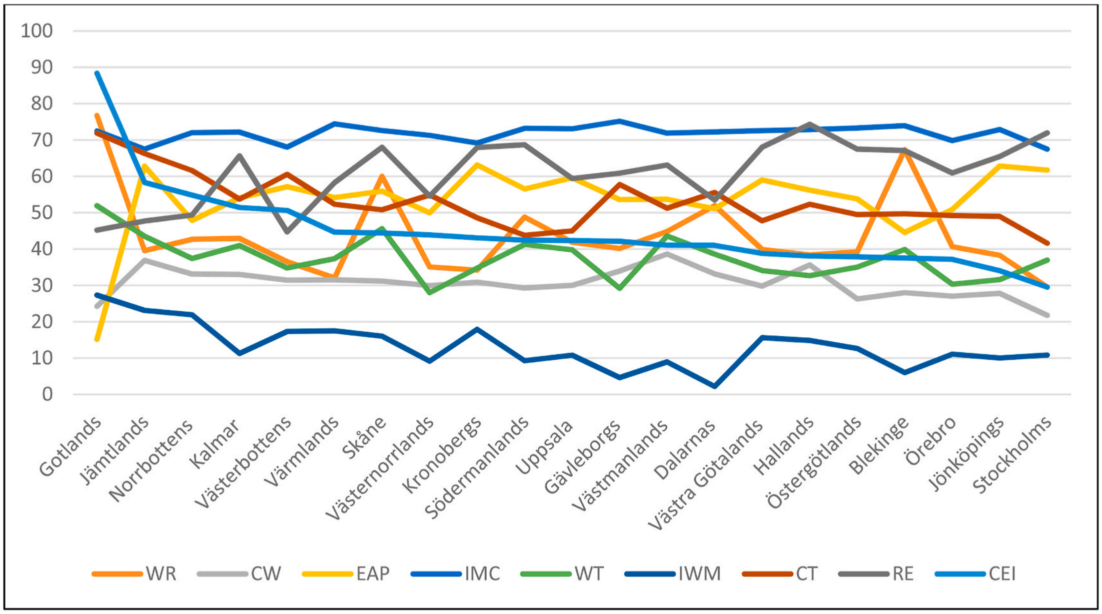

Fig. 1. Average CEI and its components across counties of Sweden, 2012–2018.

material flows: Material Inputs Per Unit of Service (MIPS), Water Footprint (WF), and Ecological Rucksack (ER). (ii) Index-based methods focused on energy flows: Cumulative Energy Demand (CED), EXergy analysis (EXA), Embodied Energy (EE), and EMergy Analysis (EMA). (iii) Index-based methods focused on land use and consumption: Sustainable Process Index (SPI), the Ecological Footprint (EF), and the Dissipation Area Index (DAI). (iv) Single indicators including: Ecosystem Damage Potential (EDP), and Carbon Footprint (CF) and multiple indicators: Life Cycle Assessment (LCA), Sustainable Environmental Performance Indicator (SEPI), and Environmental Performance Strategy Map (EPSM). Guo et al. (2017) applied CNBS's CE evaluation indicator system.

Index numbers is a comprehensive literature on various indices and their measurement and properties. We use the composite index's numbers which can be divided into two groups: non-parametric and parametric indices. The index normalizes the indicators and aggregates them into a composite index. Aggregation requires weighting the indicators. The non-parametric indices belong to the UN class of indices such as the human development index which aggregate its education, income, and longevity components assuming the same weight of 0.33 (Heshmati, 2006; Noorbakhsh, 1998). The parametric indices have the advantage that the weights are not chosen on an ad hoc basis but are estimated.

Estimation of the parametric circular economy index developed in this study is based on the principal component analysis (PCA) methodology. PCA as proposed by Hotelling (1933) is an exploratory multivariate statistical method which is used for checking the latent structures in the data (Jackson, 1991). In this technique, the dimensionality of the dataset is reduced while its variability is preserved as much as possible (Jolliffe and Cadima, 2016). Principal components (PCs) are linear combinations of sets of indicators in the initial dataset. The weights are allocated to linear combinations of those original datasets specified as eigenvectors (Wang and Wang, 2015). PCA takes *m* variables $\rho_1, \rho_2, \ldots, \rho_m$ and tries to a find linear combination of these variables to produce the principal components (Duda et al., 2001; Haykin, 1999; Hotelling, 1933). The first principal component (PC1) is a linear combination which describes the maximum variation in the data. The second principal component (PC2) is a further linear combination independent of the first which explains as much as possible the remaining variability. Additional components are added sequentially, each new component being independent of previous ones. The indicators within a principal component are highly correlated but between the components they are least correlated. Estimating a composite index representing complex multidimensional variables with fewer principle components is the main advantage of PCA (Manly, 1994; Sharma, 1996; Wang and Wang, 2015).

Traditionally researchers using the principal component analysis use only the first principal component to represent the intended index. All indicators left out from the first principal component are ignored. To use full information in the data, following Heshmati and Rashidghalam (2020) this study uses a weighted average of the principal components with eigenvalues greater than 1. The share of the total variance is used as weights in the aggregation of the principal components. This approach allows us to use the contribution of all the indicators with an eigenvector greater than 0.30 in constructing the composite index. The signs and sizes of the eigenvectors gives their contribution to the overall index.

After measuring the circular economy index (CEI) and its underlying sub-indices' components, a regression analysis was used for identifying the variables that explain the variations in the amount of CEI among different sample municipalities. A regression analysis is a widely accepted tool for estimating the statistical relationship between the variables. For the regression analysis, a model was considered where the dependent variable (CEI) was specified as a function of the explanatory variables as:

$$\begin{aligned} CEI_{it} &= \alpha_0 + \alpha_1 UNEMP_{it} + \alpha_2 GRP_{it} + \alpha_3 COMM_{it} + \alpha_4 REVE_{it} + \alpha_5 TINV_{it} \\ &+ \alpha_6 RESID_{it} + \alpha_7 EDUC_{it} + \alpha_8 ENER_{it} + \alpha_9 ASYL_{it} + \alpha_{10} WTAX_{it} \\ &+ \alpha_{11} WCOL_{it} + \varepsilon_{it} \end{aligned} \tag{1}$$

where the explanatory variables are defined as previously and the α coefficients are the unknown parameters measuring their effect on CEI.

5. Discussion

5.1. The circular economy index and its sub-indices

The composite circular economy index is estimated both as a disaggregate of eight sub-indices and aggregate single index forms. As an example, consider the waste recycling and utilization sub-index (WR). In this index, there are eight eigenvalues which is equal to the number of indicators. Only two of the eigenvalues are bigger than 1 leading to two

Table 1
Summary statistics of the data, 2012–18, 273 municipalities, N = 1911 observations.

PART A. Index Measurement:				
Categories	Labels	Indicators	Means	Std. Dev.
Waste recycling and utilization	WR_1	Household waste collected for recycling, incl. biological treatment, percentage (%)	38.07	8.85
	WR_2	Organization of waste management, (coded response options)	2.40	1.62
	WR_3	Accessibility of the largest recycling center in the evening/ weekend, hours/week	12.02	6.85
	WR_4	Total accessibility to all recycling centers, minutes/inhabitant	8.42	4.72
	WR_5	The recycling center's office lasts beyond 08–17 on weekdays, hours/week	11.60	6.06
	WR_6	Collected packaging and recycled paper, kg/inhabitant	71.76	17.41
	WR_7	Household waste collected for material recycling, incl. biological treatment, percentage (%)	38.07	8.85
	WR_8	Collected food waste that goes to biological recycling incl. home composting, percentage (%)	38.79	20.97
Collected waste	CW_1	Collected coarse waste, kg/inhabitant	209.21	79.25
	CW_2	Total household waste collected, kg/ inhabitant	211.95	35.35
	CW_3	Collected hazardous waste (incl. Electrical waste and batteries), kg/inhabitant	25.40	7.18
	CW_4	Collected food and residual waste, kg/ inhabitant	175203.20	545591.80
Emission of air pollutants	EAP_1	Emissions to air of greenhouse gases total, tons CO2 equiv/ inhabitant	1220.58	60.04
	EAP_2	Emissions to air of PM2.5 (particles <2.5 μm). kg/inhabitant	86.45	19.12
	EAP_3	Emissions to air of nitrogen oxides (NOx), total, kg/inhabitant	23.01	20.49
Infrastructure, Mechanism and culture	IMC_1	Does the municipality have a water and wastewater plan? (No = 0, Yes = 1, 2 = During development)	1.19	0.70
	IMC_2	Need Citizens Index - Environmental work	55.27	4.22
	IMC_3	Need for waste management Suitability, percentage (%)	81.89	5.47
	IMC_4	Need to visit at the recycling center, percentage (%)	85.80	6.09
	IMC_5	Need accessibility to the recycling center, percentage (%)	73.38	8.07
	IMC_6	Larger individual water utilities with some form of protection, percentage	22.34	15.80
	IMC_7	Organic food in the municipality's operations, percentage (%)	23.69	9.94
Waste tax	WT_1	Most common waste tax total incl. VAT for single and two-family houses, SEK	2056.59	436.06
	WT_2	Most common waste tax total incl. VAT for holiday home, SEK	1189.81	428.22
	WT_3	Most common waste tax total incl. VAT for housing in apartment buildings, SEK	1296.79	375.09
	WT_4	Charge for waste collection incl. VAT for type property according to the Nils Holgersson model, SEK/m2	20.52	5.52
	WT_5	Fee for water and sewage incl. VAT for type property according to the Nils Holgersson model, SEK/m2	63.21	16.97
Investment and waste management cost	IWM_1	Investment expenditure waste management, SEK/ inhabitant	61.65	159.00
	IWM_2	Investment expenditure in energy, water and waste by municipality, SEK/ inhabitant	768.93	1086.05
	IWM_3	Investment expenditure water supply and wastewater treatment, SEK/ inhabitant	696.11	993.64
	IWM_4	Cost of waste management, SEK/ inhabitant	588.24	628.75
	IWM_5	Cost of water supply and waste management, SEK/ inhabitant	1317.42	1105.23
Clean transport	CT_1	Average mileage with passenger car, mile/ passenger car	94.90	11.38
	CT_2	Environmental cars in the municipal organization, percentage (%)	41596.72	71313.17
	CT_3	Environmental cars, percentage of total cars in the geographical area, (%)	14.27	4.43
Renewable energy	RE_1	Renewable fuels for food and residual waste collection, percentage (%)	47.79	26.52
	RE_2	Electricity generation of renewable energy sources in the geographical area, percentage (%)	211.95	35.35
	RE_3	Electricity generation of hydropower in the	36.73	17.50

(continued on next page)

Table 1 (*continued*)

PART A. Index Measurement:				
Categories	Labels	Indicators	Means	Std. Dev.
		geographical area, MWh		
	RE_4	Electricity generation of wind power in the geographical area, MWh	3.76	3.04
	RE_5	District heating production of renewable energy sources at geothermal plants in the geographical area, percentage (%)	6.81	8.87
PART B. CEI's Determinants:				
UNEMP		Unemployment 18–64 years, percentage (%) of the population.	6.74	2.34
GRP		Gross regional product, SEK/inhabitant	318177.40	119865.50
COMM		Commuting to the municipality, percentage (%)	29.46	13.91
REVE		Revenue from tourism business, SEK/inhabitant	42.05	157.38
TINV		Total investment expenditure of the municipality, SEK/inhabitant	5023.82	3175.14
RESID		Residents per square kilometer, number of inhabitants/number	143.27	530.66
EDUCO		Cost of educational activities, SEK/inhabitant	27402.64	2755.69
ENER		Consumer and energy costs, SEK/inhabitant	33.75	45.03
ASYL		Asylum seekers/enrolled in Migration Board's reception system, number	343.98	498.43
WTAX		Most common waste tax total incl. VAT for single and two family houses, SEK	2056.59	436.06
WCOL		Charge for waste collection incl. VAT for type property according to the Nils Holgersson model, SEK/m2	20.52	5.52

principal components being considered for computing the weighted WR sub-index. The first principal component in the WR sub-index has a variance of 2.95, explaining 37 percent of the total variance. The second principal component has a variance of 1.85, or it explains 23 percent of the total variance. As a result, we can also say that the first two principal components explain $37 + 23 = 60$ percent of the variance in the individual components. Hence, the number of variables to be analyzed was reduced to those with eigenvectors greater than 0.30 in the two principal components.

According to Table 2A, out of the four variables in the collected waste sub-index (CW) only two principal components explained almost 60 percent of the variability. For other remaining sub-indices, the number of eigenvalues greater than 1 and the share of the variance explained by these principal components are: emission of air pollutants EAP (2, 0.71); infrastructure and mechanism and culture IMC (3, 0.59); waste tax WT (2, 0.86); investment and waste management cost IWM (1, 0.56); clean transport CT (1, 0.47); and renewable energy RE (2, 0.55) sub-indices.

We also aggregated all 40 indicators used in the estimation of the eight sub-indices to assess the overall index (CEI). In the overall aggregate index, 11 eigenvalues are bigger than 1 and together they explain 62 percent of the total variance. The contribution of these 11 principal components in explaining the variance is 15 percent by the first component which further reduces to 3 percent by the last component.

Heterogeneity in different sub-indices' components and the overall composite circular economy index can be analyzed on the basis of the differences between the municipalities and counties and the changes in the indices over the studied period. The rest of our analysis is based on performance heterogeneity in CEI across sample municipalities and counties in Sweden and their variations over time.

In we show the loading factors (eigenvectors) of the sub-indices and the overall index. Those with eigenvectors greater than 0.30 in the principal components with eigenvalues greater than 1 contribute to the sub-index and ranking positions of municipalities. By looking at the WR sub-index we note that indicators 1, 7, and 8 are the main contributors to the principal component 1 while indicators 3, 4, and 5 are contributors to the second principal component 2. It is worth mentioning here that each indicator contributes to only one principal component. Indicators 2 and 6's contributions to the WR sub-index are weak. The signs and sizes of the loading factors show the direction and magnitude of their effects.

For the CE sub-index, waste recycling and utilization (WR), the indicators WR_1, WR_7, and WR_8 are the main contributors to principal component 1, while WR_3, WR_4, and WR_5 are among contributors to principal component 2. The indicators WR_2 and WR_6 make weak contributions (see Table 2B, columns 1 and 2). In case of collected waste (CW) all the four indicators CW_1 through CW_4 contribute to the sub-index. The same is applied to the sub-index of emission of air pollutants (EAP) where all three indications EAP_1 through EAP_3 are found to contribute to the sub-index's two principal components. In the case of infrastructure and mechanism and culture (IMC) all seven indicators jointly contribute to the sub-index's three principal components. The waste tax sub-index (WT) also benefits from all the five indicators. The sub-indices investment and waste management (IWM) and clean transport (CT) have one principal component each where four of the five; and three of the three indicators are contributors respectively. The last sub-index renewable energy (RE) gains from all its five indicators. In total only three of the 40 indicators make a weak contribution to the eight sub-indices which is an indication of the indicators' relevance. Most of the indicators make positive contributions to the level of different sub-indices, while a few indicators such as WR_5, IMC_2, CT_3, and RE_4 have negative effects. A few indicators have inconclusive positive effects and negative effects through different principal components (that is, EAP_3, WT_5, and RE_5).

When looking at the aggregate CEI, which is based on 11 principal components, only 16 indicators contributed below the threshold eigenvalue of 0.30, but most of their eigenvalues were in the interval 0.20–0.30. Again, in this case the relevance of the 40 indicators is confirmed.

5.2. A Municipality's performance heterogeneity

Using the PCA method, the average aggregate CEI and its eight disaggregate sub-indices for the 273 Swedish municipalities for the period 2012–18 were calculated. The index and its sub-index components are observation specific, normalized, and relative to the municipality with the best performance. In Appendix Table A,[4] the sample municipalities are ranked in descending order based on their CEI index. The results show that the municipalities of Gotland, Härjedalen, Mörbylånga, Gällivare, Tanum, Öckerö, Strömstad, Sotenäs, Borgholm, and Åsele were the 10 best performing municipalities in CEI. Of all the municipalities studied, 23 percent had CEI more than 50. An index value of 50 represent 50 percent efficiency compared to the most efficient municipality. It is noteworthy that these municipalities are geographically located in less densely populated regions. Coastal municipalities in Sweden performed better in CEI than those located on the inner land.

Stockholm, Uppsala, Burlöv, Botkyrka, Sollentuna, Lidköping, Danderyd, Huddinge, Linköping, and Solna were the 10 poorest performing municipalities in CEI. This could indicate that the conditions for

[4] In order to conserve spaces the Appendix A is not included but it is available upon request from the authors.

Table 2A
Principal component analysis.

Variable	Eigenvalue[a]	Proportion[b]	Cumulative [c]	Variable	Eigenvalue	Proportion	Cumulative
A. Index components:				B. Overall composite CE index			
1. Waste recycling and utilization (WR)				PC(1)	6.02	0.15	0.15
PC(1)	2.95	0.37		PC(2)	3.61	0.09	0.24
PC(2)	1.85	0.23	0.60	PC(3)	3.34	0.08	0.32
2. Collected waste (CW)				PC(4)	2.12	0.05	0.37
PC(1)	1.29	0.32		PC(5)	1.93	0.05	0.42
PC(2)	1.03	0.26	0.58	PC(6)	1.82	0.04	0.46
3. Emission of air pollutants (EAP)				PC(7)	1.48	0.04	0.50
PC(1)	1.13	0.38		PC(8)	1.39	0.03	0.53
PC(2)	1.01	0.34	0.71	PC(9)	1.34	0.03	0.56
4. Infrastructure, Mechanism and culture (IMC)				PC(10)	1.23	0.03	0.59
PC(1)	1.76	0.25		PC(11)	1.11	0.03	0.62
PC(2)	1.38	0.20	0.45				
PC(3)	1.01	0.14	0.59				
5. Waste tax (WT)							
PC(1)	2.20	0.44					
PC(2)	1.20	0.24	0.68				
6. Investment and waste management cost (IWM)							
PC(1)	2.79	0.56	0.56				
7. Clean transport (CT)							
PC(1)	1.42	0.47	0.47				
8. Renewable energy (RE)							
PC(1)	1.75	0.35					
PC(2)	1.01	0.20	0.55				

[a] Eigenvalue shows a partitioning of the total variation accounted for each principle component (PC).
[b] Proportion indicates the proportion of variance explained by each eigenvalue.
[c] Cumulative indicates the cumulative proportion of the variance is accounted by the current and all preceding principal components. If the jth component retain over 90% original information, it is usually recommended to retain j component.

municipalities to achieve higher circular economy are particularly bad in Stockholm county relative to other less populated regions of the country. The municipalities' ranks are highly and negatively correlated with their population and location. Municipalities with large populations and located in central and south Sweden performed worse in circular economy's implementation.

5.3. County performance heterogeneity

In Table 3 we rank the 21 counties based on their level of CEI. As demonstrated in this table and Fig. 1, Gotland, Jämtland, Norrbotten, Kalmar, and Västerbotten are ranked the best counties for their performance in implementing the circular economy. However, Stockholm, Jönköping, Örebro, Blekinge, and Öster Götland are ranked 21 to 17 and are among the worst circular economy performing counties in Sweden.

The highest/lowest contributing sub-components of a county's CEI rank are: waste recycling and utilization (Gotland/Stockholm), collected waste (Västmanland/Stockholm), emission of different air pollutants (Kronoberg/Gotland), infrastructure and mechanism and culture (Gävleborg/Stockholm), waste tax (Gotland/Västernorrland), investments and waste management costs (Gotland/Dalarna), clean transport (Gotland/Stockholm), and renewable energy (Halland/Västerbotten).

Some counties exceeded environmental quality standards for PM_{10} (corresponding to EU's threshold values) and NO_2 (corresponding to Swedish environmental quality standards). $PM_{2.5}$ concentrations are relatively low in the country and the EU threshold value is not exceeded anywhere in Sweden. We found that the highest concentration of different air pollutants (including PM2.5) were in southern Sweden especially in Kronoberg, Skåne, and Jönköping due to long-range transboundary transport air pollution (see Fig. 4).

5.4. Improvements in CEI over time

In Table 4 and Fig. 2, we present the variations in aggregate CEI and its different sub-components over the study period for the whole country. CEI increased from 40.93 in 2012 to 44.59 in 2018 at a growth rate of 9.7 percent over 7 years at an average annual growth rate of 1.3 percent. The investment and waste management costs (IMW) and waste tax (WT) continuously increased over time, while quantities of waste generated and collected waste (CW) decreased during 2012–18 leading to improved environmental standards. The clean transportation index (CT) decreased from 54.33 in 2012 to 47.14 in 2015 and then increased again to 53.17 in 2018. Waste recycling and utilization (WR) and renewable energy (RE) had almost the same trends and reached their peak levels in 2017. Emission of air pollutants (EAP) increased during 2012–16 and reached 57.73 and remained below this level till 2018. Infrastructure and mechanism and culture (IMC) remained constant over time.

It is worth mentioning that most of the indicators used in the computation of the indices are measured in per inhabitants of municipalities but the indices are not adjusted for the growth effect in the size of economy. Thus, the yearly changes in per capita and per unit of goods and services or their values should increase over time.

The CE index of six major municipalities (Stockholm, Gothenburg, Uppsala, Vasterås, Örebro, and Linköping) are presented in Fig. 3. It is obvious that Vasterås had the best CE performance, which was much better than the other five large municipalities. Stockholm had the worst CE performance during the study period. The CE indices of Örebro in 2015 and 2016 were lower than Gothenburg's CE indices. Uppsala's CE index decreased from 2012 to 2017 and then increased in 2018. Linköping's CE index remained stable from 2012 to 2017 and then increased in 2018. Stockholm's CEI decreased between 2012 and 2015.

In Table 5 we show the correlation coefficients of the different sub-components of the circular economy and the aggregate CEI. CEI is positively and significantly correlated with all circular economy's sub-index components except IMC and RE. These correlation coefficients are relatively high for WT, IWM, and CT (0.61, 0.51, and 0.54 respectively). Various sub-indices are positively and mostly significantly correlated among themselves. The correlation table shows that the different sub-index components are related and strengthen or weaken each other in their effects. The correlated components could be considered to be merged but this is a disadvantage to loss within sub-indices and between sub-indices variations.

Table 2B
Loading factors (eigenvectors) of the indices.

		Comp1	Comp 2	Comp3		Comp1	Comp 2	Comp3	Comp 4	Comp 5	Comp 6	Comp 7	Comp 8	Comp 9	Comp 10	Comp 11
WR	WR_1	0.53	0.18		CEI	−0.13	0.41	0.10	0.03	0.14	0.07	−0.22	−0.09	0.04	0.16	0.02
	WR_2	0.25	0.03			−0.13	0.24	−0.13	0.16	−0.21	−0.16	0.00	0.09	−0.18	−0.32	0.07
	WR_3	0.23	−0.55			−0.26	−0.04	0.15	0.01	0.10	−0.04	−0.04	0.14	0.01	−0.01	−0.09
	WR_4	−0.17	0.47			0.21	0.06	−0.02	0.04	−0.14	0.10	0.22	−0.18	−0.05	0.16	0.01
	WR_5	0.18	−0.58			−0.28	−0.09	0.11	−0.05	0.06	−0.04	0.05	0.04	0.05	−0.04	−0.01
	WR_6	0.28	0.26			0.03	0.24	0.17	0.16	0.08	−0.04	−0.12	−0.14	0.08	0.25	0.08
	WR_7	0.53	0.18			−0.13	0.41	0.10	0.03	0.14	0.07	−0.22	−0.09	0.04	0.16	0.02
	WR_8	0.42	0.09			−0.12	0.33	0.08	0.04	0.05	−0.04	−0.09	−0.02	0.00	0.04	−0.01
CW	CW_1	0.69	−0.09			0.02	0.11	0.10	0.19	−0.28	0.12	0.08	−0.22	−0.13	0.07	0.13
	CW_2	0.30	−0.05			0.04	−0.25	0.15	0.41	−0.20	−0.20	−0.18	−0.03	0.23	0.07	0.02
	CW_3	0.63	0.38			0.16	0.06	0.08	0.07	−0.22	0.15	0.20	−0.01	0.01	0.08	0.29
	CW_4	−0.18	0.92			0.13	0.00	−0.10	−0.02	0.12	0.09	−0.12	0.02	0.28	−0.18	−0.20
EAP	EAP_1	0.72	0.10			0.00	−0.11	0.14	−0.27	−0.10	−0.01	0.05	0.04	−0.27	0.35	−0.02
	EAP_2	0.20	0.92			0.11	0.07	0.03	−0.01	−0.19	0.03	−0.07	0.35	−0.04	0.26	0.21
	EAP_3	−0.67	0.38			0.17	0.04	0.10	0.27	0.33	−0.23	0.11	0.13	−0.08	−0.05	0.04
IMC	IMC_1	0.01	−0.06	0.96		−0.03	−0.02	0.11	−0.08	−0.03	0.09	0.10	−0.07	0.00	−0.25	0.64
	IMC_2	0.38	−0.41	0.13		−0.23	0.03	0.06	−0.01	0.08	0.10	0.10	−0.13	0.38	−0.02	0.13
	IMC_3	0.32	0.40	0.06		−0.01	0.07	−0.02	0.21	0.03	0.35	0.07	−0.07	0.08	−0.15	−0.07
	IMC_4	0.53	0.39	0.00		−0.04	0.07	−0.02	0.29	−0.05	0.34	0.34	0.20	−0.02	0.02	−0.20
	IMC_5	0.60	0.11	−0.06		−0.12	0.01	0.09	0.25	0.00	0.32	0.33	0.23	0.05	0.10	−0.15
	IMC_6	−0.25	0.52	−0.03		0.13	0.06	−0.20	0.12	−0.02	0.03	−0.17	−0.04	−0.17	−0.04	−0.06
	IMC_7	0.24	−0.49	−0.22		−0.15	0.03	0.15	−0.09	−0.01	−0.16	0.08	0.30	0.09	−0.02	−0.18
WT	WT_1	0.48	0.46			0.04	0.26	0.17	−0.07	−0.23	−0.18	0.15	−0.09	0.12	−0.17	−0.24
	WT_2	0.37	0.65			0.00	0.19	0.26	−0.01	−0.25	−0.24	0.09	−0.19	−0.07	−0.10	−0.20
	WT_3	0.54	−0.26			0.19	0.12	0.07	−0.16	−0.13	−0.20	0.27	0.10	0.28	−0.09	−0.08
	WT_4	0.47	−0.44			0.21	0.17	0.02	−0.24	0.01	−0.06	0.19	0.12	0.37	0.02	0.13
	WT_5	0.34	−0.34			0.24	0.09	0.07	−0.01	−0.05	−0.13	−0.02	0.34	−0.25	0.12	−0.07
IWM	IWM_1	0.26				0.10	−0.06	0.15	−0.06	0.07	0.00	−0.03	−0.01	0.07	−0.25	0.14
	IWM_2	0.54				0.11	−0.05	0.43	−0.02	0.12	0.12	−0.04	0.02	−0.16	−0.25	0.03
	IWM_3	0.52				0.10	−0.04	0.43	−0.01	0.11	0.11	−0.05	0.03	−0.20	−0.22	0.00
	IWM_4	0.38				0.22	−0.16	0.18	−0.16	0.17	0.13	0.01	−0.15	0.21	0.24	−0.10
	IWM_5	0.47				0.20	−0.07	0.31	0.00	0.09	0.12	−0.05	−0.14	−0.03	0.12	−0.16
CT	CT_1	0.60				0.14	0.07	0.08	−0.08	−0.21	0.26	−0.33	0.24	0.10	−0.19	−0.04
	CT_2	0.49				0.10	0.13	−0.02	0.10	0.13	−0.06	−0.11	0.37	0.17	0.13	0.25
	CT_3	−0.63				−0.28	−0.11	0.18	−0.08	−0.02	−0.14	0.12	0.10	−0.04	0.17	0.07
RE	RE_1	0.48	0.21			−0.21	−0.04	0.14	0.04	0.09	0.03	−0.02	0.10	−0.10	−0.09	0.02
	RE_2	0.05	0.86			0.04	−0.25	0.15	0.41	−0.20	−0.20	−0.18	−0.03	0.23	0.07	0.02
	RE_3	0.58	0.11			−0.26	−0.06	0.10	0.04	0.00	0.01	0.05	0.12	0.10	0.04	0.07
	RE_4	−0.57	0.14			0.25	0.06	−0.07	0.15	0.30	−0.06	0.01	0.11	−0.03	−0.12	−0.04
	RE_5	−0.31	0.42			0.06	0.05	−0.04	0.19	0.35	−0.28	0.35	−0.15	−0.09	0.04	0.12

Note: The literature refers to eigenvectors greater than 0.30 as major contributors to an index component.

Table 3
Circular Economy Index (CEI) and its components of 21 counties in Sweden, 2012–2018.

Rank	Counties	CEI	WR	CW	EAP	IMC	WT	IWM	CT	RE
1	Gotland	**88.35**	76.71	24.24	15.16	72.47	51.91	27.32	71.88	45.19
2	Jämtland	**58.33**	39.57	36.89	62.80	67.47	43.50	23.11	66.26	47.71
3	Norrbotten	**54.85**	42.67	33.11	47.86	72.00	37.40	21.91	61.61	49.37
4	Kalmar	**51.43**	42.94	33.01	54.06	72.15	40.97	11.28	53.71	65.65
5	Västerbotten	**50.62**	36.53	31.43	57.17	68.02	34.79	17.31	60.57	44.72
6	Värmland	**44.62**	32.02	31.50	54.17	74.44	37.36	17.47	52.32	58.27
7	Skåne	**44.39**	59.99	31.15	55.91	72.60	45.59	16.02	50.82	68.00
8	Västernorrland	**43.89**	35.08	29.96	49.96	71.27	28.01	9.16	54.86	54.57
9	Kronoberg	**43.08**	34.21	30.88	63.11	69.17	34.76	17.92	48.60	67.92
10	Södermanland	**42.42**	48.80	29.27	56.51	73.20	41.29	9.29	43.78	68.68
11	Uppsala	**42.34**	41.88	29.98	59.59	73.07	39.79	10.77	44.98	59.38
12	Gävleborg	**42.13**	40.15	33.96	53.61	75.16	29.20	4.64	57.78	60.86
13	Västmanland	**41.05**	44.84	38.63	53.68	71.89	43.59	8.95	51.24	63.13
14	Dalarna	**41.00**	51.96	33.16	51.08	72.20	38.60	2.20	55.57	53.50
15	Västra Götaland	**38.81**	39.87	29.81	58.99	72.55	34.08	15.58	47.76	68.05
16	Halland	**38.06**	38.40	35.64	56.19	72.84	32.68	14.82	52.30	74.31
17	Östergötland	**37.82**	39.25	26.29	53.81	73.27	35.03	12.62	49.47	67.46
18	Blekinge	**37.53**	67.33	28.00	44.57	73.91	39.89	5.99	49.66	67.09
19	Örebro	**37.17**	40.65	27.05	50.86	69.84	30.32	11.06	49.20	60.94
20	Jönköping	**34.04**	38.26	27.81	62.82	72.87	31.61	10.03	48.95	65.46
21	Stockholm	**29.50**	29.57	21.75	61.74	67.47	36.95	10.85	41.59	71.98

5.5. *Determinants of the circular economy in Sweden*

The model in equation (1) containing possible determinants of CE is estimated using the fixed effects estimation method (see Table 6). A fixed effects model is preferred to a random effects model because the sample of municipalities is almost the same as the population of the

Table 4
Mean CEI and its components over time.

Year	CEI	WR	CW	EAP	IMC	WT	IWM	CT	RE
2012	**40.93**	40.68	31.77	55.95	73.00	34.36	12.96	54.34	63.08
2013	**40.82**	40.51	30.98	55.20	71.80	35.46	12.22	51.94	63.04
2014	**41.48**	43.32	30.66	56.39	72.71	36.44	12.35	49.57	62.22
2015	**40.96**	42.94	29.76	56.94	70.22	36.68	12.67	47.15	62.51
2016	**41.81**	43.25	29.74	57.74	70.71	38.16	13.41	49.06	63.77
2017	**42.39**	43.59	29.88	56.72	71.43	38.99	14.34	51.96	64.79
2018	**44.59**	41.44	28.89	54.59	72.03	40.19	15.41	53.17	63.31

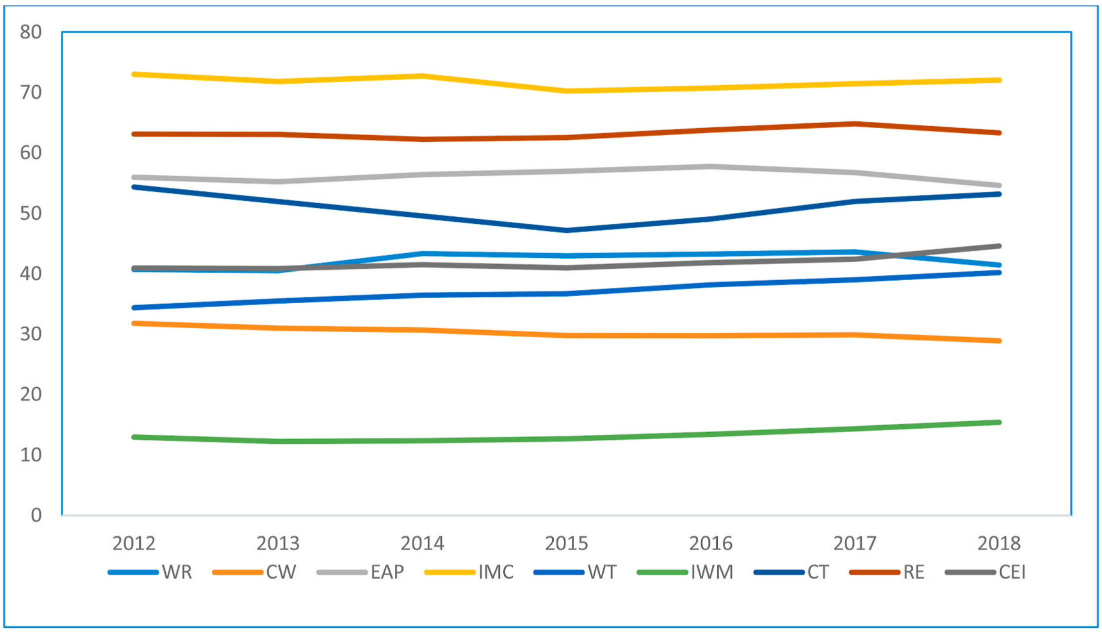

Fig. 2. Development of mean CEI and its sub-index components over time.

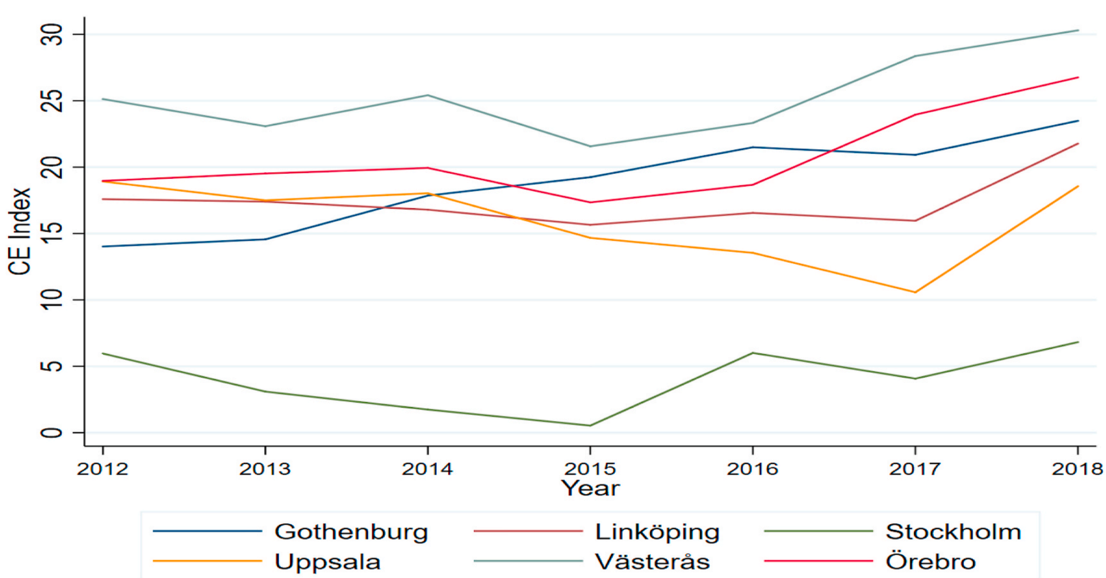

Fig. 3. Level and development of CEI in major cities in Sweden.

municipalities. The Hausman test confirms that our assumption of correlated determinants and municipality effects is correct. The fixed effects model has 12 statistically significant determinant variables of expected signs explaining variations in the composite circular economy index. Tourism revenue is found to be insignificant. For a sensitivity analysis of the results, the model is also estimated with pooled OLS ignoring an individual municipality's heterogeneity effects. Despite both models being estimated with robust standard errors, the pooled

Rank	Counties	CEI
1	Gotland	88.35
2	Jämtland	58.33
3	Norrbotten	54.85
4	Kalmar	51.43
5	Västerbotten	50.62
6	Värmland	44.62
7	Skåne	44.39
8	Västernorrland	43.89
9	Kronoberg	43.08
10	Södermanland	42.42
11	Uppsala	42.34
12	Gävleborg	42.13
13	Västmanland	41.05
14	Dalarna	41.00
15	Västra Götaland	38.81
16	Halland	38.06
17	Östergötland	37.82
18	Blekinge	37.53
19	Örebro	37.17
20	Jönköping	34.04
21	Stockholm	29.50

Map. 1. Location of counties in Sweden and their rank.

Table 5
Correlation among the index components, n = 1911 obs.

	CEI	WR	CW	EAP	IMC	WT	IWM	CT	RE
CEI	1.000								
WR	0.232[a]	1.000							
CW	0.436[a]	0.010	1.000						
EAP	0.052	−0.062[a]	0.059[a]	1.000					
IMC	−0.077[a]	0.102[a]	0.124[a]	−0.050	1.000				
WT	0.615[a]	0.306[a]	0.207[a]	0.096[a]	−0.125[a]	1.000			
IWM	0.506[a]	−0.091[a]	0.215[a]	0.095[a]	−0.062[a]	0.224[a]	1.000		
CT	0.542[a]	0.107[a]	0.295[a]	0.020	0.010	0.159[a]	0.181[a]	1.000	
RE	−0.504[a]	−0.051	−0.123[a]	0.020	0.083[a]	−0.168[a]	−0.055	−0.455[a]	1.000

[a] Significance at less than 1% level.

OLS method's results may be biased as it ignores individual heterogeneity effects. The two models explain more than 50 percent of the variations in CEI. The joint F-test statistics also confirm the non-zero effects' relevance of the explanatory variables.

There is a minor difference in the estimated effects between the fixed effects and pooled OLS estimation methods. The cost of education and unemployment have unexpected effects in the pooled OLS model. The variables' revenue from tourism business is not significantly different from zero in the fixed effects model. Unemployment is significant and relates negatively to the circular economy interpreted as the lower the unemployment rate, the higher the level of the circular economy. According to the theory of private provision of public goods and services, unemployment decreases the extent of pro-environmental behavior which requires monetary contributions. A 1 percent increase in unemployment reduces the CEI index by 0.23 percent.

As expected, the relation between commuting to the municipality and the circular economy is significant and negative. Commuting is linked to environmental problems like poor air quality, poor water quality, and damaged soil. According to a report by the Swedish Agency for Transport Policy Analysis (2013), major commuter flows are in the

Table 6
Pooled and Fixed Effects estimation results, Dependent variable CEI, n = 1911 obs.

	Variable definition	Pooled OLS Coef.	Pooled OLS Robust Std. Err.	Fixed Effect Coef.	Fixed Effect Robust Std. Err.
	Intercept	15.1628***	2.8933	15.6544***	2.8794
UNEMP	Unemployment 18–64 years, %	0.1934**	0.1051	−0.2280**	0.1526
GRP	Gross regional product (BRP), SEK/inhabitant	0.0000***	0.0000	0.0000***	0.0000
COMM	Commuting to the municipality, %	−0.2716***	0.0219	−0.2092*	0.1275
REVE	Revenue from tourism business, SEK/inhabitant	0.0055***	0.0014	0.0004	0.0025
TINV	Total investment expenditure, SEK/ inhabitant	0.0004***	0.0001	0.0001*	0.0000
RESID	Residents per square kilometer	−0.0019***	0.0006	−0.0106***	0.0047
EDUCO	Cost of educational activities, SEK/ inhabitant	−0.0003***	0.0001	0.0002***	0.0000
ENER	Consumer and energy costs, SEK/ inhabitant	0.0124***	0.0050	0.0051*	0.0045
ASYL	Asylum seekers	−0.0059***	0.0005	−0.0011***	0.0004
WTAX	Common waste tax for single and two family houses	0.0097***	0.0005	0.0082***	0.0007
WCOL	Charge for waste collection incl. VAT, SEK/m2	0.8876***	0.0448	0.4984***	0.0910
F-value		199.4		70.08	
R^2 adj		0.5333			

Note: ***,** and * indicate significant at less than 1%, 5% and 10%, respectively. Robust standard errors.

Stockholm region. Gothenburg is strongly dominant as a work commuting destination and its labor market is characterized by monocentricity. A 1 percent increase in the number of commuters reduces CEI by 0.21 percent. Residents per square kilometer (population density) as a proxy for the degree of urbanization has a significant and negative relation to CE. Large municipalities with high population densities have increased demand for energy and water resources which will pose challenges in the management of increased solid waste and air and water pollution. An increase in population density with 100 persons per square km will reduce CE by 0.31 units.

The significant and positive impact of the cost of educational activities on CE shows that education can equip all ages, in particular the youth, with the knowledge, skills, and mindset required for making a system that works for the economy, society, and the environment. The same positive relation with CE holds for aggregate municipality investments in infrastructure. This study found a significant and negative relationship between the number of asylum seekers residing in each municipality and their effect on the circular economy. This reflects that lower education, skills, and concerns for environment in their home countries are different from those among local Swedish residents. Pollution of water resources, soil erosion, deforestation, and lack of public transportation are among the most significant problems associated with refugee-affected areas. During recent decades, Sweden has been one of the countries that has received the most number of migrants as a share of its population and today one-fifth of the Swedish population has been born abroad (Sweden Population Statistics, 2017).

This study tested the nexus between charge for waste collection and application of the most common waste tax and the circular economy in Sweden. The coefficient of charge for waste collection showed that this variable significantly and highly increased the level of CE in Sweden. An increase in charges for waste collection per cubic meter waste increased CE by 0.50 units. A common waste tax for single and two-family houses also increased CE. The relation between common waste tax and CE is positive as expected. A high level of gross regional product per capita is conductive for municipalities' CE.

6. Summary and conclusion

This study assessed the current state of development of the circular economy in Sweden. It had several objectives. First, it introduced a standard for a circular economy that is multidimensional and covers different aspects of material use, reuse, and recycle at the municipality level. The index is composed of eight components covering the areas of waste collection, waste recycling and utilization, emission of air pollutants, infrastructure, mechanism and culture, waste tax, investment and waste management costs, clean transport, and renewable energy. Second, it estimated a composite index that is in line with the important principles of a circular economy. Third, the index was used for evaluating the practice of the circular economy at the municipality level. More specifically, it included the management of residues in both urban and rural areas covering all sectors of the economy. The empirical analysis was based on a population of 273 municipalities in Sweden observed during the period 2012–18. We investigated how the general environmental and circular economy conditions have developed during recent years. Fourth, municipalities and counties were ranked by their performance in adapting the circular economy. The temporal development of their performance was also analyzed. Finally, in a separate stage the circular economy index was regressed on a number of indicators that influenced the level and development of a circular economy.

The key research findings include:

- From the regional point of view, our results show that there are significant differences between the Swedish municipalities in CE and its sub-components. Some of these differences are due to geographical conditions, population density, concentration of industries, and investment programs in the circular economy's infrastructure.
- At a disaggregate level, the municipalities of Gotland, Härjedalen, Mörbylånga, Gällivare, and Tanum performed well in CEI. In contrast, Stockholm, Uppsala, Burlöv, Botkyrka, and Sollentuna municipalities had the lowest ranks in CEI.
- At a more aggregate level, Gotland, Jämtland, Norrbotten, Kalmar, and Västerbotten counties were ranked the best performing in circular economy. However, Stockholm, Jönköping, Örebro, Blekinge, and Västergötland were among the worst performing counties in Sweden.
- CEI and most of its components improved during the study period 2012–18. CEI had a growth rate of 9.7 percent over 7 years at an average annual growth rate of 1.3 percent. This continuous improvement in environmental quality suggests that the goals can be achieved by 2030.

In the second part of the paper, we identified the determinants of the variations in the CE index. A number of determinants were identified and their effects estimated. The fixed effects estimation results showed that unemployment was significant and negatively related to the circular economy. The relation between commuting to-from the municipality and the circular economy was also negative. This study found a significant negative relationship between asylum seekers residing in each municipality and its circular economy. We found a significant positive relation between cost of educational activities and CE. The variable charge for waste collection significantly and highly increased the level of CE in Sweden. The relation between common waste tax and CE was also positive as expected.

Using these results, municipal governance can make better strategic decisions based on various indices for improving their environmental quality. The central government can also provide incentive programs to enable the municipalities individually and jointly to achieve the sustainable development goals. The incentive programs can target wider application of technologies and policies employed by best performing municipalities and by supporting the transfer of knowledge and resources for strengthening municipalities that have a weak performance. The government should promote investments in public education via information campaigns on the circular economy. In addition, Sweden should lower taxes for the labor force employed by remanufacturing, repairing, and reusing businesses. Future studies can investigate the association between the level of industrialization in the different municipalities and the CEI index. Further, future research should also be devoted to the development of a CE business model in Sweden.

CRediT authorship contribution statement

Almas Heshmati: Methodology, Supervision, Writing- Reviewing and Editing. **Masoomeh Rashidghalam:** Software, Data collection, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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