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Mapping Circular Economy Innovation in Europe: A Patent Analysis Using Advanced Natural Language Processing Models

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The circular economy (CE) paradigm has recently gained increasing attention in both academic and policy circles. Existing literature has stressed that the transition to the CE paradigm implies innovation aiming to change consumption and production behaviors and technologies. Empirical studies have focused on the drivers and effects of the adoption and generation of CE innovations, based on survey and patent data, respectively. However, identifying and tracking CE innovations through patents has been challenging due to the lack of a domainspecific classification system. Existing methods are often insufficient to capture the diversity and complexity of CE technologies. This paper proposes a novel methodology for the identification and classification of CE-related patents, combining large language models (LLMs), pre-trained language models (PLMs), and topic modelling techniques. By applying these methodologies to patent data, we uncover significant trends in the distribution of CE patents in sectors, technological fields, and geographical regions. Our exploratory findings highlight a growing cross-sector engagement with CE principles, underscoring the transformative potential of circular economy innovations in driving sustainable industrial practices. This paper contributes to advancing the classification and understanding of CE innovations, offering valuable insights to policymakers, researchers, and industry stakeholders.

Keywords: Circular Economy; Patents; BERT; Large-Language Models.

JEL Classification: O33.

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1 Introduction

In recent decades, the debate about circular economy (CE) has gained momentum, as it represents a promising alternative to the traditional linear model of "take, make, and dispose" [Barros et al., 2020]. Increasing environmental concerns, supportive global policies, technological advancements and emerging business opportunities are the main factors driving this growing interest, as the world faces resource depletion, waste accumulation and climate change [Geissdoerfer et al., 2017, Nikolaou et al., 2021].

CE can be defined as an industrial system intentionally designed to be restorative or regenerative, focusing on renewable energy use, elimination of toxic chemicals that hinder reuse, and waste reduction through innovative design in materials, products, systems, and business models [Ellen MacArthur Foundation, 2013]. Unlike linear models that prioritize resource consumption, it highlights the crucial role of environmental sustainability by improving resource management [Yuan et al., 2006] and allowing the decoupling of economic growth from resource consumption [Bocken et al., 2016, Wijkman and Berglund, 2017, Kjaer et al., 2019].

Exploring CE through the lens of innovation economics offers valuable insight into how transformative innovations can drive economic development while ensuring environmental sustainability and resource efficiency [Stankevičienė and Nikanorova, 2020]. Building on Schumpeter's theory of economic development, which identifies innovation as the main force behind economic progress and global competitiveness [Schumpeter, 2017], integrating CE principles into the eco-innovation economic framework could provide a theoretical basis for understanding the economic mechanisms and incentives that promote the development of circular solutions [de Jesus and Mendonça, 2018, Grafström and Aasma, 2021]. This approach is particularly relevant in contexts where environmental sustainability has become a critical policy imperative [Hobson and Lynch, 2016, Fratini et al., 2019, Campbell-Johnston et al., 2020].

In view of the relevance of innovation in achieving the transition to CE, a growing number of empirical studies have investigated the determinants and effects of both the adoption and generation of CE innovations, using different measurement approaches. On the one hand, studies focusing on adoption have exploited information drawn from ad hoc surveys to gain information on firms' actual decisions to change their business models, suppliers, raw materials, or product and process technologies to align with the pillars of the CE paradigm [Ren and Albrecht, 2023, Antonioli et al., 2022a,b, Quatraro and Ricci, 2023, Segarra-Blasco et al., 2024]. On the other hand, the focus on innovation generation has largely dealt with CE technologies, exploiting patent data as the main source of information [Fusillo et al., 2024, Valero-Gil and Scarpellini, 2024, Rainville et al., 2025].

One of the problems that scholars have faced in tracking CE patents, and thus circular innovation technologies, lies in the absence of a CE domain-specific classification. The methods used so far rely primarily on either keyword retrieval approaches or on either the Cooperative Patent Classification (CPC) or the International Patent Classification (IPC). However, both approaches have significant limitations that hinder their effectiveness in capturing the full scope of CE innovations. The keyword retrieval method, in particular, faces challenges due to the inherent heterogeneity of CE technologies, which span a wide range of sectors and processes, making them difficult to define within a single framework [Burger et al., 2019]. Furthermore, patent abstracts typically focus on describing the technical aspects of an invention, rather than its alignment with broader environmental goals, such as in this case circularity [Terragno, 1979]. Keywords can be too broad or vague, leading to the inclusion of irrelevant patents, or too narrow, excluding key innovations that align with CE principles but use non-standard terminology [Hambarde and Proença, 2023]. This misalignment between the technical descriptions in patents and the terminology used to describe CE principles creates gaps in patent identification, resulting in an incomplete understanding of the innovations driving the transition to CE. The other approach used most often for the identification of CE patents is based on CPC or IPC classification [Nikolova-Minkova, 2023, Eurostat, 2022, Fusillo et al., 2024, Caldarola et al., 2024]. This system categorizes patents based on technical domains, but is not designed for emerging fields like CE. The patent class more closed to CE topics is the Y02W, related to "Climate Change mitigation technologies related to wastewater treatment or waste management", still it does not include different aspects related to CE, such as optimization practices, resource efficiency, and design for reuse or remanufacturing.

Given the shortcomings for both keyword retrieval and CPC/IPC classification approaches, a more refined and specialized classification system is needed that accurately captures the nuances of circular economy innovations. Such a system would facilitate a more precise tracking of CE technologies, offering deeper insights into the development of sustainable innovations and their contributions to economic transformation. This paper aims to address this gap by proposing a novel classification framework tailored specifically to CE-related patents, enhancing our ability to monitor and analyze innovation patterns in the circular economy.

The paper is organized as follows. After the introduction, which outlines the context and objectives of the study, the literature review synthesizes existing circular economy (CE) frameworks and identifies key methodologies for detecting CE principles in patents. In the following section, the paper details the data and methodology used for the classification and identification of CE patents. The methodology consists of a two-step approach: first, a binary classification of patents using large language models (LLMs), including GPT-3.5-turbo-16k and BERT for Patents, to identify CE-related patents; and second, the identification of CE subclasses using topic modeling techniques through which CE patents are classified into specific topics. The results section presents a comprehensive analysis of the CE patents identified, providing insights into their distribution across various dimensions, temporal trends, geographical patterns, and sectorial contributions. In the last section of the results, the correlation between CE patents and the quality indicators identified by the OECD is investigated. Finally, the conclusion summarizes the key findings and discusses the implications of the results for researchers and practitioners in the field of circular economy, offering recommendations for future research and potential policy applications.

2 Literature Review

2.1 Innovation, new technologies and the CE transition

While the origins of the Circular Economy concept can be dated back to the second half of the 1900s, the debate around it gained momentum only a decade ago in policy circles. Environmental and industrial policies have hence substantially neglected the issue of resource depletion and waste production for a long time, leaving production and consumption activities to evolve along a trajectory marked by the *take-make-dispose* paradigm.

In this linear model, natural resources are extracted, transformed into products, and ultimately discarded, with minimal consideration for reuse or regeneration [Ellen MacArthur Foundation, 2013, Stahel, 2016]. The persistence of such linear economic models is largely explained by path dependency and technological lock-in [Arthur, 1989, Stack and Gartland, 2003, Boschma, 2007]. Path dependency describes how historical choices shape technological trajectories, often reinforcing inefficient or unsustainable practices over time Arthur [1989]. Similarly, technological lock-in occurs when dominant designs and established industrial ecosystems hinder the adoption of alternative, more sustainable technologies, making it challenging for circular innovations to emerge and scale [David, 1985, Unruh, 2002].

Growing policy emphasis on sustainability and circularity has played a crucial role in breaking these entrenched patterns and promoting CE adoption. Governments and international organizations have introduced regulations, financial incentives, and strategic frameworks that encourage industries to transition toward more sustainable practices [Geissdoerfer et al., 2017, Kirchherr et al., 2017]. Examples include the European Union's Circular Economy Action Plan and national policies targeting waste reduction, extended producer responsibility, and eco-design principles [European Commission, 2020b]. Multi-stakeholder engagement is also key to fostering CE innovation, as collaboration across industries, policymakers, and consumers ensures that economic, social, and environmental considerations are integrated, reducing resistance to change and enhancing the effectiveness of circular strategies [Blomsma et al., 2019].

Innovation is central to overcoming lock-in effects and accelerating the CE transition. Firms can adopt new technologies and business models that enhance resource efficiency, minimize waste, and enable circular material flows [Rennings, 2000]. Eco-innovation, defined as innovation that reduces environmental impacts while enhancing economic performance, is closely linked to CE since it promotes sustainable resource use, pollution reduction, and system-wide efficiency gains [OECD, 2010, Kemp, 2010, de Jesus and Mendonça, 2018]. By embedding CE within eco-innovation frameworks, firms can leverage synergies between environmental sustainability and economic growth, ensuring that CE-driven transformations are both viable and scalable [Carrillo-Hermosilla et al., 2010].

In summary, the transition to a circular economy necessitates a departure from established linear economic frameworks through innovation, policy support, and collaboration among multiple stakeholders. Despite the challenges posed by path dependency and technological lock-in, focused policies, advancements in technology, and eco-innovation provide promising avenues to promote circularity. The forthcoming section will examine the methodologies employed by researchers to identify and quantify circular economy innovation, evaluating their respective strengths and limitations.

2.2 Technologies for CE: measurement challenges for a multi-dimensional concept

In recent decades, scholars have provided several definitions of CE [Bocken et al., 2016, Geissdoerfer et al., 2017, Kirchherr et al., 2017, Ghisellini et al., 2018, Nobre and Tavares, 2021, Figge et al., 2023]. Kirchherr et al. [2017] stresses that the main challenge in establishing a universally accepted definition of CE stems from its inherent complexity and its multifaceted nature, which encompasses various dimensions - economic, social, and environmental. Bocken et al. [2016] and Geissdoerfer et al. [2017] highlight that the primary reason for this complexity lies in the multidisciplinary aspect of the CE concept, which can be viewed through lenses ranging from waste management to sustainable business practices, through efficiency and optimization methods, each providing a distinct focus that influences how the concept is understood and implemented. In addition to the diverse definitions of CE, scholars have also developed various operational frameworks to describe its principles. One of the most widely recognized is the 3R framework (Reduce, Reuse and Recycle), which provided the foundational basis for understanding CE practices [King et al., 2006, Kirchherr et al., 2017].

This framework has evolved significantly over time, adapting to several variations [Sihvonen and Ritola, 2015, Kirchherr et al., 2017]: the Directive on the European Union Waste Framework introduced a fourth R (Recover) [European Commission, 2008], while other scholars have expanded this further, proposing 5R [Reike et al., 2018], 6R [Sihvonen and Ritola, 2015], 9R [Buren et al., 2016] or even 10R frameworks [Potting et al., 2017]. Another important model, the ReSOLVE framework, builds on similar principles, categorizing the key interventions needed for the transition to a CE: "Regenerate, Share, Optimize, Loop, Virtualize, and Exchange" [Kouhizadeh et al., 2020]. The Ellen MacArthur Foundation differentiates instead between core CE strategies directly related to material flow and enable elements, aimed at removing obstacles to the implementation of the firsts [Ellen MacArthur Foundation, 2013].

Considering the complexities inherent in the definition of CE, the development of a classification methodology capable of handling its heterogeneity thus appears to be a significant challenge. As highlighted, scholars have primarily employed two strategies to identify CE patents: the keyword approach on the one hand, and the use of CPC/IPC codes on the other. The first strategy, the keyword approach, relies on targeted keyword searches to identify CE-related documents based on specific terms associated with circular economy concepts. For example, Fontana et al. [2021] apply this methodology to identify academic papers related to CE, as well as de Jesus and Mendonça [2018], Okorie et al. [2018], Morales and Sossa [2020] and García-Valderrama et al. [2024]. de Freitas Juchneski and de Souza Antunes [2022] employ the keyword approach in patents, focusing on the intersection with electrical and electronic equipment. An enhanced variation of this methodology is employed by Spreafico et al. [2019], who perform syntactic analysis on sentences in documents retrieved through a search query involving terms such as "circular economy" along with related concepts, e.g. "recycle" paired with specific waste types. In a subsequent study, Spreafico and Spreafico [2021] propose a method to automatically extract information related to waste recycling and reuse from patents using syntactic analysis and word dependence patterns. Giordano et al. [2024] made a significant contribution to the identification of circular economy (CE) patents employing named entity recognition (NER) algorithms, as proposed by Giordano et al. [2021] and Bishop et al. [2022], to detect CE-related technologies. Although this approach represents an advance in automating the identification of CE innovations, the dataset on which the NER algorithm is applied was still selected using keyword retrieval methods, so subject to the limitations here discussed. Although the keyword retrieval approach is relatively straightforward and computationally efficient, it has two main limitations. The first is that, given the heterogeneity of the CE concept, it is difficult to capture it into a list of keywords. Relying on this strategy could easily lead to the inclusion of irrelevant patents or the exclusion of relevant ones that do not use standard CE terminology. Furthermore, patent abstracts focus on technical descriptions, often using highly specialized language, and for this reason the might often lack explicit CE references [Terragno, 1979, Hambarde and Proença, 2023].

The second common approach involves the use of CPC/IPC codes. In their work on the relationship between local knowledge bases and recombinant dynamics in CE technologies, Fusillo et al. [2024] use the 4-digit CPC code Y02W, related to "Climate change mitigation technologies related to wastewater treatment or waste management", to identify relevant patents. Caldarola et al. [2024] use both the 3-digit CPC code Y02 (namely, "Technologies or applications for mitigation or adaptations against climate change") and the 4-digit CPC code Y04S ("Information or communication technologies having an impact on other technology area") to identify patents dealing with the environmental sustainability topic. The Eurostat indicator on patents related to waste management and recycling is based on the Y02W CPC code, which includes "Technologies for wastewater treatment", "Technologies for solid waste management", and "Enabling technologies or technologies with a potential or indirect contribution to greenhouse gas [GHG] emissions mitigation" [Eurostat, 2022]. Then, different scholars used this indicator to study CE dynamics in Europe, such as Ilić et al. [2022], Mazur-Wierzbicka [2021], Bianchi and Cordella [2023], and Platon et al. [2023]. Moreover, to identify Environmentally sound technologies (EST), Nikolova-Minkova [2023] refer to eight IPC codes. The main advantage of using these classifications is the fact that they are a structured and standardized way of categorizing patents that are widely recognized [Bonaccorsi et al., 2019]. However, they are not specifically designed for emerging fields like CE, which could easily lead to misclassification, reducing the visibility of CE innovations.

Given these limitations, this study proposes an alternative methodology that goes beyond the conventional use of keywords and CPC/IPC codes. By addressing the challenges posed by CE's inherent heterogeneity and the specialized language of patent documentation, this approach aims to enhance the precision and reliability of CE patent identification. The proposed method seeks to capture a broader spectrum of CE-related innovations while minimizing misclassifications, offering a more comprehensive framework for tracking technological developments in the field.

3 Data and Methodology

3.1 Data

Regarding the selection of patents to be submitted to the LLM, the 2023 Spring Edition of PATSTAT is used. A subset of almost 150,000 patent abstracts is selected randomly, focusing on English abstracts with EU and US application authority. One patent abstract per family is selected to reduce the number of patents and make the training phase more computationally manageable. Among these, 21,310 were classified as related to CE by the LLM developed. Among the patents not belonging to the CE, 21,310 patents are selected: together with those classified as circular, they constitute the balanced dataset to be used to train the BERT for Patents model. The trained model is used to classify English patent abstracts, with application authorities either from EU, and application filing year from 2000 to 2019.

In order to improve the results of the LLM, a Retrieval-Augmented Generation (RAG) technique is implemented. As will be described in the methodological paragraph, RAG is a machine learning technique that combines retrieval-based and generation-based models to improve the accuracy and relevance of the output generated by an LLM [Melz, 2023, Gao et al., 2024, Zhao et al., 2024]. It has been shown to be particularly effective in reducing LLM hallucinations and improving their performance and efficiency [Lewis et al., 2021, Izacard and Grave, 2021]. To effectively implement this technique, a set of 13 relevant documents is selected for retrieval as listed in Table A.1.

Regarding the OLS regression, four patent quality indicators proposed by the OECD Patent Quality Indicators database are used: generality, originality, radicalness, and a composite quality index[Squicciarini et al., 2013]. The control set is selected randomly among patents not classified as circular, with comparable application authority, earliest filing year, and technological sector.

3.2 Methodology

3.2.1 Using LLM and BERT for the identification and classification of CE patents

In recent years, the remarkable advancements in the field of NLP, particularly in PLMs and LLMs, have significantly impacted various research fields. By improving textual comprehension capabilities, these technologies have opened new avenues for research in innovation economics [Just, 2024]. The methodology outlined in this section uses these advances to more effectively identify and classify CE-related patents. NLP comprises a set of algorithms and techniques to analyze and extract grammatical structure and meaning from textual data [Chowdhary, 2020, Khurana et al., 2023]. Among the most advanced tools within NLP, there are PLMs and LLMs [Naveed et al., 2023].

LLMs are a special class of pre-trained language models (PLMs) obtained by scaling model size, pre-training corpus, and computation [Naveed et al., 2023]. They demonstrate 'emerging abilities' that allow them to achieve remarkable performance without any task-specific training [Brown et al., 2020, Wei et al., 2022, Liu et al., 2024]. This capability has made LLMs particularly valuable in scenarios where labeled data is scarce [Gilardi et al., 2023, Alizadeh et al., 2023], and in particular when pre-trained language models such as BERT or GPT-2 cannot be fine-tuned to downstream tasks [Devlin et al., 2019, Radford et al., 2019].

The methodology proposed in the following uses these tools to establish a novel classification framework for CE patents. It is structured into two main steps:

1. **Binary classification of patents**. In this step, patents are classified as related to CE principles or not through a two-phase process:
   (a) a sample of patent abstracts is classified as "CE-related" or "non CE-related" using the GPT-3.5-turbo-16k model developed by OpenAI;
   (b) the dataset generated serves as train set for fine-tuning the BERT for Patents model [Srebrovic and Yonamine, 2022], which is then used to classify the selected set of English patent abstracts.
2. **Identification of CE subclasses**. This step utilizes topic-modeling algorithms to identify and organize specific subclasses within the CE domain:
   (a) a zero-shot BERTopic algorithm is used to map patent abstracts to the most closed 5R ('Reduce', 'Reuse', 'Repair', 'Refurbish', and 'Recycle');
   (b) clustering algorithms are used to classify the patent abstracts into 10 CE topics.

The following sections provide a detailed analysis of these steps.

Binary classification of patents The classification of patents with an LLM is based on three key steps: the construction of the RAG architecture, the generation of an effective and clear prompt, and then the execution of the model.

The RAG technique allows the LLM to dynamically access external information during the generation process, effectively increasing its capabilities. For our purposes, the reference corpus comprised 13 documents specific to the circular economy (CE), carefully selected after conducting trials involving iterative testing and evaluation (listed in Table A.1). Given a query, the retrieval module searches for the most relevant pieces of information, which are then passed to the LLM that uses them as reference in providing a coherent response.

The prompt is defined by an iterative process: first, a simple natural language instruction is provided, asking the model to classify whether the content of a patent pertains to the CE. This prompt is tested on a sample of patents and modified with additional guidance based on the outcomes. The final prompt includes clear instructions and relevant examples of how the task should be performed. This level of specificity is vital to minimize variability in interpreting what constitutes a CE-related patent. Once the prompt is finalized, each patent is processed through the developed chain, which includes the RAG architecture, the refined prompt, and the GPT-3.5-turbo-16k model. In the final classification setup, the output for over 400 patent abstracts is manually verified, with 84% of the results being accurately classified.

To extend the classification to all patents, the BERT for Patents model is used [Srebrovic and Yonamine, 2022]. BERT for Patents is a PLM model provided by Google and available on Hugging Face. It is based on BERTLARGE [Devlin et al., 2019] and is fine-tuned on more than 100 million patents. The LLM classified data set is split into a training and a validation set. Tthe Optuna library is used to optimize the performance of the model. Once the dataset is trained and validated with the test set, the binary model is run over the whole dataset of patents which are therefore classified.

The model achieved an evaluation accuracy of 0.823, indicating that approximately 82.3% of the predictions matched the ground truth. The F1 score was slightly higher at 0.824, reflecting the model's balanced performance in handling both false positives and false negatives. The precision and recall metrics were also closely aligned, at 0.824 and 0.823, respectively, further validating the model's reliability. The evaluation was carried out after 5 epochs of training, indicating a sufficiently iterative learning process to achieve optimal results.

Identification of CE subclasses The target of this paper is not only to identify CE patents but also to dive deeper into this concept. For this reason, CE subclasses are investigated both deductively and inductively.

For what concerns the deductive subclasses, the 5R framework was chosen. To assign each patent abstract to the thematic closer R, the zero-shot BERTopic algorithm is used [Grootendorst, 2022]. By defining as zero-shot topics the 5R ('Reduce', 'Reuse', 'Repair', 'Refurbish', and 'Recycle'), the algorithm maps the patents to the closest circular economy topic based on semantic similarity.

Taking into account the inductive subclass, clustering algorithms are used to identify CE subtopics. Here, document embeddings are generated using the all-MiniLM-L6-v2 model, and their dimensionality is reduced using the UMAP (Uniform Manifold Approximation and Projection) dimension reduction technique. The resulting low-dimensional representations are clustered using the HDBSCAN clustering algorithm and further refined through agglomerative clustering, which organizes the embeddings into 10 topics. The resulting outliers are assigned to the closest matching topic, through cosine distance. Although this step may dilute the distinctiveness of certain topics, as some outliers may not align perfectly with the thematic core of their assigned clusters, it strikes a balance between maintaining representativeness and ensuring comprehensive coverage, ultimately enabling a more robust and systematic analysis.

The titles and brief definitions for each topic are constructed by selecting the top 40 most representative words per topic through a class-based TF-IDF algorithm [Grootendorst, 2022]. These words, combined with the most frequent CPC and NACE codes, plus the most common technological fields per topic, are combined and used to define a title and a definition for the topic. A manual check of over a hundred patents is then performed to ensure the representativeness of the assigned titles and definitions.

4 Results

Using the methodology illustrated previously, 864,714 European patent families are identified as CE-related.

Two examples of improvement with respect to the identification strategies previously used are provided in Table 1 and Table 2. In Table 1 provides an example of a patent that would have difficulty being included while using the keyword retrieval approach - since it does not make any specific reference to the CE and neither to one of the usually correlated terms as "recycle" -, but that is identified when using the methodology proposed here. Table 2, on the other hand, highlights two types of misclassifications when relying solely on CPC/IPC codes. The first example is a CE-related patent - it describes kitchen garbage treatment equipment, thus promoting biodegradation and efficient waste processing - and would be overlooked using the Y02W code. The second example instead is a patent classified as Y02W but not directly related to CE, as it describes a method and composition to reduce the emission of methane and carbon dioxide from farm fertilizers during storage. Although environmentally beneficial, this invention focuses on the mitigation of climate change rather than CE.

CE patent not mentioning keywords
Methods and systems are provided for **mapping the distribution of residue material in an environment in which one or more agricultural machines are operable**. A sensing arrangement comprising one or more sensors mounted or otherwise coupled to an agricultural machine operating within the environment is used to obtain sensor data indicative of residue material [...]

Table 1: Example of misclassification while using keywords

CE patent not Y02W	**Y02W patent not CE**
The invention discloses **kitchen garbage treatment equipment based on biodegradation**, the equipment comprises a filtering mechanism, a stirring mechanism, a crushing mechanism and a fermentation mechanism, the filtering mechanism is connected with the crushing mechanism and the stirring mechanism, and the fermentation mechanism is arranged in the crushing mechanism and the stirring mechanism; [...].	The present invention relates to a method and to the use of a composition, each for reducing the emission of the environmentally harmful climate gases methane and/or carbon dioxide from farm fertilizers while they are being stored.

Table 2: Example of potential misclassification while using CPC codes

When looking at the distribution of CE patents across the 5R, it is possible to observe a predominance of patents related to the categories "Reuse" and "Recycle", respectively, 29.7% and 26.2% of the total dataset (Figure 1). In third place there is the topic "Reuse" (20.0%), followed by "Recycle" (15.91%), and "Refurbish" (8.2%).

Looking instead at the 10 CE topics, we can observe their distribution in Figure 2 (Table A.2). The topic concerning "Adaptive structures and materials" is the most common topic across patents, collecting 23.07% of the whole dataset. Almost 20% of

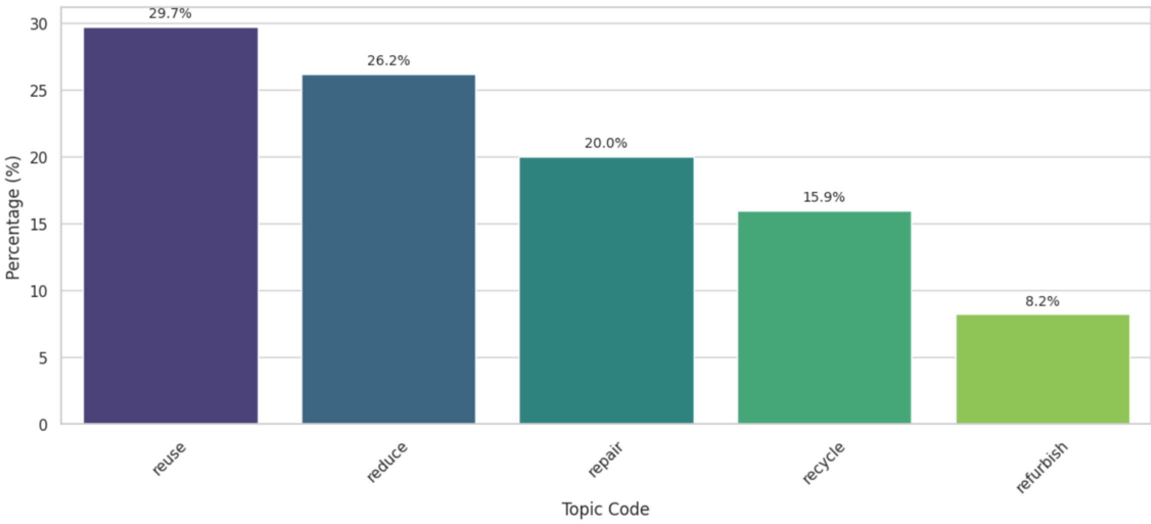

Figure 1: Distribution by 5R topics

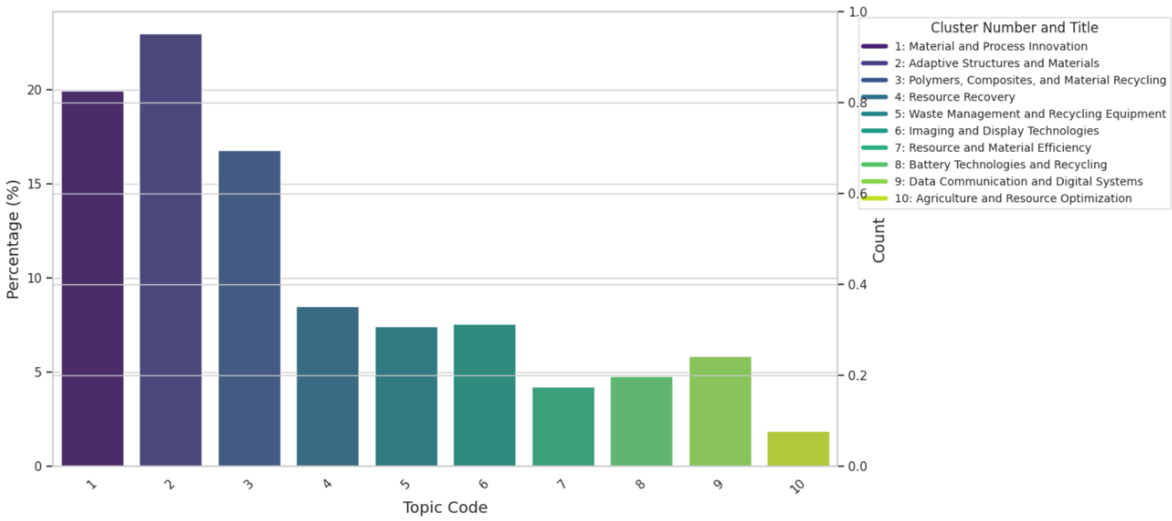

Figure 2: Distribution by 10 CE topics

the patents concern "Material and process innovation", while 16.8% "Polymers, composites, and material recycling". Moving on, there is a noticeable jump in terms of topic size, as the next one covers 8.5% of patents and it is related to "Resource efficiency and water treatment", 7.5% both to "Imaging and display technologies" and "Waste management and recycling equipment", and 5.8% to "Data communication and digital systems". Finally, 4.81% of the patents refer to "Battery technologies and recycling", 4.2% "Resource and material efficiency", and 1.9% "Agriculture and resource optimization".

Table 5 provides examples for each of these topics. The following paragraphs provide a comprehensive mapping of the classified datasets. The analysis provides insight into the temporal patterns of CE innovation, its geographical distribution and sectorial activity, incorporating data on CPC classes, NACE2 codes, and technology classifications. For each dimension, the analysis is conducted both at an aggregated level and by differentiated between the 5R principles and the 10 CE topics. This multifaceted approach ensures a thorough understanding of the dynamics that drive CE innovation.

4.1 Annual trend

Between 1990 and 2019, the trajectory of CE patents largely mirrors the overall growth trend, but exhibits a significantly steeper upward trend beginning in the early 2000s (Figure 3). Compared to Y02W patents, CE patents demonstrate both a faster growth and a higher overall magnitude. This pattern holds across the 5R topics (Figure A.1), with significant increases observed for "Reduce" and "Reuse" patents in the late 1990s. A distinct rise in "Repair" patents becomes evident starting in 2007, while growth in "Recycle" patents appears to plateau and converge from 2010 onwards. Figure A.2 differentiates the trend in the ten CE topics previously described. Overall, the topic "Material and process innovation" and "Adaptive structures and materials" consistently shows the highest counts throughout the period, peaking around 2010 and exhibiting slight fluctuations thereafter. Other topics like "Polymers, composites, and material recycling" show a steady upward trend, stabilizing in the later years, while "Resource recovery", "Battery technologies and recycling", and "Resource and material efficiency" exhibit moderate but consistent growth.

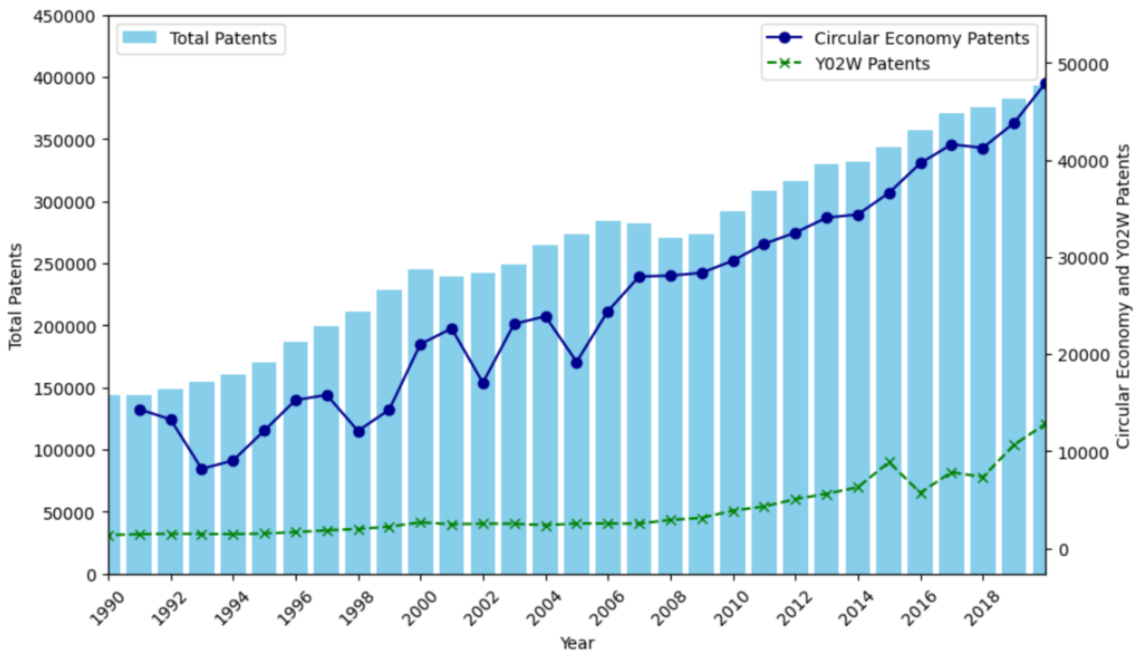

Figure 3: Annual trend of CE patents

4.2 Geographical mapping

At a spatial level, CE patent activity shows a marked concentration in key innovation hubs throughout Europe, as shown in Figure 4 (the top 10 Nuts 3 areas are listed in Table A.4). Main-Kinzig-Kreis, in Germany (5,382 patents, 2.08%), Paris, in France (4,060 patents, 1. 57%) and Helsinki, in Finland (3,179 patents, 1.23%) lead the rankings. Other industrial centers, such as Hauts-de-Seine, Zurich, and Milan, also show significant activity. When analyzed according to 5R topics, the distribution of CE patents reveals nuanced regional strengths (Table A.5). Regions such as Main-Kinzig-Kreis, in Germany, excel in "Reduce" (1.90%) and "Repair" (1.61%) innovations, while Paris leads in both "Reuse" (1.67%) and "Refurbish" (1.53%). Milan, Zurich, and Copenhagen show strong, balanced contributions across multiple Rs, reflecting their diverse industrial and technological bases. Further analysis of the 10 CE topics further enriches this geographical mapping in Table A.6. Main-Kinzig-Kreis stands still out across multiple CE topics, with a notable focus on "Data Communication and Digital Systems" (4.31%), "Material and Process Innovation" (2.11%) and "Adaptive Structures and Materials" (2.32%). Paris, in contrast, shows a more diversified profile, leading in categories like "Resource and Material Efficiency" (1.92%) and "Resource Recovery" (1.86%), which reflects its advanced infrastructure and role in digital transformation. Copenhagen performs well in topics such as "Polymers, composites, and material recycling" (2.55%), while Freiburg is recognized for its strengths in "Recycling equipment and waste management" (2.08%).

4.3 Distribution per CPC codes

At the aggregate level, the technological classifications reveal a strong focus on class B32B for layered products (38.68%), H01M focuses on processes or means for the direct conversion of chemical energy into electrical energy, for example batteries (35.64%), B29C on the shaping or joining of plastics (23.36%), as can be observed in Table 3. In terms of technological focus according to 5R principles (Table A.7), "Reduce" emphasizes energy and material efficiency, with processes such as H01M (processes or means, e.g. batteries, 5.80%) and B01D (separation, 4.27%) leading. "Reuse" is dominated by layered products (B32B, 5.59%) and plastic shaping technologies (B29C, 4.94%). "Recycle" highlights innovations in plastic reprocessing (B29C, 7.37%) and waste management (Y02W, 3.59%). "Repair" technologies have a strong presence in batteries and water treatment, while "Refurbish" emphasizes layered materials and structural enhancements in building and manufacturing.

The 10 CE topics illustrate a nuanced distribution of patents in various technological domains (Table A.8). "Material and process innovation" is a major factor in container technology (B65D, 5.66%) and semiconductor devices (H01L, 5.21%). Similarly, "Adaptive structures and materials" is characterized by a strong presence of plastic shaping technologies (B29C, 6.29%) and layered products (B32B 5.61%). Also in "Polymers, composites, and material recycling," layered products and plastic technologies (B32B, 10.29%; B29B, 7.29%) are dominant, illustrating a focus on high-tech

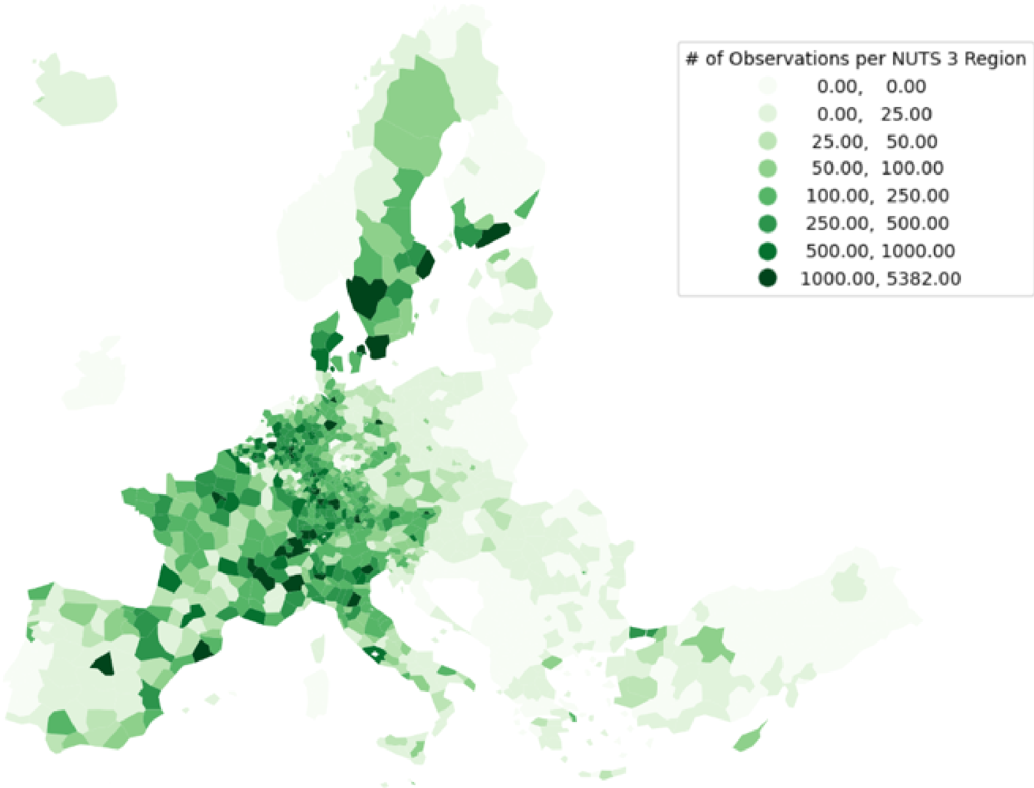

Figure 4: Distribution of CE patents at Nuts3 level

Code	**Title**	**n. patents**	**% patents**
B32B	Layered products	106,388	38.68%
H01M	Processes or means	104,980	38.17%
B29C	Shaping or joining of plastics	96,691	35.16%
C02F	Treatment of water, waste water, sewage, or sludge	75,929	27.61%
H01L	Semiconductor devices not covered by class H10	63,859	23.22%
Y10T	Technical subjects covered by former US classification	59,281	21.56%
B01D	Separation	57,754	21.00%
B65D	Containers for storage or transport of articles or materials	57,551	20.93%
C04B	Lime, magnesia; slag; cements; compositions thereof	47,150	17.14%
Y02E	Reduction of greenhouse gas (GHG) emissions, related to energy generation, transmission or distribution	39,573	14.39%

Table 3: Distribution of CE patents across CPC codes

materials essential for recycling and reuse. For "Resource recovery", treatment of water (C02F, 10.32%) and separation (B01D, 9.46%) lead, highlighting the integration of advanced materials in the management of environmental resources.

4.4 Sectorial level

Industries identified through the NACE classification illustrate a broad engagement with CE (Table 4). The manufacture of basic chemicals dominates (16.79%), while other sectors such as special purpose machinery (10.28%) and rubber and plastic products (6.94%) also show significant contributions, underscoring the diverse applicability of circular economy approaches in industrial domains.

	Code	Name	n. patents	% patents (%)
1	20.10	Manufacture of basic chemicals	46,185	16.79%
2	28.90	Manufacture of other special-purpose machinery	28,296	10.28%
3	22.00	Manufacture of rubber and plastic products	19,109	6.94%
4	26.10	Manufacture of electronic components and boards	17,489	6.35%
5	21.00	Manufacture of basic pharmaceutical products	15,840	5.75%
6	28.29	Manufacture of other general-purpose machinery n.e.c.	15,623	5.68%
7	26.30	Manufacture of communication equipment	13,914	5.05%
8	27.20	Manufacture of batteries and accumulators	13,242	4.81%
9	26.20	Manufacture of computers and peripheral equipment	12,795	4.65%
10	28.10	Manufacture of general-purpose machinery	12,639	4.59%

Table 4: Distribution of CE patents across NACE codes

Sectorial diversification expands further when we look at differences between the 5R categories (Table A.9). For "Reduce," the chemical and pharmaceutical industries dominate, while "Reuse" shows strong engagement from rubber and plastic manufacturing (5.22%), and "Recycle" is led by machinery and motor vehicle manufacturing.

The 10 CE topics insights presented in Table A.10 further delineate the sectoral contributions. For "Material and process innovation", the manufacture of of other special-purpose technologies (8.78%) plays a significant role, while "Data Communication and Digital Systems" sees a robust presence of computers manufacturing (15.54%). "Agriculture and Resource Optimization" stands out for the dominance of basic chemicals (20.90%), pharmaceuticals (16.54%), and food preparations (9.44%). Across all topics, the assigned NACE codes appear to align well with the corresponding CE dimensions, reflecting the sectoral relevance to each area of circular economy innovation.

4.5 Technical Fields

At the aggregate level, the largest share is held by "Other special machines", accounting for 13.3% of total patents. This category encompasses a wide variety of specialized machinery, reflecting the broad scope of innovation in manufacturing and industrial technologies. The following closely are "Electrical machinery, apparatus, and energy", (10.3%), and "Chemical engineering" (8.8%). The fields of "Electronic components and boards manufacturing" (8.6%) and Handling (8.2%) also contribute significantly, demonstrating the importance of advanced manufacturing, logistics, and automation technologies in the wider technological landscape.

Tech. Field	Name	n. patents	% patents (%)
29	Other special machines	36,586	13.30%
1	Electrical machinery, apparatus, energy	28,388	10.32%
23	Chemical engineering	24,210	8.80%
25	Manufacture of electronic components and boards	23,590	8.57%
24	Handling	22,669	8.24%
35	Civil engineering	18,165	6.60%
20	Materials, metallurgy	17,978	6.53%
19	Basic materials chemistry	17,550	6.38%
28	Textile and paper machines	17,210	6.25%
32	Transport	17,126	6.22%

Table 5: Distribution of CE patents across IPC technological fields

When examining the distribution of patents across the 5R topics, the ”Reduce” one is dominated by ”Electrical machinery, apparatus, energy” (7.93%), followed by ”Chemical engineering” (7.16%) and ”Other special machines” (6.56%). The Reuse category sees a clear dominance of ”Other special machines” (10.14%) and ”Manufacture of electronic components and boards” (5.62%), while patents under the ”Recycle” category are heavily concentrated in ”Other special machines” (8.86%), followed by ”Transport” (7.54%) and ”Mechanical elements” (6.48%), while ”Handling” stands out as the most patent-intensive field in the ”Repair” category, with 17.65% patents.
At a more granular level, when examining the 10 CE topic distribution of patents across specific topics, in the category ”Material and Process Innovation”, ”Handling” (10.70%) leads the charge. ”Other special machines” (7.44%) and ”Chemical engeneering” (7.10%) also play an important role. Patents in the ”Imaging and Display Technologies” category show a focus on ”Optics” (17.82%), while the ”Resource recovery” category sees strong contributions from ”Environmental technologies” (15.21%).

4.6 Main Actors

At the company level, Table A.13 presents the top ten patent applicants in the sector of the circular economy. The leader of the list is Procter & Gamble, known for its consumer goods, including household and personal care products, with 3,631 patents, accounting for 1.32% of the total. Samsung Electronics Co. Ltd., a leader in consumer electronics, follows with 3,506 patents (1.27%). Siemens AG, a multinational company focused on industrial automation, energy, healthcare, and digital transformation, ranks third with 3,305 patents (1.20%), just ahead of Robert Bosch GmbH, which holds 3,200 patents (1.16%) and specializes in engineering and electronics. Novozymes A/S, a biotechnology company, follows closely with 3,151 patents (1.15%). Other notable contributors include Hewlett Packard Development Co. LP and Matsushita Electric Industrial Co. Ltd.
The leading actors are especially focused on the 5R principles, as illustrated in Ta-

ble A.14. Procter & Gamble's dominance is particularly evident in "Reduce" and "Refurbish", as their innovations aim to reduce resource consumption in consumer goods and enhance product longevity. Samsung Electronics and Siemens AG are pivotal in "Repair," leveraging advancements in electronic components and modular systems. Robert Bosch GmbH demonstrates strong engagement with "Recycle" through its contributions to material recovery technologies. Meanwhile, Novozymes A/S drives innovation in "reuse," with biobased solutions enabling the reintegration of biological materials into production cycles.
Looking at the leading actors per CE topic, the data reveal a diverse range of company specializations across CE topics within the circular economy. In "Material and process innovation", Hewlett Packard Development Co. LP and LG Electronics prevails(0. 67%), while in "Adaptive structures and materials, Novozymes A/S stands out with 728 patents (0.948%). or "Imaging and Display Technologies", Samsung Electronics Co. Ltd. excels with 510 patents (1.483%). "Adaptive Structures and Materials" is once again notably influenced by the activities of Hewlett Packard Development Co. LP, while in "Agriculture and Resource Optimization", E.I. du Pont de Nemours & Co prevails among others. Table A.15 provides a complete mapping of the main applicant.

4.7 Addressing the CE patents quality

In order to investigate the correlation between CE patents and several key quality measures taken from the OECD Patent Quality Indicator database was analyzed. In particular, four indexes were selected: generality, originality, radicalness, and a composite quality index. The paper by Squicciarini, Dernis, and Criscuolo illustrates how these measures were constructed [Squicciarini et al., 2013]. The generality index is higher when a patent is cited by patents belonging to a wide range of fields, while the originality index refers to the breadth of the technology fields on which a patent relies: inventions relying on a large number of diverse knowledge sources are supposed to lead to original results. Radicalness is related to the fact that the more patent citations belong to classes other than the ones it is in, the more the invention should be considered radical. Finally, the quality index 4-4 components is made up of the number of forward citations (up to 5 years after publication), the size of the patent family, the number of claims, and the patent generality index.

Regr.	Independent Variables	Generality	Originality	Radicalness	Quality Index
1.	Circular	0.0155*** (0.0015)	0.0241*** (0.0012)	0.0224*** (0.0013)	0.0256*** (0.0007)
	Sector controls	Yes	Yes	Yes	Yes
	Country controls	Yes	Yes	Yes	Yes
2.	Recycle	0.0184*** (0.0032)	0.0205*** (0.0026)	0.0184*** (0.0028)	0.0203*** (0.0015)
	Reduce	0.0065* (0.0025)	0.0116*** (0.0020)	0.0096*** (0.0022)	0.0232*** (0.0012)

Regr.	Independent Variables	Generality	Originality	Radicalness	Quality Index
	Refurbish	0.0445*** (0.0055)	0.0422*** (0.0043)	0.0024*** (0.0048)	0.0358*** (0.0027)
	Repair	−0.0195*** (0.0059)	0.0026 (0.0045)	0.0024 (0.0051)	0.0141*** (0.0027)
	Reuse	0.0236*** (0.0026)	0.0399*** (0.0019)	0.0366*** (0.0023)	0.0316*** (0.0012)
	Sector controls	Yes	Yes	Yes	Yes
	Country controls	Yes	Yes	Yes	Yes
3.	Material and process innovation	0.0013 (0.0032)	0.0051 (0.0026)	0.0119*** (0.0028)	0.0250*** (0.0015)
	Adaptive structures and materials	0.0235*** (0.0029)	0.0213*** (0.0024)	0.0177*** (0.0026)	0.0236*** (0.0013)
	Polymers, composites, and material recycling	0.0424*** (0.0034)	0.0585*** (0.0023)	0.0595*** (0.0031)	0.0334*** (0.0016)
	Resource recovery	−0.0135 (0.0060)	−0.0078 (0.0047)	0.0042 (0.0051)	0.0044*** (0.0026)
	Recycling equipment and waste management	−0.0217*** (0.0054)	−0.0053 (0.0045)	−0.0076 (0.0046)	0.0025*** (0.0024)
	Imaging and display technologies	0.0480*** (0.0053)	0.0457*** (0.0038)	0.0449*** (0.0046)	0.0457*** (0.0026)
	Resource and material efficiency	−0.0218** (0.0079)	0.0474*** (0.0054)	0.0262*** (0.0067)	0.0106*** (0.0034)
	Battery technologies and recycling	−0.0498*** (0.0062)	0.0030 (0.0042)	−0.0456*** (0.0053)	0.0187*** (0.0029)
	Data communication and digital system	0.0548*** (0.0065)	0.0419*** (0.0048)	0.0466*** (0.0059)	0.0499*** (0.0032)
	Agriculture and resource optimization	0.0599*** (0.0109)	0.0322*** (0.0078)	0.0481*** (0.0110)	0.0386*** (0.0055)
	Sector controls	Yes	Yes	Yes	Yes
	Country controls	Yes	Yes	Yes	Yes

Table 6: OLS regressions over Patent Quality Indexes

Three OLS regressions are performed to explore the correlation between quality indicators and circularity, assessing the strength of these relationships. As shown in Table 6, the first regression analyzes circular patents in general, while the second distinguishes between the five 5R categories ("Recycle", "Reduce", "Refurbish", "Repair", and "Reuse"). Finally, the third incorporates the 10 CE topics to gain a more nuanced

view. The following discussion delves into the results of these three regressions, highlighting key insights and patterns.
In the first regression, CE patents exhibit a positive and statistically significant relationship with all four quality measures. CE patents are generally more cited across a broad range of technologies, are more original, more radical in their approach, and have higher overall quality, as captured by the composite index. This is relevant because it suggests that circular economy patents tend to span multiple areas of technology and introduce novel solutions.

The second regression analysis differentiates the 5R categories, revealing different patterns in patent characteristics. The "Recycle" category exhibits strong positive correlations with all quality measures, while "Reduce" has a modest effect on the generality index, indicating that patents in this category tend to be more specific and less broad in their applications. "Refurbish" patents show a particularly strong positive impact on both generality and originality indexes, whereas patents in the "Repair" category show a negative generality index, even if still positively and significantly contributing to overall patent quality. Finally, "Reuse" patents demonstrate consistent and significant positive relationships across all quality measures, being not only innovative and high-quality but also contributing significantly to technological progress.

The third regression focuses on the 10 CE topics as previously defined. Topics regarding "Polymers, composites, and material recycling", "Imaging and display technologies", and "Data communication and digital systems" exhibit particularly strong and consistent positive correlations with all quality measures. The topics "Resource recovery", "Recycling equipment and waste management", and "Battery technologies and recycling" show instead a more mixed pattern, with negative correlations in some measures (e.g., generality and originality) but still a positive relationship with the quality index.

5 Conclusions

Based on the growing interest that the topic of CE has also attracted in the field of Innovation Economics, this study presents a novel methodology for identifying CE patents using advanced NLP techniques. The methodology developed leverages the OpenAI GPT-3.5-turbo-16k language model, customized using the RAG technique, along with the PLM BERT for Patents, the BERTopic algorithm and clustering algorithms. This approach transcends traditional patent classification methods, such as keyword retrieval and CPC/IPC systems. By integrating these advanced techniques, the methodology enables more accurate identification and analysis of circular economy (CE) innovations, effectively addressing the complexities and diversity inherent in the rapidly evolving field of CE technologies.
Analysis of CE patents across the 5R principles reveals a dominance of "Reuse" and "Recycle," emphasizing the focus on resource recovery and waste reduction—key drivers of circular economy practices. Among the 10 identified CE topics, "Adaptive Structures and Materials" and "Material and Process Innovation" stand out, indicating a shift toward material innovation and versatile, sustainable solutions across industries. The geographical distribution of CE patents highlights concentrated innovation hubs

in Europe, while the distribution of patents across technological classifications and sectors highlights the deep integration of CE principles in areas such as layered products, battery technologies, and plastic shaping. Sectoral contributions from industries like chemicals, rubber, plastics, and machinery underscore the broad application of circular economy practices, demonstrating the alignment between innovation and sustainability.

The analysis also shows a strong positive correlation between circularity and patent quality measures, such as generality, originality, radicalness, and quality. Circular patents often span multiple technological fields and introduce novel solutions, signaling their potential to drive disruptive innovation across sectors.

Overall, this study highlights the growing importance of circular economy innovations in transforming industries by enhancing resource efficiency and reducing environmental impact. By refining the classification framework for CE-related patents, this research provides policymakers and researchers with a valuable tool to track and promote sustainable innovations, contributing to a deeper understanding of the evolving landscape of the circular economy.

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Appendix

Title and Reference	n. pages
Circular chemistry to enable a circular economy [Keijer et al., 2019]	1-4
Towards a Circular Economy - Waste management in the EU [Lee et al., 2017]	63-88
Artificial Intelligence and the Circular Economy [Ellen MacArthur Foundation, 2019]	6-34
Logistics in the Circular Economy: Challenges and Opportunities [Beames et al., 2021]	5-12
Circular Business Models for the Circular Economy [OECD, 2019]	23-60
Circular Economy Action Agenda: Food [Platform for Accelerating the Circular Economy, 2021]	16-23, 28-44
Jobs & Skills in the Circular Economy [Ellen MacArthur Foundation, 2021]	6-7
Digitalisation for the transition to a resource efficient and circular economy [Eva Börkey, 2022]	16-30
Redefining Value: The Manufacturing Revolution [UNESCO, 2018]	39-58
Circular Economy Gap Report 2023 [Circle Economy, 2023]	13-59
Circular Economy Action Plan [European Commission, 2020a]	6-22
Towards the Circular Economy [Ellen MacArthur Foundation, 2013]	full report
Designing innovations for the circular economy [World Economy Forum, 2023]	full page

Table A.1: Key Documents and Page Ranges Related to Circular Economy

Topic	Title	Description	n. patents	% patents
2	Adaptive Structures and Materials	This topic focuses on the design, manufacture, and application of collapsible, foldable, or layered structures integrated with advanced materials. These structures are developed using shaping, joining, and compounding processes, enabling flexible, multifunctional, and lightweight solutions	63,242	22.99%
1	Material and Process Innovation	This topic focuses on innovative approaches to materials and processes, emphasizing the development of new technologies to improve functionality, sustainability, and efficiency across various sectors	54,833	19.93%
3	Polymers, Composites, and Material Recycling	This topic focuses on advancements in polymer and composite materials, their synthesis, applications, and recycling processes, emphasizing sustainable material use and circular economy principles	46,164	16.78%
4	Resource Recovery	This topic addresses processes and technologies for water purification, wastewater treatment, and the recovery of resources such as energy, nutrients, and biogas from organic and industrial waste streams	23,419	8.51%
6	Imaging and Display Technologies	This topic explores innovations in imaging, display, and sensor technologies, with applications in electronics, visual systems, and devices for communication and interaction	20,757	7.54%
5	Recycling Equipment and Waste Management	This topic addresses equipment and processes for waste sorting, recycling, and disposal, including pyrolysis, crushing, separation mechanisms, and machinery for handling plastics, metals, and other materials	20,496	7.45%
9	Data Communication and Digital Systems	This topic encompasses the development and application of digital systems used for communication, data transmission, and secure transactions. It includes technologies like cloud computing, blockchain, cryptography, and telecommunications, with a focus on improving energy efficiency, reducing emissions, and optimizing resource use	16,067	5.84%
8	Battery Technologies and Recycling	This topic covers advancements in batteries and energy storage, emphasizing recycling, electrochemical processes, and materials for efficient and sustainable energy systems	13,204	4.80%
7	Resource and Material Efficiency	This topic emphasizes the efficient use of resources and materials across industries, focusing on reducing waste, optimizing supply chains, and enhancing resource recovery through advanced processes and technologies	11,663	4.24%
10	Agriculture and Resource Optimization	This topic focuses on sustainable agricultural practices, optimizing soil management, nutrient cycles, and resource use for efficient cultivation and farming systems	5,168	1.87%

Table A.2: Distribution of patents per CE topics

Topic	Example a	Example b	Example c
Material and Process Innovation	The invention relates to an installation for purifying a fibrous suspension, having multiple hydrocyclones (1) arranged adjacent to one another in a row, which hydrocyclones each have at least one feed connection (2), one accepted stock connection (3) and one reject material connection (4), and having at least one supply collecting line (5) which is connected to multiple feed connections (2) and which serves for the feed of the fibrous suspension, and/or having at least one accepted stock collecting line (6) which is connected to multiple accepted stock connections (3) and which serves for the drainage of the accepted stock [...].	A recyclable, laminated polyolefin-based film structure comprises two or more film plies laminated to each other. Each of the laminated film plies comprises one or more polyolefin-based films. The film structure has an energy-cured coating layer disposed on the outermost outward facing surface of the film structure and a printed ink layer on an interior surface of one of the polyolefin-based polyolefin layers.	According to one embodiment, a method for generating a dynamic watering plan that reduces water consumption requirements for vegetation is disclosed. An example method includes estimating root depth of vegetation watered by a watering system; determining an allowed water depletion threshold of the vegetation based on the root depth; determining a training watering plan to increase the root depth of the vegetation over time based on the root depth and the allowed water depletion threshold; and transmitting the training watering plan to a flow controller for execution by the watering system.
Adaptive Structures and Materials	Devices and methods for cleaning an array of solar panels in side-by-side relation employ one or more elongated flexible elements, preferably implemented as translucent strips (14a, 14b, 14c, 14d), anchored at their ends relative to the array of solar panels (12). Each strip spans two or more solar panels, and is wind-displaceable so as to contribute to cleaning of at least two of the solar panels (12).	A watchband, the watchband comprising: a substantially non-flexible main member (100A, 100B); a flexible auxiliary member (102) coupled to the substantially non-flexible main member (100A, 100B); and a tensioning member (104) coupled to the flexible auxiliary member (102). In use, the tensioner (104) is configured to maintain a selected degree of tension, and the flexible auxiliary member (102) is configured to be resilient.	Collapsible reusable carrying cases are provided in sizes varying from small food containers to large push cart bins on casters. The cases are assembled or disassembled from a joined flat space-saving configuration to a functioning case and vice-versa. All parts that make up a carrying case do not separate from the carrying case and no parts can be removed. The cases are formed from rigid plastic panels, and are assembled or disassembled without tools. [...] The carrying cases are resistant to water, dirt, bacteria, molds, allergens, and inclement weather.

Topic	Example a	Example b	Example c
Polymers, Composites, and Material Recycling	Provided are a method and an apparatus for manufacturing a fiber-reinforced resin molding material by which, when the fiber-reinforced resin molding material is manufactured, separated fiber bundles can be supplied to a cutting machine in stable condition while avoiding the influence of meandering of the fiber bundles or slanting or meandering of filaments occurring in the fiber bundles. A method for manufacturing a sheet-shaped fiber-reinforced resin molding material in which spaces between filaments of cut-out fiber bundles (CF) are impregnated with resin includes [...].	A method of upcycling polymers to useful hydrocarbon materials. A catalyst with nanoparticles on a substrate selectively docks and cleaves longer hydrocarbon chains over shorter hydrocarbon chains. The nanoparticles exhibit an edge to facet ratio to provide for more interactions with the facets.	A resealable beverage can lid has a lid having a top side having a score line forming a panel, a first rivet formed in the lid and extending outwardly from the top side of the lid, a second rivet formed in the panel and extending outwardly from the top side of the lid, and a tab portion connected to the first rivet and the second rivet.
Resource Recovery	The disclosed technology includes blister package assemblies that include a reusable blister pouch. The blister package assembly can have an enclosure housing having a first card and a second card. The second card can be opposed to a separably joinable to the first card. The blister package assembly can have a reusable blister pouch that can enclose an object and have a fastener that transition the reusable blister pouch between an open configuration and a closed configuration.	Hydro excavation vacuum apparatus that process spoil material onboard the apparatus by separating water from the cut earthen material are disclosed. C)0 (N	A semiconductor apparatus may include a repair circuit configured to activate a redundant line of a cell array region by comparing repair information and address information. The semiconductor apparatus may include a main decoder configured to perform a normal access to the cell array region by decoding the address information. The address information may include both column information and row information.

Topic	Example a	Example b	Example c
Waste Management and Recycling Equipment	A knife is provided that includes a replaceable blade element. The knife employs a blade carrier that is fixedly interconnected to or foldable with respect to a handle. The blade carrier selectively receives the replaceable blade element that is locked into the blade carrier by way of a hook and movable pin combination. The replaceable blade element is designed to be inserted within the blade carrier quickly, easily, and safely.	Systems and methods for detecting a waste receptacle, the system including a camera for capturing an image, a convolutional neural network, and processor. The convolutional neural network can be trained for identifying target waste receptacles. The processor can be mounted on the waste-collection vehicle and in communication with the camera and the convolutional neural network configured for using the convolutional neural network. The processor can be configured for using the convolutional neural network to generate an object candidate based on the image [...]	Systems and methods for classifying and sorting of plastic materials utilizing a vision system and one or more sensor systems, which may implement a machine learning system in order to identify or classify each of the materials, which may then be sorted into separate groups based on such an identification or classification.

Topic	Example a	Example b	Example c
Imaging and Display Technologies	A material sorting system sorts materials utilizing a vision system that implements a machine learning system in order to identify or classify each of the materials, which are then sorted into separate groups based on such an identification or classification. The material sorting system may include an x-ray fluorescence system to perform a classification of the materials in combination with the vision system, whereby the classification efforts of the vision system and x-ray fluorescence system are combined in order to classify and sort the materials.	A bifacial solar module with enhanced power output including first and second transparent support layers, a plurality of electrically interconnected bifacial solar cells arranged between the transparent support layers with gaps between one or more of the interconnected solar cells and edges of the first and second transparent support layers, the bifacial solar cells having a first side directly exposed to solar radiation and a second side opposite the first. The bifacial solar module further includes one or more micro-structured reflective tapes positioned coincidentally with the gaps and attached to a surface of the second support layer such that light passing through the second support layer is reflected back into the second support layer at angles such that light reflecting from the tape is absorbed by either the first or second side of the bifacial solar cells.	A device and/or apparatus that comprises a dynamic optical lens is provided. A first apparatus includes a first lens component having a first surface and a second surface. The first apparatus further includes a second lens component that comprises a flexible element. [...] The flexible element of the second lens component is such that it conforms to the first surface of the first lens component when an amount of fluid between the first surface of the first lens component and the second lens component is sufficiently low. The flexible element of the second lens component is also such that it does not conform to the first surface of the first lens component when an amount of fluid between the first surface of the first lens component and the second lens component is sufficiently great.

Topic	Example a	Example b	Example c
Resource and Material Efficiency	The invention relates to the supplemental generation of energy from operation of a train, and specifically to the generation of energy in connection to the rotation of disc brake rotors in combination with generators. Rotation of the disc brake rotors creates rotational energy that is transmitted to the generators, which then transmits the energy to a series of batteries for storage. The batteries may be stored in the platform for the train and/or within the train car itself. Energy from the batteries may be utilized by removal of the batteries from the train or through a number of outlets, sockets or connectors associated with the train car or platform.	[Problem] To provide a building material having excellent durability. [Solution] A building material having a convex part formed on a surface thereof, the convex part having a first lateral surface part and a second lateral surface part corresponding to the first lateral surface part. The building material is made of a mixture containing a hydraulic material, an admixture, and a plant-based reinforcing material. The plant-based reinforcing material, at least in the convex part, is distributed in the mixture with the hydraulic material and the admixture attached thereto. The distribution of the plant-based reinforcing material in the first lateral surface part and the distribution of the plant-based reinforcing material in the second lateral surface part are substantially the same. [...]	Described herein are compositions and methods for waste-to-energy ash in engineered aggregate in road construction.
Battery Technologies and Recycling	The invention relates to a system for wirelessly charging an electrically chargeable device, in particular a mobile inspection robot, in a potentially explosive environment. The invention also relates to a charging station for use in such a system according to the invention. The invention further relates to an electrically chargeable device, in particular an inspection robot, for use in such a system according to the invention. [...]	The present invention provides a secondary battery which comprises an electrode assembly and an outer package that houses the electrode assembly. With respect to this secondary battery, the outer package is provided with a metal plate that is bonded thereto with an insulating material being interposed therebetween; the outer package has an opening; and either the peripheral edge of the opening or the outer edge of the metal plate is bent so as to be away from the insulating material.	A process for removal of aluminium and iron in the recycling of rechargeable batteries comprising providing a leachate from black mass, adding phosphoric acid (H3PO4) to said leachate and adjusting the pH to form iron phosphate (FePO4) and aluminium phosphate (AlPO4), precipitating and removing the formed FePO4 and AlPO4, and forming a filtrate for further recovery of cathode metals, mainly NMC-metals and lithium.

Topic	Example a	Example b	Example c
Data Communication and Digital Systems	A computer-based system collects data associated with a user activity. The data is transmitted from an app running on a computing device with a user account authenticated by the computer-based system. A carbon footprint of the user activity is calculated based on the data associated with the user activity. The system calculates a proof of environmental impact in response to a function of the carbon footprint and a baseline value. An amount of cryptocurrency is generated based on the proof of environmental impact by writing a transaction for the amount of cryptocurrency to a blockchain in response to proof of environmental impact. The amount of cryptocurrency is assigned to the user account authenticated with the computer-based system.	A method for providing economic information based on geographic parameters that includes providing a map for display on a device, receiving a user-defined area on the map, and providing data relating to the user-defined area. Obtaining the relevant information or data about a particular geographic region frequently involves consulting a plurality of sources. The current method is much more efficient and cost effective to retrieve from fewer sources and provide the information in a quick and easy to comprehend format.	A computer-implemented system and method for inferring operational specifications of a photovoltaic power generation system using net load is provided. Photovoltaic plant configuration specifications can be accurately inferred with net load data and measured solar resource data. A time series of net load data is evaluated to identify, if possible, a time period with preferably minimum and consistent power consumption. Power generation data is simulated for a range of hypothetical photovoltaic system configurations based on a normalized solar power simulation model. Net load data is estimated based on a base load and, if applicable, any binary loads and any variable loads.

Topic	**Example a**	**Example b**	**Example c**
Agriculture and Resource Optimization	Techniques for providing improvements in agricultural science by optimizing irrigation treatment placements for testing are provided, including analyzing a plurality of digital images of a field to determine vegetation density changes in a sector of the field. The techniques proceed by comparing a distribution of pixel characteristics in the digital images for each field sector to determine sectors in which minimal density deviations are present. Instructions for irrigation placements and testing may be displayed or modified based on the results of the sector determinations.	Implementations are described herein for edge-based real time crop yield predictions made using sampled subsets of robotically-acquired vision data. In various implementations, one or more robots may be deployed amongst a plurality of plants in an area such as a field. [...] A subset of multiple high resolution images may then be sampled from the superset of high resolution images. Data indicative of the subset of high resolution images may be applied as input across a machine learning model, with or without additional data, to generate output indicative of a real time crop yield prediction.	System and method for treating harvested plant material, such as cannabis, with ozone. Embodiments include tumbling the plant material in a rotating vessel, such as a drum, while exposing the plant material to ozone.

Table A.3: Examples CE topics

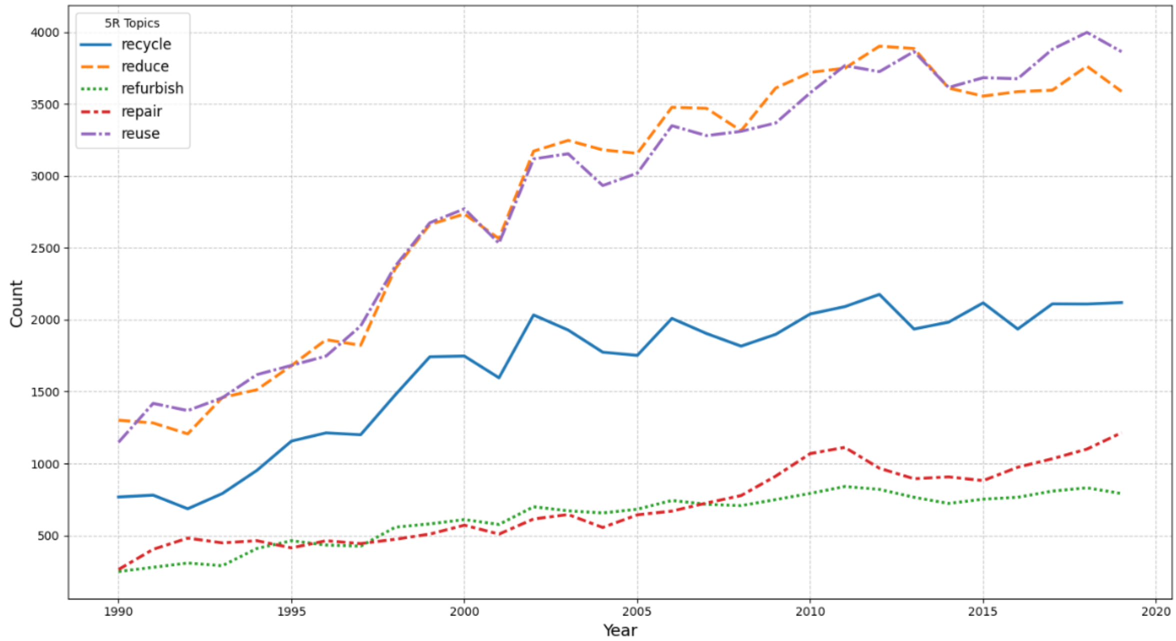

Figure A.1: Annual trend of CE patents by 5R topics

	NUTS Code	Region Name	n. patents	% patents
1	DE212	Main-Kinzig-Kreis, Germany	5,382	2.08%
2	FR101	Paris, France	4,060	1.57%
3	FI1B1	Helsinki-Uusimaa, Finland	3,179	1.23%
4	FR105	Hauts-de-Seine, France	3,101	1.20%
5	CH040	Zurich, Switzerland	2,817	1.09%
6	NL414	Flevoland, Netherlands	2,595	1.00%
7	ITC4C	Milan, Italy	2,542	0.98%
8	DK012	Copenhagen City, Denmark	2,359	0.91%
9	DE111	Region Hannover, Germany	2,257	0.87%
10	SE224	Västra Götaland, Sweden	2,191	0.84%

Table A.4: Distribution of CE patents at Nuts3 level

Topic	NUTS3 Code	Region Name	n. patents	% patents
Reduce	DE212	Main-Kinzig-Kreis, Germany	1,446	1.90%
	FR101	Paris, France	1,230	1.62%
	NL414	Flevoland, Netherlands	1,114	1.47%
	FI1B1	Helsinki-Uusimaa, Finland	1,020	1.34%
	FR105	Hauts-de-Seine, France	908	1.20%
	ITC4C	Milan, Italy	847	1.12%
	CH040	Zurich, Switzerland	816	1.07%
	CH011	Lausanne, Switzerland	739	0.97%

Topic	NUTS3 Code	Region Name	n. patents	% patents
	DK012	Copenhagen City, Denmark	722	0.95%
	SE110	Stockholm, Sweden	708	0.93%
Reuse	DE212	Main-Kinzig-Kreis, Germany	1,638	1.85%
	FR101	Paris, France	1,476	1.67%
	DK012	Copenhagen City, Denmark	1,263	1.43%
	FI1B1	Helsinki-Uusimaa, Finland	1,221	1.38%
	DEA11	Düsseldorf, Germany	1,099	1.24%
	FR105	Hauts-de-Seine, France	1,014	1.14%
	CH040	Zurich, Switzerland	915	1.03%
	NL414	Flevoland, Netherlands	901	1.02%
	ITC4C	Milan, Italy	851	0.96%
	DEB34	Region Hannover, Germany	782	0.88%
Recycle	DE212	Main-Kinzig-Kreis, Germany	1,643	2.88%
	FR101	Paris, France	783	1.37%
	DE111	Region Hannover, Germany	686	1.20%
	FR105	Hauts-de-Seine, France	675	1.18%
	CH040	Zurich, Switzerland	668	1.17%
	FI1B1	Helsinki-Uusimaa, Finland	531	0.93%
	DE115	Karlsruhe, Germany	519	0.91%
	DE929	Gießen, Germany	506	0.89%
	ITC4C	Milan, Italy	497	0.87%
	DE600	Hamburg, Germany	453	0.79%
Repair	DE212	Main-Kinzig-Kreis, Germany	279	1.61%
	FR101	Paris, France	262	1.51%
	FI1B1	Helsinki-Uusimaa, Finland	231	1.33%
	DE111	Region Hannover, Germany	207	1.19%
	FR105	Hauts-de-Seine, France	206	1.19%
	CH040	Zurich, Switzerland	199	1.14%
	DE300	Berlin, Germany	193	1.11%
	SE110	Stockholm, Sweden	184	1.06%
	ITC4C	Milan, Italy	176	1.01%
	DE600	Hamburg, Germany	152	0.87%
Refurbish	DE212	Main-Kinzig-Kreis, Germany	376	1.86%
	SE224	Västra Götaland, Sweden	324	1.60%
	FR101	Paris, France	309	1.53%
	FR105	Hauts-de-Seine, France	298	1.47%
	CH040	Zurich, Switzerland	212	1.05%
	DE600	Hamburg, Germany	203	1.00%
	FI1B1	Helsinki-Uusimaa, Finland	176	0.87%
	FR714	Haute-Garonne, France	173	0.86%
	ITC4C	Milan, Italy	171	0.85%
	DE111	Region Hannover, Germany	139	0.69%

Table A.5: Distribution of patents per 5R topics across at Nuts3 level

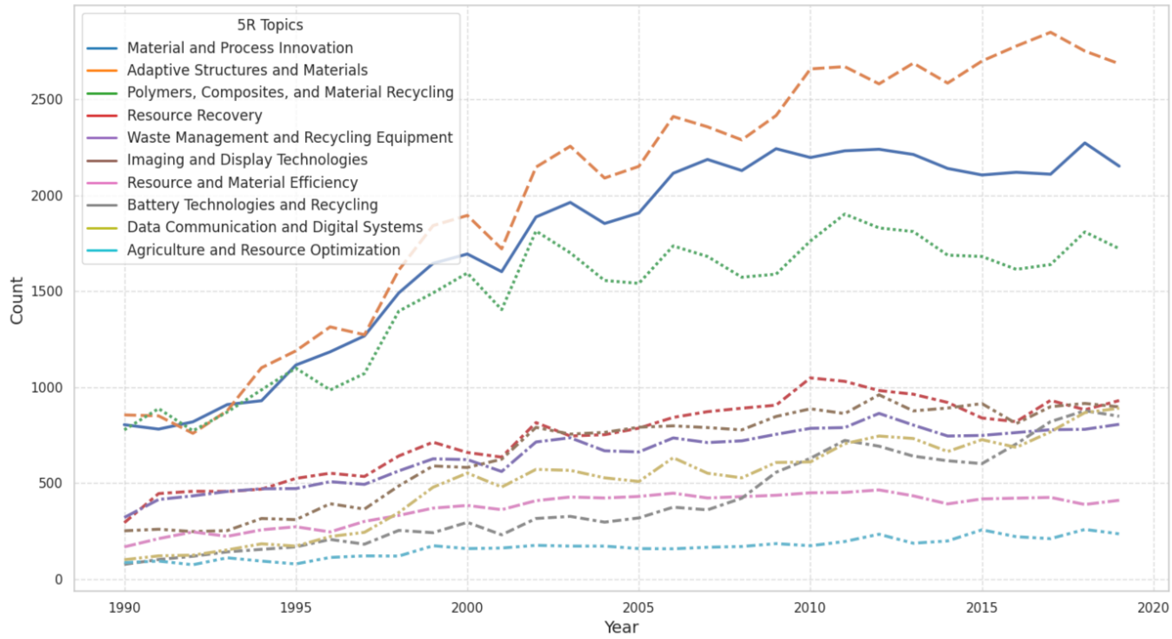

Figure A.2: Annual trend of CE patents by 10 CE topics

Topic	**NUTS Code**	**Region Name**	**n. patents**	**% patents**
Material and Process Innovation	DE212	Main-Kinzig-Kreis, Germany	1,048	2.11%
	FR101	Paris, France	802	1.62%
	CH040	Zurich, Switzerland	566	1.14%
	FR105	Hauts-de-Seine, France	566	1.14%
	DE11C	Düsseldorf, Germany	495	1.00%
	ITC4C	Lombardy, Italy	477	0.96%
	DE111	Stuttgart, Germany	452	0.91%
	FI1B1	Uusimaa, Finland	431	0.87%
	CH011	Lausanne, Switzerland	429	0.87%
	ITH55	Tuscany, Italy	417	0.84%
Polymers, Composites, and Material Recycling	DK012	Copenhagen, Denmark	1,443	2.55%
	DE212	Main-Kinzig-Kreis, Germany	952	1.68%
	FI1B1	Uusimaa, Finland	945	1.67%
	FR101	Paris, France	863	1.53%
	DEA11	Düsseldorf, Germany	821	1.45%
	DEB34	Karlsruhe, Germany	751	1.33%
	DK013	Zealand, Denmark	688	1.22%
	CH011	Lausanne, Switzerland	659	1.17%
	FR105	Hauts-de-Seine, France	563	0.99%
	CH040	Zurich, Switzerland	541	0.96%
Imaging and Display Technologies	NL414	North Brabant, Netherlands	426	2.71%
	DE212	Main-Kinzig-Kreis, Germany	417	2.66%

Topic	NUTS3 Code	Region Name	n. patents	% patents
	FR101	Paris, France	361	2.30%
	FR105	Hauts-de-Seine, France	246	1.57%
	DE11D	Upper Bavaria, Germany	222	1.41%
	ITC4C	Lombardy, Italy	219	1.39%
	FR107	Rhône, France	200	1.27%
	FR714	Provence-Alpes-Côte d'Azur, France	193	1.23%
	SE110	Stockholm, Sweden	185	1.18%
	CH040	Zurich, Switzerland	177	1.13%
Adaptive Structures and Materials	DE212	Main-Kinzig-Kreis, Germany	1,402	2.32%
	FI1B1	Uusimaa, Finland	741	1.23%
	NL414	North Brabant, Netherlands	717	1.19%
	SE224	Västra Götaland, Sweden	681	1.13%
	FR101	Paris, France	675	1.12%
	ITH34	Emilia-Romagna, Italy	662	1.10%
	ITC4C	Lombardy, Italy	646	1.07%
	DE929	Bavaria, Germany	601	0.99%
	FR105	Hauts-de-Seine, France	596	0.99%
	DE111	Stuttgart, Germany	588	0.97%
Agriculture and Resource Optimization	DK012	Copenhagen, Denmark	114	2.21%
	DE300	Berlin, Germany	94	1.82%
	FR101	Paris, France	84	1.63%
	ITC4C	Lombardy, Italy	72	1.39%
	NL221	Groningen, Netherlands	71	1.37%
	FI1B1	Uusimaa, Finland	61	1.18%
	DEB3I	Freiburg, Germany	59	1.14%
	DEA1C	Lower Saxony, Germany	59	1.14%
	DK013	Zealand, Denmark	59	1.14%
	DEA11	Düsseldorf, Germany	59	1.14%
Data Communication and Digital Systems	DE212	Main-Kinzig-Kreis, Germany	408	4.31%
	SE110	Stockholm, Sweden	225	2.38%
	FR105	Hauts-de-Seine, France	208	2.20%
	FR101	Paris, France	208	2.20%
	SE224	Västra Götaland, Sweden	167	1.77%
	FI1B1	Uusimaa, Finland	165	1.74%
	NL414	North Brabant, Netherlands	154	1.63%
	CH040	Zurich, Switzerland	147	1.55%
	DE111	Stuttgart, Germany	130	1.37%
	UKH12	East of England, UK	94	0.99%
Resource and Material Efficiency	FR101	Paris, France	234	1.92%
	CH040	Zurich, Switzerland	230	1.89%

Topic	NUTS3 Code	Region Name	n. patents	% patents
	FR105	Hauts-de-Seine, France	222	1.82%
	DE212	Main-Kinzig-Kreis, Germany	169	1.39%
	DE128	Bremen, Germany	140	1.15%
	CH033	Espace Mittelland, Switzerland	139	1.14%
	DEA11	Düsseldorf, Germany	136	1.12%
	FR714	Provence-Alpes-Côte d'Azur, France	131	1.07%
	DE125	Baden-Württemberg, Germany	119	0.98%
	DK013	Zealand, Denmark	119	0.98%
Resource Recovery	FR101	Paris, France	369	1.86%
	FR105	Hauts-de-Seine, France	355	1.79%
	DE212	Main-Kinzig-Kreis, Germany	345	1.74%
	FR103	Île-de-France, France	253	1.28%
	FI1B1	Uusimaa, Finland	233	1.17%
	SE224	Västra Götaland, Sweden	215	1.08%
	CH040	Zurich, Switzerland	211	1.06%
	DE111	Stuttgart, Germany	209	1.05%
	ITC4C	Lombardy, Italy	205	1.03%
	SE110	Stockholm, Sweden	175	0.88%
Battery Technologies and Recycling	FR101	Paris, France	247	3.03%
	DE212	Main-Kinzig-Kreis, Germany	236	2.90%
	DE111	Stuttgart, Germany	235	2.88%
	FR714	Provence-Alpes-Côte d'Azur, France	181	2.22%
	CH011	Lausanne, Switzerland	136	1.67%
	NL414	North Brabant, Netherlands	128	1.57%
	FR105	Hauts-de-Seine, France	123	1.51%
	DEB34	Karlsruhe, Germany	117	1.44%
	CH040	Zurich, Switzerland	116	1.42%
	DE300	Berlin, Germany	102	1.25%
Recycling Equipment and Waste Management	DE115	Freiburg, Germany	461	2.08%
	DE212	Main-Kinzig-Kreis, Germany	358	1.61%
	FI1B1	Uusimaa, Finland	279	1.26%
	BE251	Flanders, Belgium	269	1.21%
	AT312	Upper Austria, Austria	254	1.15%
	CH040	Zurich, Switzerland	235	1.06%
	DE111	Stuttgart, Germany	224	1.01%
	FR101	Paris, France	217	0.98%
	DEA11	Düsseldorf, Germany	211	0.95%
	NL414	North Brabant, Netherlands	196	0.88%

Topic	NUTS3 Code	Region Name	n. patents	% patents

Table A.6: Distribution of patents per CE topics across at Nuts3 level

Topic	CPC Code	CPC Title	n. patents	% patents
Reduce	H01M	Processes or means, e.g., batteries	40,806	5.80%
	B01D	Separation	30,033	4.27%
	C02F	Treatment of water, waste water, sewage, or sludge	29,145	4.14%
	H01L	Semiconductor devices not covered by class H10	19,264	2.74%
	B29C	Shaping or joining of plastics	18,800	2.67%
	B32B	Layered products, i.e., products built-up of strata of flat or non-flat	16,934	2.41%
	B65D	Containers for storage or transport of articles or materials	16,343	2.32%
	Y10T	Technical subjects covered by former US classification	15,359	2.18%
	Y02E	Reduction of greenhouse gas [GHG] emissions, related to energy generation, transmission or distribution	13,918	1.98%
	G06F	Electric digital data processing	13,633	1.94%
Reuse	B32B	Layered products, i.e., products built-up of strata of flat or non-flat	42,328	5.59%
	B29C	Shaping or joining of plastics	37,393	4.94%
	H01M	Processes or means	32,781	4.33%
	C04B	Lime, magnesia; slag; cements; compositions thereof	23,621	3.12%
	B65D	Containers for storage or transport of articles or materials	22,759	3.01%
	H01L	Semiconductor devices not covered by class H10	22,627	2.99%
	Y10T	Technical subjects covered by former US classification	21,149	2.80%
	C12N	Microorganisms or enzymes	13,861	1.83%
	C02F	Treatment of water, waste water, sewage, or sludge	13,384	1.77%
	Y02W	Climate change mitigation technologies related to wastewater treatment or waste management	13,166	1.74%
Recycle	B29C	Shaping or joining of plastics	28,654	7.37%
	B32B	Layered products, i.e., products built-up of strata of flat or non-flat	18,900	4.86%
	Y10T	Technical subjects covered by former US classification	13,954	3.59%
	B65D	Containers for storage or transport of articles or materials	10,498	2.70%

Topic	CPC Code	CPC Title	n. patents	% patents
	H01L	Semiconductor devices not covered by class H10	9,703	2.50%
	C02F	Treatment of water, waste water, sewage, or sludge	8,617	2.22%
	H01M	Processes or means, e.g., batteries, for the direct conversion of chemical energy into electrical energy	6,511	1.68%
	G06F	Electric digital data processing	6,340	1.63%
	F16C	Shafts; flexible shafts; elements or crankshaft mechanisms; rotary bodies other than gearing elements	5,883	1.51%
	C04B	Lime, magnesia; slag; cements; compositions thereof	5,486	1.41%
Repair	H01M	Processes or means, e.g., batteries	23,494	11.90%
	C02F	Treatment of water, waste water, sewage, or sludge	21,302	10.79%
	Y02W	Climate change mitigation technologies related to wastewater treatment or waste management	9,677	4.90%
	B01D	Separation	9,202	4.66%
	Y02E	Reduction of greenhouse gas [GHG] emissions, related to energy generation, transmission or distribution	7,326	3.71%
	H01L	Semiconductor devices not covered by class H10	5,480	2.78%
	A47L	Domestic washing or cleaning	5,003	2.53%
	B65D	Containers for storage or transport of articles or materials	4,355	2.21%
	B32B	Layered products, i.e., products built-up of strata of flat or non-flat, e.g., cellular or honeycomb, form	4,352	2.20%
	Y02P	Climate change mitigation technologies in the production or processing of goods	3,941	2.00%
Refurbish	B32B	Layered products, i.e., products built-up of strata of flat or non-flat	23,874	14.27%
	B29C	Shaping or joining of plastics	9,225	5.51%
	Y10T	Technical subjects covered by former US classification	6,927	4.14%
	H01L	Semiconductor devices not covered by class H10	6,785	4.05%
	C04B	Lime, magnesia; slag; cements; compositions thereof; artificial stone; ceramics; refractories; treatment of natural stone	5,673	3.38%
	B65D	Containers for storage or transport of articles or materials	3,596	2.14%
	C02F	Treatment of water, waste water, sewage, or sludge	3,481	2.08%
	E04F	Finishing work on buildings	3,203	1.91%
	B01D	Separation	2,807	1.67%

Topic	CPC Code	CPC Title	n. patents	% patents
	E04B	General building constructions	2,767	1.65%

Table A.7: Distribution of patents per 5R topic across CPC codes

Topic	CPC Code	CPC Title	n. patents	% patents
Material and Process Innovation	B65D	Containers for storage or transport of articles or materials	23,690	5.66%
	H01L	Semiconductor devices not covered by class H10	21,797	5.21%
	B29C	Shaping or joining of plastics	21,100	5.04%
	B32B	Layered products	14,689	3.51%
	H01M	Processes or means, e.g., batteries, for the direct conversion of chemical energy into electrical energy	14,010	3.35%
	B01D	Separation	12,550	3.00%
	Y10T	Technical subjects covered by former US classification	11,098	2.65%
	C02F	Treatment of water, waste water, sewage, or sludge	9,953	2.38%
	B01L	Chemical or physical laboratory apparatus for general use	9,156	2.19%
	B41J	Typewriters; selective printing mechanisms	8,261	1.97%
Polymers, Composites, and Material Recycling	B32B	Layered products	40,999	10.29%
	B29C	Shaping or joining of plastics	29,022	7.29%
	C12N	Microorganisms or enzymes; compositions thereof; genetic engineering	16,034	4.03%
	Y10T	Technical subjects covered by former US classification	15,657	3.93%
	C08J	Working-up; general processes of compounding	13,199	3.31%
	C08L	Compositions of macromolecular compounds	10,000	2.51%
	B29K	Indexing scheme associated with moulding materials or materials for moulds	9,764	2.45%
	B65D	Containers for storage or transport of articles or materials	9,102	2.28%
	B01J	Chemical or physical processes, e.g., catalysis	9,062	2.27%
	C04B	Lime, magnesia; slag; cements	8,180	2.05%
Imaging and Display Technologies	G02B	Optical elements, systems or apparatus	15,572	9.30%
	H01L	Semiconductor devices not covered by class H10	14,455	8.63%
	B32B	Layered products	8,362	5.00%
	H04N	Pictorial communication, e.g., television	7,310	4.36%
	G06F	Electric digital data processing	5,223	3.12%
	G02F	Optical devices or arrangements for the control of light	4,390	2.62%
	Y10T	Technical subjects covered by former US classification	3,877	2.31%
	C08L	Compositions of macromolecular compounds	3,837	2.29%

Topic	CPC Code	CPC Title	n. patents	% patents
	G06T	Image data processing or generation	3,779	2.26%
	B29C	Shaping or joining of plastics	3,598	2.15%
Adaptive Structures and Materials	B29C	Shaping or joining of plastics; shaping of materials or articles made of plastics	29,572	6.29%
	B32B	Layered products, i.e., products built-up of strata of flat or non-flat materials	26,361	5.61%
	Y10T	Technical subjects covered by former US classification	17,634	3.75%
	A43B	Characteristic features of footwear	16,088	3.42%
	B65D	Containers for storage or transport of articles or materials	12,836	2.73%
	H01L	Semiconductor devices not covered by class H10	12,520	2.66%
	H01M	Processes or means, e.g., batteries, for the direct conversion of chemical energy into electrical energy	9,324	1.98%
	B33Y	Additive manufacturing, e.g., 3D printing	8,218	1.75%
	B22F	Working metallic powder; manufacture of articles from metallic powder	8,113	1.73%
	G06F	Electric digital data processing	6,665	1.42%
Agriculture and Resource Optimization	C12N	Microorganisms or enzymes; compositions thereof; genetic engineering; culture media	2613	7.41%
	C02F	Treatment of water, waste water, sewage, or sludge	1906	5.4%
	C05F	Organic fertilisers not covered by subclasses C05B, C05C, e.g. fertilisers from waste or refuse	1469	4.16%
	C12P	Fermentation or enzyme-using processes to synthesise a desired chemical compound or composition	1249	3.54%
	A23L	Foods, foodstuffs, or non-alcoholic beverages	1242	3.52%
	H01M	Processes or means, e.g. batteries, for the direct conversion of chemical energy into electrical energy	1178	3.34%
	Y02W	Climate change mitigation technologies related to wastewater treatment or waste management	1142	3.24%
	A01N	Preservation of bodies of humans or animals or plants or parts thereof	1085	3.07%
	A01G	Horticulture; cultivation of vegetables	968	2.74%
	Y02P	Climate change mitigation technologies in the production or processing of goods	852	2.41%
Data Communication and Digital Systems	G06F	Electric digital data processing	12096	9.02%
	H04L	Transmission of digital information	9076	6.77%
	G06Q	Information and communication technology	8709	6.50%
	H04N	Pictorial communication	6817	5.08%
	H02J	Circuit arrangements or systems for supplying or distributing electric power	5501	4.10%
	H01M	Processes or means, e.g. batteries, for the direct conversion of chemical energy into electrical energy	5397	4.02%
	B60L	Propulsion of electrically-propelled vehicles	4239	3.16%
	H04M	Telephonic communication	3597	2.68%

Topic	CPC Code	CPC Title	n. patents	% patents
	H04W	Wireless communication networks	2861	2.13%
	B29C	Shaping or joining of plastics	2601	1.94%
Resource and Material Efficiency	C04B	Lime, magnesia; slag; cements; compositions thereof	22239	11.19%
	B32B	Layered products	4920	5.11%
	Y02W	Climate change mitigation technologies related to wastewater treatment or waste management	4504	4.68%
	H01M	Processes or means	3941	4.10%
	B01J	Chemical or physical processes, e.g. catalysis or colloid chemistry	2170	2.25%
	Y10T	Technical subjects covered by former US classification	2147	2.23%
	G11B	Information storage based on relative movement between record carrier and transducer	2138	2.22%
	C02F	Treatment of water, waste water, sewage, or sludge	1663	1.73%
	H04R	Loudspeakers, microphones, gramophone pick-ups or like acoustic electromechanical transducers	1626	1.69%
	B29C	Shaping or joining of plastics	1616	1.68%
Resource Recovery	C02F	Treatment of water, waste water, sewage, or sludge	46014	10.32%
	B01D	Separation	18782	9.46%
	Y02W	Climate change mitigation technologies related to wastewater treatment or waste management	8714	4.38%
	H01M	Processes or means, e.g. batteries, for the direct conversion of chemical energy into electrical energy	6061	3.05%
	Y02E	Reduction of greenhouse gas [GHG] emissions, related to energy generation, transmission or distribution	4841	2.43%
	B01J	Chemical or physical processes, e.g. catalysis or colloid chemistry	4616	2.32%
	C12M	Apparatus for enzymology or microbiology; bioreactors or fermenters	3585	1.80%
	B32B	Layered products	3543	1.78%
	H01L	Semiconductor devices not covered by class H10	3236	1.63%
	F24S	Solar heat collectors; solar heat systems	3062	1.54%
Battery Technologies and Recycling	H01M	Processes or means, e.g. batteries	57519	7.84%
	Y02E	Reduction of greenhouse gas [GHG] emissions, related to energy generation, transmission or distribution	8719	6.29%
	H02J	Circuit arrangements or systems for supplying or distributing electric power	5388	3.88%
	B60L	Propulsion of electrically-propelled vehicles	4643	3.34%
	C01P	Indexing scheme relating to structural and physical aspects of solid inorganic compounds	3184	2.29%
	Y02T	Climate change mitigation technologies related to transportation	3159	2.27%
	Y02P	Climate change mitigation technologies in the production or processing of goods	2805	2.02%

Topic	**CPC Code**	**CPC Title**	**n. patents**	**% patents**
	H01L	Semiconductor devices not covered by class H10	2706	1.95%
	H01G	Capacitors	2001	1.44%
	B65D	Containers for storage or transport of articles or materials	1978	1.42%
Recycling Equipment and Waste Management	B65D	Containers for storage or transport of articles or materials	1978	5.01%
	B01D	Separation	13002	4.95
	B29C	Shaping or joining of plastics	6128	3.90%
	Y02W	Climate change mitigation technologies related to wastewater treatment or waste management	5380	3.42%
	B29B	Preparation or pretreatment of the material to be shaped	4498	2.86%
	B32B	Layered products, i.e. products built-up of strata of flat or non-flat form	4346	2.76%
	H01M	Processes or means	4173	2.65%
	F16C	Shafts; flexible shafts; elements or crankshaft mechanisms	4046	2.57%
	B65D	Containers for storage or transport of articles or materials	3915	2.49%
	C02F	Treatment of water, waste water, sewage, or sludge	3701	2.35%
	Y10T	Technical subjects covered by former US classification	3583	2.28%

Table A.8: Distribution of patents per CE topics across CPC codes

Topic	**NACE Code**	**NACE Title**	**n. patents**	**% patents**
Reduce	20.10	Manufacture of basic chemicals	14,197	10.13%
	28.90	Manufacture of other special-purpose machinery	9,082	6.48%
	28.29	Manufacture of other general-purpose machinery	7,290	5.20%
	26.30	Manufacture of communication equipment	6,061	4.32%
	26.10	Manufacture of electronic components and boards	5,641	4.02%
	21.00	Manufacture of basic pharmaceutical products and preparations	5,501	3.92%
	26.20	Manufacture of computers and peripheral equipment	5,437	3.88%
	27.20	Manufacture of batteries and accumulators	5,191	3.70%
	29.10	Manufacture of motor vehicles	4,177	2.98%
	28.10	Manufacture of general-purpose machinery	4,172	2.98%
Reuse	20.10	Manufacture of basic chemicals	16,522	11.38%
	28.90	Manufacture of other special-purpose machinery	9,684	6.67%
	21.00	Manufacture of basic pharmaceutical products and preparations	7,782	5.36%
	22.00	Manufacture of rubber and plastic products	7,580	5.22%
	26.10	Manufacture of electronic components and boards	5,601	3.86%
	26.20	Manufacture of computers and peripheral equipment	4,333	2.99%

Topic	NACE Code	NACE Title	n. patents	% patents
	32.90	Manufacturing	4,197	2.89%
	28.23	Manufacture of office machinery and equipment	4,161	2.87%
	26.30	Manufacture of communication equipment	4,047	2.79%
	23.50	Manufacture of cement, lime and plaster	3,999	2.76%
Recycle	28.10	Manufacture of general-purpose machinery	5,499	6.91%
	22.00	Manufacture of rubber and plastic products	5,070	6.37%
	20.10	Manufacture of chemicals and chemical products	5,023	6.31%
	29.10	Manufacture of motor vehicles	4,586	5.76%
	28.90	Manufacture of other special-purpose machinery	4,488	5.64%
	26.30	Manufacture of communication equipment	3,078	3.87%
	28.40	Manufacture of metal forming machinery and machine tools	3,060	3.85%
	26.10	Manufacture of electronic components and boards	2,725	3.43%
	26.50	Manufacture of instruments for measuring, testing and navigation	2,404	3.02%
	26.20	Manufacture of computers and peripheral equipment	2,246	2.82%
Repair	20.10	Manufacture of basic chemicals	7,726	21.56%
	28.90	Manufacture of other special-purpose machinery	3,006	8.39%
	27.20	Manufacture of batteries and accumulators	2,916	8.14%
	28.29	Manufacture of other general-purpose machinery	2,198	6.13%
	26.10	Manufacture of electronic components and boards	1,827	5.10%
	27.50	Manufacture of electric lighting equipment	1,195	3.33%
	28.99	Manufacture of other special-purpose machinery	1,078	3.01%
	22.20	Manufacture of plastics products	1,059	2.95%
	24.00	Manufacture of basic metals	728	2.03%
	29.10	Manufacture of motor vehicles	698	1.95%
Refurbish	20.10	Manufacture of basic chemicals	2,717	8.59%
	43.00	Specialised construction activities	2,429	7.68%
	28.90	Manufacture of other special-purpose machinery	2,036	6.44%
	22.00	Manufacture of rubber and plastic products	1,896	6.00%
	23.00	Manufacture of other non-metallic mineral products	1,841	5.82%
	26.10	Manufacture of electronic components and boards	1,695	5.36%
	29.10	Manufacture of motor vehicles	1,467	4.64%
	23.50	Manufacture of cement, lime and plaster	979	3.10%
	31.00	Manufacture of furniture	873	2.76%
	28.29	Manufacture of other general-purpose machinery	838	2.65%

Table A.9: Distribution of patents per 5R topics across NACE codes

Topic	NACE Code	NACE Title	n. patents	% patents
Material and Process Innovation	28.90	Manufacture of other special-purpose machinery	7,322	8.78%
	20.10	Manufacture of basic chemicals	6,525	7.83%
	26.10	Manufacture of electronic components and boards	4,807	5.77%

Topic	**NACE Code**	**NACE Title**	**n. patents**	**% patents**
	32.90	Manufacturing	4,205	5.04%
	28.29	Manufacture of other general-purpose machinery	3,967	4.76%
	22.00	Manufacture of rubber and plastic products	3,530	4.23%
	27.50	Manufacture of domestic applianceManufacture of general-purpose machinery	3,316	3.98%
	28.10	Manufacture of general-purpose machinery	3,114	3.73%
	28.23	Manufacture of office machinery and equipment	3,023	3.63%
	26.50	Manufacture of instruments and appliances for measuring, testing and navigation	2,564	3.08%
Polymers, Composites, and Material Recycling	20.10	Manufacture of basic chemicals	12,601	16.41%
	21.00	Manufacture of basic pharmaceutical products and preparations	8,750	11.39%
	22.00	Manufacture of rubber and plastic products	5,277	6.87%
	28.90	Manufacture of other special-purpose machinery	4,062	5.29%
	10.00	Manufacture of food products	3,844	5.01%
	23.00	Manufacture of other non-metallic mineral products	3,660	4.77%
	22.20	Manufacture of plastics products	1,715	2.23%
	26.50	Manufacture of instruments and appliances for measuring, testing and navigation	1,652	2.15%
	28.29	Manufacture of other general-purpose machinery	1,637	2.13%
	13.00	Manufacture of textiles	1,626	2.12%
Imaging and Display Technologies	26.70	Manufacture of other electrical equipment	4,699	13.67%
	26.10	Manufacture of electronic components and boards	3,501	10.18%
	26.20	Manufacture of computers and peripheral equipment	2,879	8.37%
	26.30	Manufacture of communication equipment	2,742	7.98%
	20.10	Manufacture of basic chemicals	2,357	6.86%
	28.23	Manufacture of office machinery and equipment	1,857	5.40%
	26.50	Manufacture of instruments and appliances for measuring, testing and navigation	1,506	4.38%
	28.90	Manufacture of other special-purpose machinery	1,090	3.17%
	32.90	Manufacturing	1,036	3.01%
	27.40	Manufacture of electric lighting equipment	902	2.62%
Adaptive Structures and Materials	28.90	Manufacture of other special-purpose machinery	7,548	7.91%
	22.00	Manufacture of rubber and plastic products	6,734	7.05%
	28.10	Manufacture of general-purpose machinery	5,381	5.64%
	29.10	Manufacture of motor vehicles	4,911	5.14%
	43.00	Specialised construction activities	4,569	4.79%
	20.10	Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	3,970	4.16%

Topic	NACE Code	NACE Title	n. patents	% patents
	28.40	Manufacture of metal forming machinery and machine tools	3,904	4.09%
	26.10	Manufacture of electronic components and boards	3,555	3.72%
	32.00	Other manufacturing	3,510	3.68%
	15.00	Manufacture of leather and related products	3,302	3.46%
Agriculture and Resource Optimization	20.10	Manufacture of basic chemicals	1,666	20.90%
	21.00	Manufacture of basic pharmaceutical products and preparations	1,319	16.54%
	10.00	Manufacture of food products	753	9.44%
	28.30	Manufacture of other machinery	656	8.23%
	20.20	Manufacture of pesticides	441	5.53%
	20.20	Manufacture of pesticides and other agrochemical products	441	5.53%
	28.90	Manufacture of other special-purpose machinery	270	3.39%
	26.50	Manufacture of instruments and appliances for measuring, testing and navigation	192	2.41%
	28.29	Manufacture of other general-purpose machinery	165	2.07%
	32.90	Manufacturing	165	2.07%
	22.00	Manufacture of rubber and plastic products	162	2.03%
Data Communication and Digital Systems	26.20	Manufacture of computers and peripheral equipment	3,958	15.54%
	26.30	Manufacture of communication equipment	3,896	15.29%
	62.00	Computer programming	2,089	8.20%
	28.23	Manufacture of office machinery	2,062	8.09%
	26.50	Manufacture of measuring instruments	1,345	5.28%
	26.50	Manufacture of instruments and appliances for measuring, testing and navigation	1,345	5.28%
	27.12	Manufacture of electricity distribution and control apparatus	1,188	4.66%
	29.10	Manufacture of motor vehicles	1,086	4.26%
	27.20	Manufacture of batteries and accumulators	754	2.96%
	28.90	Manufacture of other special-purpose machinery	601	2.36%
	26.10	Manufacture of electronic components and boards	590	2.32%
Resource and Material Efficiency	23.50	Manufacture of cement, lime and plaster	4,129	21.95%
	20.10	Manufacture of basic chemicals	2,642	14.04%
	28.90	Manufacture of other special-purpose machinery	1,211	6.44%
	43.00	Specialised construction activities	1,106	5.88%
	24.00	Manufacture of basic metals	570	3.03%
	24.00	Manufacture of basic metals	570	3.03%
	23.30	Manufacture of clay building materials	564	2.99%
	27.20	Manufacture of batteries and accumulators	542	2.88%
	26.30	Manufacture of communication equipment	529	2.81%

Topic	NACE Code	NACE Title	n. patents	% patents
	23.00	Manufacture of other non-metallic mineral products	461	2.45%
	22.00	Manufacture of rubber and plastic products	393	2.09%
Resource Recovery	20.10	Manufacture of basic chemicals	10,361	28.04%
	28.29	Manufacture of other general-purpose machinery	4,083	11.05%
	28.90	Manufacture of other special-purpose machinery	1,486	4.02%
	21.00	Manufacture of basic pharmaceutical products and preparations	1,263	3.42%
	32.50	Manufacture of electronic equipment	1,146	3.10%
	28.30	Manufacture of agricultural and forestry machinery	1,048	2.84%
	27.50	Manufacture of domestic appliances	977	2.64%
	26.10	Manufacture of electronic components and boards	946	2.56%
	28.99	Manufacture of other special-purpose machinery	939	2.54%
	27.20	Manufacture of batteries and accumulators	902	2.44%
Battery Technologies and Recycling	27.20	Manufacture of batteries and accumulators	6,816	33.80%
	20.10	Manufacture of basic chemicals	2,109	10.46%
	26.10	Manufacture of electronic components and boards	1,423	7.06%
	27.12	Manufacture of electric batteries	1,251	6.20%
	29.10	Manufacture of motor vehicles	838	4.16%
	28.90	Manufacture of other special-purpose machinery	571	2.83%
	27.90	Manufacture of other electrical equipment	496	2.46%
	24.00	Manufacture of basic metals	495	2.45%
	30.00	Manufacture of other transport equipment	382	1.89%
	28.23	Manufacture of office machinery and equipment	365	1.81%
Recycling Equipment and Waste Management	28.90	Manufacture of other special-purpose machinery	4,135	12.56%
	20.10	Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms	3,411	10.36%
	28.29	Manufacture of other general-purpose machinery	2,622	7.97%
	28.40	Manufacture of metal forming machinery and machine tools	1,883	5.72%
	22.20	Manufacture of rubber and plastic products	1,284	3.90%
	28.10	Manufacture of general-purpose machinery	1,225	3.72%
	28.99	Manufacture of other special-purpose machinery	1,133	3.44%
	22.00	Manufacture of rubber and plastic products	1,112	3.38%
	28.30	Manufacture of agricultural and forestry machinery	1,065	3.24%
	27.50	Manufacture of domestic appliances	1,012	3.07%

Table A.10: Distribution of patents per CE topics across NACE codes

Topic	Tech. Field	Name	n. patents	% patents
Reduce	1	Electrical machinery, apparatus, energy	11,027	7.93%
	23	Chemical engineering	9,964	7.16%
	29	Other special machines	9,124	6.56%
	24	Handling	8,375	6.02%
	25	Manufacture of electronic components and boards	7,655	5.50%
	32	Transport	5,685	4.09%
	15	Biotechnology	5,538	3.98%
	6	Computer technology	5,427	3.90%
	9	Optics	5,095	3.66%
	28	Textile and paper machines	4,978	3.58%
Reuse	29	Other special machines	14,714	10.14%
	25	Manufacture of electronic components and boards	8,150	5.62%
	19	Basic materials chemistry	8,081	5.57%
	20	Materials, metallurgy	8,081	5.57%
	15	Biotechnology	7,798	5.38%
	28	Textile and paper machines	7,563	5.21%
	23	Chemical engineering	7,226	4.98%
	1	Electrical machinery, apparatus, energy	7,193	4.96%
	21	Surface technology, coating	5,895	4.06%
	17	Macromolecular chemistry, polymers	5,515	3.80%
Recycle	29	Other special machines	6,962	8.86%
	32	Transport	5,922	7.54%
	31	Mechanical elements	5,092	6.48%
	1	Electrical machinery, apparatus, energy	5,029	6.40%
	25	Manufacture of electronic components and boards	4,592	5.85%
	35	Civil engineering	4,350	5.54%
	34	Other consumer goods	3,144	4.00%
	26	Machine tools	3,000	3.82%
	28	Textile and paper machines	2,683	3.42%
	33	Furniture, games	2,669	3.40%
Repair	24	Handling	6,303	17.65%
	1	Electrical machinery, apparatus, energy	4,222	11.83%
	23	Chemical engineering	3,755	10.52%
	29	Other special machines	2,575	7.21%
	19	Basic materials chemistry	2,010	5.63%
	20	Materials, metallurgy	1,812	5.08%
	25	Handling	1,749	4.90%
	8	Semiconductors	1,472	4.12%
	33	Furniture, games	1,292	3.62%
	35	Civil engineering	1,248	3.50%
Refurbish	35	Civil engineering	3,223	10.40%
	29	Other special machines	3,211	10.36%
	21	Surface technology, coating	2,406	7.76%
	32	Transport	1,898	6.12%
	20	Materials, metallurgy	1,738	5.61%

Topic	Tech. Field	Name	n. patents	% patents
	33	Furniture, games	1,525	4.92%
	25	Manufacture of electronic components and boards	1,444	4.66%
	8	Semiconductors	1,334	4.30%
	34	Other consumer goods	1,246	4.02%
	28	Textile and paper machines	1,123	3.62%

Table A.11: Distribution of patents per 5R topics across IPC technological fields

Topic	Tech. Field	Name	n. patents	% patents
Material and Process Innovation	25	Handling	8,984	10.70%
	29	Other special machines	6,249	7.44%
	23	Chemical engineering	5,961	7.10%
	28	Textile and paper machines	4,767	5.68%
	33	Furniture, games	4,110	4.89%
	1	Electrical machinery, apparatus, energy	3,982	4.74%
	24	Environmental technology	3,684	4.39%
	8	Semiconductors	3,638	4.33%
	35	Civil engineering	3,119	3.71%
	32.0	Transport	3,032	3.61%
Polymers, Composites, and Material Recycling	29.0	Other special machines	10,365	13.26%
	15.0	Biotechnology	8,308	10.63%
	17.0	Macromolecular chemistry, polymers	5,940	7.60%
	19.0	Basic materials chemistry	5,792	7.41%
	28.0	Textile and paper machines	5,318	6.80%
	21.0	Surface technology, coating	4,498	5.75%
	18.0	Civil engineering	4,029	5.15%
	23.0	Chemical engineering	3,938	5.04%
	25.0	Handling	3,900	4.99%
	20.0	Basic communication processes	2,617	3.35%
Imaging and Display Technologies	9	Optics	6,053	17.82%
	8	Semiconductors	3,070	9.04%
	2	Audio-visual technology	2,770	8.15%
	6	Computer technology	2,211	6.51%
	1	Electrical machinery, apparatus, energy	2,108	6.21%
	29	Other special machines	1,655	4.87%
	10	Measurement	1,492	4.39%
	17	Macromolecular chemistry, polymers	1,348	3.97%
	21	Surface technology, coating	1,222	3.60%
	3	Telecommunications	1,025	3.02%
Adaptive Structures and Materials	29	Other special machines	9,228	10.01%

Topic	**Tech. Field**	**Name**	**n. patents**	**% patents**
	32	Transport	7,325	7.95%
	35	Civil engineering	7,287	7.91%
	34	Other consumer goods	6,864	7.45%
	1	Electrical machinery, apparatus, energy	6,164	6.69%
	25	Handling	5,469	5.93%
	33	Furniture, games	5,042	5.47%
	31	Mechanical elements	4,655	5.05%
	26.0	Machine tools	4,329	4.70%
	28	Textile and paper machines	3,487	3.78%
Agriculture and Resource Optimization	19	Basic materials chemistry	1,493	18.53%
	15	Biotechnology	1,343	16.67%
	29	Other special machines	910	11.29%
	18	Civil engineering	781	9.69%
	24	Environmental technology	592	7.35%
	25	Handling	5,469	5.93%
	33	Furniture, games	5,042	5.47%
	31	Mechanical elements	4,655	5.05%
	26	Machine tools	4,329	4.70%
	28	Textile and paper machines	3,487	3.78%
Data Communication and Digital Systems	6	Computer technology	4,677	18.21%
	1	Electrical machinery, apparatus, energy	2,195	8.54%
	7	IT methods for management	2,089	8.13%
	4	Digital communication	2,073	8.07%
	3	Telecommunications	1,818	7.08%
	12	Control	1,418	5.52%
	10	Measurement	1,311	5.10%
	2	Audio-visual technology	1,230	4.79%
	32	Transport	1,225	4.77%
	29	Other special machines	883	3.44%
Resource and Material Efficiency	20	Materials, metallurgy	5,073	17.31%
	35	Civil engineering	1,742	9.38%
	29	Other special machines	1,481	7.97%
	19	Basic materials chemistry	1,241	6.68%
	1	Electrical machinery, apparatus, energy	932	5.02%
	24	Materials, metallurgy	870	4.68%
	2	Audio-visual technology	802	4.32%
	23	Chemical engineering	766	4.12%
	21	Surface technology, coating	743	4.00%
	17	Macromolecular chemistry, polymers	657	3.54%
Resource Recovery	24	Environmental technology	9,435	15.21%
	23	Chemical engineering	4,901	13.10%
	19	Basic materials chemistry	1,933	5.17%

Topic	Tech. Field	Name	n. patents	% patents
	15	Biotechnology	1,781	4.76%
	29	Other special machines	1,738	4.64%
	35	Civil engineering	1,628	4.35%
	25	Handling	1,477	3.95%
	1	Electrical machinery, apparatus, energy	1,350	3.61%
	30	Thermal processes and apparatus	1,308	3.50%
	33	Furniture, games	1,062	2.84%
Battery Technologies and Recycling	1	Electrical machinery, apparatus, energy	8,525	14.71%
	20	Materials, metallurgy	1,694	8.88%
	32	Transport	1,198	6.28%
	8	Semiconductors	848	4.45%
	21	Surface technology, coating	837	4.39%
	23	Chemical engineering	620	3.25%
	25	Handling	468	2.45%
	29	Other special machines	434	2.28%
	28	Textile and paper machines	417	2.19%
	24	Environmental technology	404	2.12%
Recycling Equipment and Waste Management	23	Chemical engineering	4,542	14.06%
	29	Other special machines	3,643	11.28%
	24	Environmental technology	3,314	10.26%
	26	Machine tools	2,068	6.40%
	25	Handling	1,634	5.06%
	20	Materials, metallurgy	1,532	4.74%
	19	Basic materials chemistry	1,364	4.22%
	35	Civil engineering	1,300	4.02%
	1	Electrical machinery, apparatus, energy	1,224	3.79%
	31	Mechanical elements	1,119	3.46%

Table A.12: Distribution of patents per CE topics across IPC technological fields

Name	n. patents	% patents	
1	Procter & Gamble	3,631	1.32%
2	Samsung Electronics Co., Ltd.	3,506	1.27%
3	Siemens AG	3,305	1.20%
4	Robert Bosch GmbH	3,200	1.16%
5	Novozymes A/S	3,151	1.15%
6	Hewlett Packard Development Company, L.P.	2,723	0.99%
7	Matsushita Electric Industrial Co., Ltd.	2,644	0.96%
8	BASF SE	2,627	0.96%
9	E.I. du Pont de Nemours and Company & CO	2,488	0.90%
10	LG Electronics	2,481	0.90%

Name	n. patents	% patents	

Table A.13: Top applicants CE patents

Topic	Company Name	n. patents	% patents
Reduce	Samsung Electronics Co., Ltd.	1,217	0.87%
	Matsushita Electric Industrial Co., Ltd.	839	0.60%
	LG Electronics	642	0.46%
	Hewlett Packard Development Company	607	0.43%
	Robert Bosch GmbH	542	0.39%
	General Electric Co.	536	0.38%
	E.I. du Pont de Nemours and Company	492	0.35%
	Siemens AG	474	0.34%
	Toyota Jidosha CO. Ltd.	462	0.33%
	Procter & Gamble	459	0.33%
Reuse	Hewlett Packard Development Company, L.P.	1,172	0.81%
	Procter & Gamble	1,066	0.73%
	LG Chem Ltd.	645	0.44%
	E.I. du Pont de Nemours and Company	624	0.43%
	Novozymes A/S	594	0.41%
	Samsung Electronics Co., Ltd.	584	0.40%
	3M Innovative Properties Co.	540	0.37%
	BASF SE	534	0.37%
	Matsushita Electric Industrial Co., Ltd.	476	0.33%
	General Electric Co.	446	0.31%
Recycle	Siemens AG	572	0.72%
	General Electric Co.	470	0.59%
	Samsung Electronics Co., Ltd.	433	0.54%
	Robert Bosch GmbH	415	0.52%
	The Boeing Co.	394	0.50%
	LG Electronics	377	0.47%
	Bayerische Motoren Werke AG	367	0.46%
	E.I. du Pont de Nemours and Company	288	0.36%
	Hewlett Packard Development Company, L.P.	260	0.33%
	Halliburton Energy Services Inc.	254	0.32%
Repair	Samsung Electronics Co., Ltd.	299	0.83%
	LG Chem Ltd.	208	0.58%
	Robert Bosch GmbH	186	0.52%
	LG Electronics	167	0.47%
	Matsushita Electric Industrial Co., Ltd.	157	0.44%
	Voith Patent GmbH	125	0.35%
	Procter & Gamble	123	0.34%
	SANYO Electric Co., Ltd.	120	0.33%
	Siemens AG	117	0.33%

Topic	Company Name	n. patents	% patents
	BASF SE	91	0.25%
Refurbish	The Boeing Co.	225	0.71%
	General Electric Co.	177	0.56%
	3M Innovative Properties Co.	142	0.45%
	E.I. du Pont de Nemours and Company	136	0.43%
	Procter & Gamble	125	0.40%
	Siemens AG	112	0.35%
	Airbus Operations GmbH	97	0.31%
	Hewlett Packard Development Company, L.P.	92	0.29%
	Hoechst AG	85	0.27%
	SCHOTT AG	82	0.26%

Table A.14: Top applicants per 5R topics

Topic	Company Name	n. patents	% patents
Material and Process Innovation	Hewlett Packard Dev Co LP	562	0.67%
	LG Electronics Inc	557	0.67%
	The Procter & Gamble Co	459	0.55%
	Samsung Electronics Co Ltd	412	0.49%
	Matsushita Electric Ind Co Ltd	395	0.47%
	Voith Patent Gmbh	292	0.35%
	The Boeing Co	279	0.33%
	Siemens Ag	278	0.33%
	Robert Bosch Gmbh	273	0.33%
	E I Du Pont De Nemours & Co	255	0.31%
Polymers, Composites, and Material Recycling	Novozymes As	728	0.95%
	The Procter & Gamble Co	649	0.85%
	E I Du Pont De Nemours & Co	641	0.83%
	Basf Se	464	0.60%
	Basf Ag	404	0.53%
	Voith Patent Gmbh	377	0.49%
	Dsm Ip Assets Bv	314	0.41%
	The Regents Of The University Of California	300	0.39%
	Henkel Ag&Co Kgaa	291	0.38%
	Bayer Ag	268	0.35%
Imaging and Display Technologies	Samsung Electronics Co Ltd	510	1.48%
	Matsushita Electric Ind Co Ltd	280	0.81%
	3M Innovative Properties Co	265	0.77%
	Fujifilm Corp	249	0.72%
	Eastman Kodak Co	242	0.70%
	Canon Co Ltd	231	0.67%

Topic	Company Name	n. patents	% patents
	Apple Inc	193	0.56%
	LG Electronics Inc	179	0.52%
	Kon Philips Elect Nv	171	0.50%
	Halliburton Energy Services Inc	160	0.47%
Adaptive Structures and Materials	Hewlett Packard Dev Co LP	896	0.94%
	Samsung Electronics Co Ltd	681	0.71%
	General Elect Co	638	0.67%
	Nike Inc	523	0.55%
	Siemens Ag	483	0.51%
	The Boeing Co	427	0.45%
	Robert Bosch Gmbh	410	0.43%
	LG Electronics Inc	392	0.41%
	The Procter & Gamble Co	360	0.38%
	United Tech Corp	298	0.31%
Agriculture and Resource Optimization	E I Du Pont De Nemours & Co	75	0.94%
	Novozymes As	58	0.73%
	Basf Ag	56	0.70%
	Varco I P Inc	56	0.70%
	Dsm Ip Assets Bv	49	0.61%
	Fujifilm Corp	40	0.50%
	The Regents Of The University Of California	30	0.38%
	Michelin Recherche Et Technique Sa	27	0.34%
	Farmer, Sean	26	0.33%
	Murata Manufacturing Co Ltd	26	0.33%
Data Communication and Digital Systems	Samsung Electronics Co Ltd	291	1.14%
	Hewlett Packard Dev Co LP	255	1.00%
	Apple Inc	213	0.84%
	Siemens Ag	185	0.73%
	General Elect Co	181	0.71%
	Sony Corp	158	0.62%
	Robert Bosch Gmbh	140	0.55%
	Matsushita Electric Ind Co Ltd	133	0.52%
	Toyota Jidosha Co Ltd	123	0.48%
	Silverbrook Research Pty Ltd	122	0.48%
Resource and Material Efficiency	Halliburton Energy Services Inc	177	0.94%
	Ajinomoto Co Inc	102	0.54%
	Sika Tech Ag	88	0.47%
	United States Gypsum Co	81	0.43%
	Basf Se	78	0.41%
	Construction Research & Tech Gmbh	75	0.40%
	3M Innovative Properties Co	70	0.37%

Topic	**Company Name**	**n. patents**	**% patents**
	Siemens Ag	61	0.32%
	Matsushita Electric Ind Co Ltd	57	0.30%
	Degussa Ag	54	0.29%
Resource Recovery	Samsung Electronics Co Ltd	139	0.38%
	Robert Bosch Gmbh	135	0.37%
	LG Chem Ltd	122	0.33%
	Siemens Ag	112	0.30%
	The Procter & Gamble Co	110	0.30%
	General Elect Co	99	0.27%
	LG Electronics Inc	94	0.25%
	The Regents Of The University Of California	92	0.25%
	Matsushita Electric Ind Co Ltd	88	0.24%
	Degremont	85	0.23%
Battery Technologies and Recycling	LG Chem Ltd	517	2.56%
	Matsushita Electric Ind Co Ltd	306	1.52%
	Samsung Electronics Co Ltd	271	1.34%
	Robert Bosch Gmbh	261	1.29%
	Toyota Jidosha Co Ltd	241	1.20%
	Contemporary Amperex Tech Co Ltd	131	0.65%
	Murata Manufacturing Co Ltd	122	0.61%
	Siemens Ag	114	0.57%
	Sanyo Elect Co Ltd	113	0.56%
	Basf Se	107	0.53%
Recycling Equipment and Waste Management	Mann Hummel Gmbh	272	0.83%
	The Procter & Gamble Co	167	0.51%
	Siemens Ag	148	0.45%
	Deere & Co	133	0.40%
	Robert Bosch Gmbh	128	0.39%
	Ntn Corp	118	0.36%
	Cnh Industrial Belgium Nv	108	0.33%
	Matsushita Electric Ind Co Ltd	107	0.33%
	Samsung Electronics Co Ltd	101	0.31%
	Ab Skf	88	0.27%

Table A.15: Top applicants per CE topics

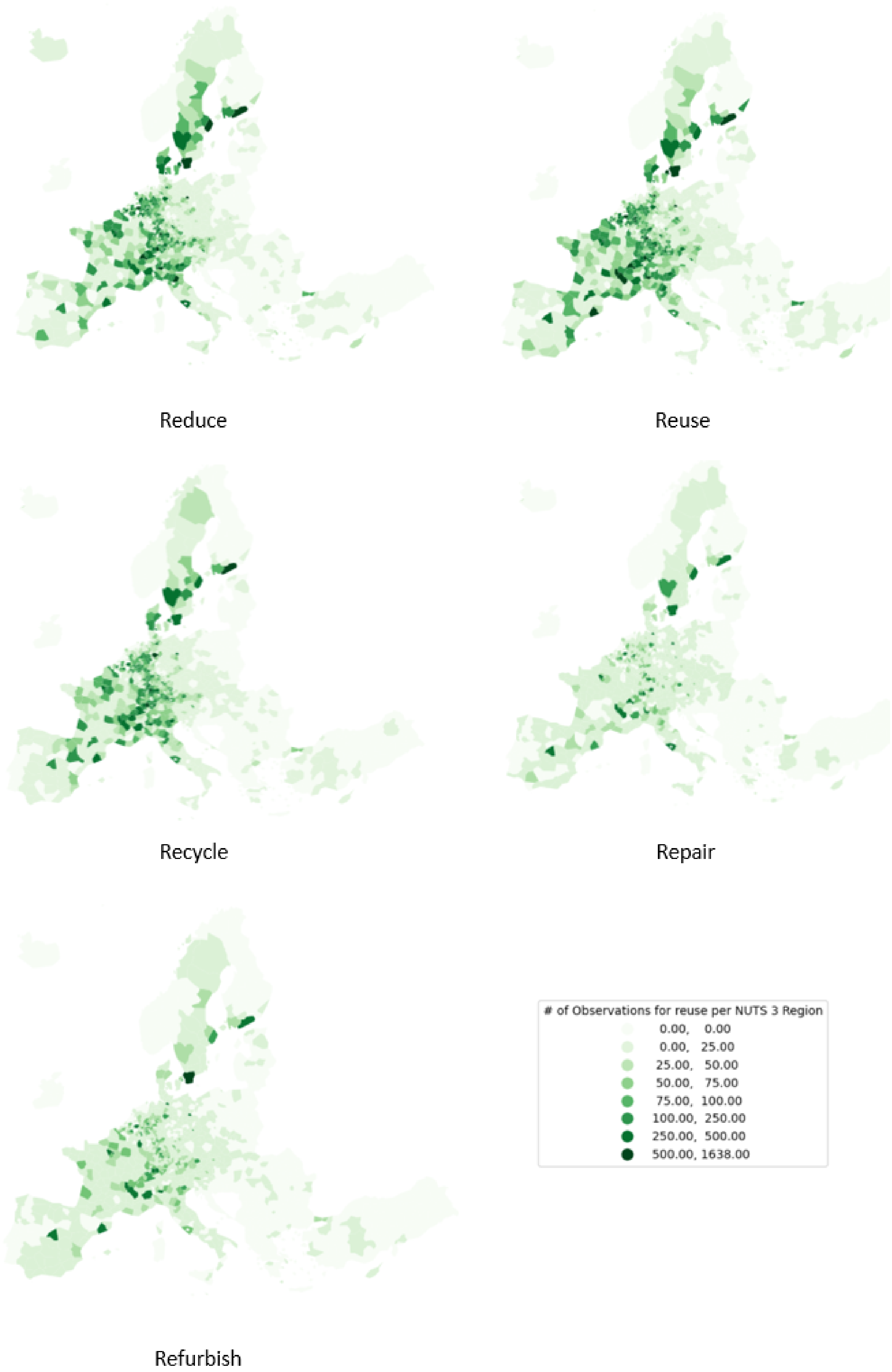

Figure A.3: Distribution of CE patents per 5R topics at Nuts3 level