Two Urban Metabolism Based Approaches to Implement Circular Economy at the Urban Scale

Master of Science thesis in Industrial Ecology

YANGJINQI (VIGIL) YU

Department of Architecture and Civil Engineering
Division of Water Environment Technology
Urban Metabolism Group
CHALMERS UNIVERSITY OF TECHNOLOGY
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Department of Architecture and Civil Engineering
Division of Water Environment Technology
Urban Metabolism Group
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 1000

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ABSTRACT

Our civilization has come a long way from the stone age to the era of internet, through which every aspect of the human life from transportation, food to communication has been evolving dramatically, what remains true is our dependence on natural resources every step of the way.

In recent decades, as the negative environmental impact of the linear model of extraction, consumption and disposal of natural resources has become better recognized, efforts are made to decouple our economic growth from exploitation of nature. However, the progress made towards decoupling is not matching the growing global population and their demand for economic growth, which will still be dependent on exploiting natural resources soon exceed nature's limit, either in the form of collateral impact like greenhouse effect or the very depletion of essential materials.

Circular economy has been a buzzword recently proposing a paradigm shift of our relationship with resources from the traditional linear model to a circular model where materials' value is preserved for as long as possible in the economy. Predominantly the business world has been exploring this concept and developing circular business models, however realized projects are quite sporadic and limited.

The objective of the thesis is to explore circular economy implementation at the urban scale because cities host 50% and very soon 75% of the global population and uses 70% of resources to provide 70% of total GDP. So far a few cities have attempted to implement the circular economy vision. Their plans are examined against a set of criteria both on the methodologies and on their ability to achieve the circular vision. Gaps will be identified and two new systematic approaches will be introduced in attempt to fill these gaps. The approaches are based on an Urban Metabolism model developed by Rosado (2012) to optimize the material flow accounting with extensions to consider lifespan, economic activities, life stage of the products and etc.

This model will be used to account the material flow of the city of Gothenburg as a case study, which was the basis for the development of the two systematic approaches proposed. The two approaches are: the product approach and the sector approach; the approaches were introduced and then tested on one product (CN code 3917: tubes, pipes and hose of plastic) and one sector (NACE code 4521: general construction).

The approaches are also examined by the previously introduced criteria of the circular economy vision and their merits and limitation will be discussed.

Key words: Circular Economy, Urban Metabolism, UMan Model, Cities, Resources, Product-Service System, Systems thinking, Close the loop

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Preface

This Master of Science thesis was carried out mainly between January and July 2016 (finalised in May 2017) at the Department of Civil and Environmental Engineering at Chalmers University of Technology in Gothenburg, Sweden.

I am very fortunate to have people in my life who have always been there for me and supported me throughout, without them this journey of exploration would not have been possible. Therefore, I would like to express my gratitude for them here.

First and foremost, I would like to thank my thesis examiner, Yuliya Kalmykova for her patience, understanding and guidance during the past year. The inception of this thesis topic came from her originally and she has been an inspiration throughout the whole process. Also crucial to this work is Leonardo Rosado, my supervisor. I would like to thank him for his time and valuable feedback, but most importantly for that I was able to always count on him to bring clarity when I felt lost in my thinking process.

I would also like to thank my master program, Erasmus Mundus Master of Industrial Ecology for this amazing education experience, for the opportunity to pursue my passion in sustainability and for bringing many like-minded people into my life.

And last but not least, I am grateful to my family and friends for their listening ears when I was going though ups and downs during this work and life in general.

This thesis was crucial to the start of my career in the sustainability field. The most important thing I have learned was that there is so much more to be learned. And I very much look forward to it.

Beijing, May 2017
Vigil Yangjinqi Yu

1. Introduction

1.1 Two troubling megatrends and an opportunity

1.1.1 Resource depletion

The First Industrial Revolution began in the Great Britain in the late 18th century, which first brought mechanization to the textile industry. Hundreds of weaving labour could be replaced by a single cotton mill that can work tirelessly as long as proper fuel was fed to the steam engines. Thus, the factory was born. The Second Industrial Revolution followed in the early 20th Century and the art of mass production was perfected by Henry Ford and his moving assembly line, accompanied by a reconfiguration of capital with the development of corporation and bank investment systems (The Economist, 2012; Heck et al, 2015). Mass production was brought to a massive scale as the world has been becoming better connected by roads, cars, electric grid and now, the internet. Such technological and social advancements have benefited our society tremendously in the form of economic growth, urbanization, and overall higher quality of life. However, it has come with a price.

The boom of economic development relies heavily on the exploitation of natural resources and it is obvious that our resource consumption has been steeply rising, especially in recent decades along with the increase of GDP (see Figure 1 which shows the correlation between GDP growth and mineral, fossil, construction and biomass resource extraction). All relevant scientific studies showed that such trend of increasing resource exploitation has been having adverse impact on the climate and geological environment, pushing the limit of earth's capacity (UNEP, 2011). Donella Meadows ran a world model four decades ago and found that that if the present growth trends in population, industrialization, pollution, food production and resource depletion persists, we will reach the limits to growth on this planet in the next one hundred years due to the unbearable ecological constraints related to finite resources and emissions (Meadows, 1972). Such is one of the troubling global megatrend: Climate change and resource scarcity (Global Megatrends, 2015).

At the dawn of another speculative revolution rooted in digitalization, we found ourselves struggling to develop sustainably while supporting the steeply increasing demand from nearly 40% of the world's population who will become industrialized for the first time, mostly in China and India, followed by parts of Asia and South America. This translates as an additional 2.5 billion people having the material and energy demand resembles the current western middle class (Heck et al, 2015). To avoid going beyond the carrying capacity of the planet, actions need to be taken to reduce our ecological footprint.

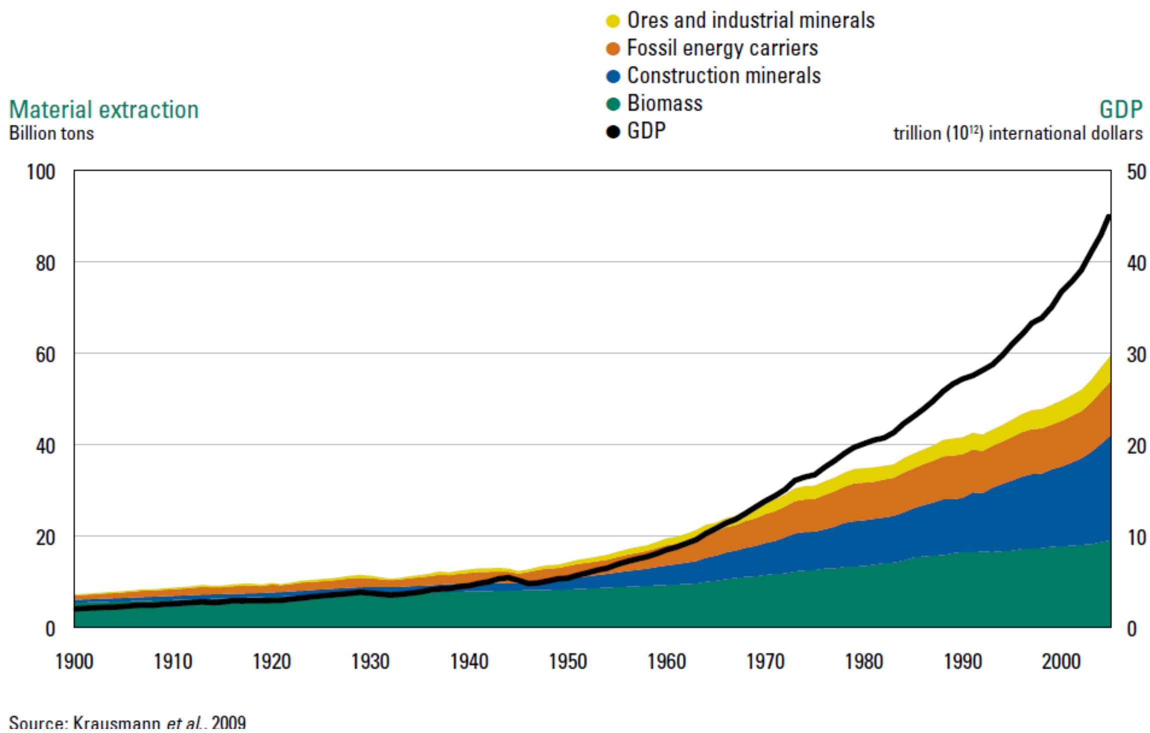

Figure 1. Global Material Extraction in Billion Tons 1900-2005 (Krausmann et al, 2009)

1.1.2 Rapid Urbanization

Urbanization, one of the fruits of modernization thanks to the increase in productivity has been on the rise at unprecedented scale. In 1800, only 2% of the world's population lived in cities and now the number has reached 50% (Global Megatrends, 2015). Moreover, it has been identified as one of the megatrends of our time that the projected urban population share will reach 80% by 2050 (GOR, 2015). Such rapid urbanization is bringing about alarming challenges in terms of intense resource exploitation, consumption and disposal. In fact, cities, occupying only 3% of global land surface, are responsible for 70% of global anthropogenic production of greenhouse gas emissions and use 75% of global natural resources (UNEP). These figures illustrate the importance of taking actions at the urban level to reach the sustainable development goals.
Such urbanization while posed a lot of challenges to the ecosystem, also brought opportunities for better and more efficient resource management. Cities are the central hub of economic activities, generating 80% of global GDP. As the powerhouse of major commercial activities, they have huge potential to reduce human ecological footprint with their complex networks of interlocked infrastructures that host resource flows. After COP21, countries declared goals of carbon emission reduction. Cities have big roles to play and many cities already have their own sustainability plans. Much of it focuses on energy and transportation, the benefit of resource efficiency should be brought more into the spotlight (C40, 2016).

1.1.3 Opportunities: Circular Economy for Cities

Fortunately, opportunities often lie where the challenges are. Cities can be fertile ground for sustainable changes due to the proximity of citizens, retailers and service providers; the highly-skilled workforce and technology savvy markets; and high concentrations of biological and technical nutrients (Stokes). The concept of "circular economy" is a great tool to help conceptualize and eventually achieve more sustainable urbanization.

Circular economy has long been a buzzword in the European policy sphere, for its goal to change the current linear economic model and its potential to maximize resources efficiency. The notion was briefly defined by the Ellen Macarthur Foundation (2013) as "an industrial system that is restorative or regenerative by intention and design." The idea is to eliminate waste through smart design of materials, products, business models and the entire socio-economic systems for a flow of resources in a closed loop, free of toxic chemicals, driven by services and powered by renewable energies. Numerous studies have been done on this topic, however, they are largely only focused on either industrial symbiosis or the business model case studies. Only a few cases of urban implementation of circular economy were found and will be introduced in more details later.

1.2 Objectives

The main objective of the study is to explore the frontier of the theory and practice of implementing circular economy at the urban scale. First a literature review of the state of the art circular economy concept and practice will be done. A set of evaluation criteria of circular economy at the urban scale will be developed from the existing studies. The criteria will then be applied to evaluate four case studies of circular economy at the urban scale to identify gaps in the approaches and their effectiveness in achieving circular economy goals. Finally, two novel systematic approaches of urban circular economy derived from urban metabolism studies will be the proposed, applied to the city of Gothenburg and then evaluated against the previous criteria. The advantages and limitations of the new approaches will be discussed in the end.

1.3 Scope

The geographical scope of both the case study and proposed approaches is set for European cities. Mainly because the data and its coding (NACE and CN statistical codes) are from Eurostat which is the standard accounting tool for European cities. Real data from the city of Gothenburg in Sweden will be used to test the proposed approaches.
In terms of the material flow life cycle impact, this study did not consider the raw material extraction and production phase of the studied products, but only focused on the final consumption and end of life phase as the raw material extraction and the production activities usually occurs elsewhere.

2. Background

2.1 Circular economy concept

The concept of circular economy has been under development since 1966 when Boulding proposed an economic model which, contrary to the linear system, is circular, as in a spaceship where everything moved in a closed loop and the only input is the solar energy (Boulding, 1966). Following Boulding's idea, a series of related concepts emerged:

- Otto Schimitt's "Biomimicry" where the technosphere should imitate the system of nature and aim to establish products and processes in a way that decreases the environmental impact and ensures regeneration of resources (Schmitt, 1969).
- Stahel and Reday-Mulvey in 1981 proposed the notion to slow down material consumption and more importantly, close the loop (Stahel and Reday-Mulvey, 1981).

- In the 1980s scientists, politicians and industries started paying attention to waste management for its increasing environmental impact and policy guidelines. Swiss Federal Waste Guideline of 1986 first coined the “polluters pay principle” (WRF, 2014).
- In 1989, the scarcity of raw material triggered economic interest in waste as resources, which lead to the concept of “industrial ecology” where one industry’s waste could be another’s resource input (WRF).
- 1990s onwards, a shift from single product and process to more integrated, holistic systems thinking approach occurred, in the form of international initiatives like Life Cycle Initiative and the form of the International Resource Panel (WRF, 2014).
- Cradle to cradle (McDonough and Braungart, 2002)
- Service economy (EMF, 2013)
- Sharing economy (Chase, 2015)

All of them can be seen to be related to the concept circular economy in the sense that they all contribute to keeping the resources circulating in a closed loop. Many attempts have been made to define or describe circular economy by various scholars, NGOs and governmental agencies and a synthesis can be found in Appendix 1 and some common elements of Circular Economy identified are:

- It should be an economic model
- Non-biological materials should keep circulating in a closed loop without entering the biosphere
- Biological material can re-enter biosphere safely
- It should be a restorative system by intention and design
- Value maximization is based on usage but not consumption
- It is only powered by renewable energy and labour

2.2 Circular Economy Implementation

The concept of Circular Economy has been carried out in practice in the form of regulations, policies and various business models. **On the national policy level**, China has made notable effort to promote the recirculation of waste materials through setting very ambitious targets and adopting policies, financial measures and legislation like the Circular Economy promotion law in 2008 (first CE in constitution). The implementation of circular economy was done at 3 levels: micro, meso and macro covering scales from product design, eco-industrial parks, and urban or regional level. Though there is still much challenge in bridging the gap between the top level government’s ambition and lower level executive power, much has been achieved in terms of building up 1000 demonstration industrial parks and 100 demonstration cities that showed positive results in reducing environmental impact either through industrial symbiosis, increasing energy and water efficiency or waste management (Su et al, 2012). However, while recognizing the commendable results, there is still not much systematic change in terms of truly closing the material loop or designing a restorative system. Most achievements were only capturing low hanging fruit through technology and networking in the industrial production phase with a focus on metal, water and energy which already have considerable economic value. Not much bottom up effort has been observed and consumers are largely missing from the picture.

Other national level efforts include:
Japan: major legal framework came into force in Jan 2002 to build a recycling based society (METI, 2004. Morioka et al., 2005).
Germany: waste management laws-(“Closed Substance Cycle and Waste Management Act”) have been in place since 1966 and were even renewed in 2012 to incorporate new EU guidelines on improving the environment, and climate and resources protection. It was stated that “waste” should be considered a property or a resource instead of

waste. In addition, a five step hierarchy regarding the “waste” issue was proposed: avoidance, recovery (reuse, recycle, energy recovery), disposal. (BMU 2013)
Switzerland: a smaller economy hosted various national initiatives suggesting adaptable everyday principles regarding Circular Economy: “Recycle to produce new goods, repair existing products as far as possible, focus on the benefit of a product rather than the product itself, and start to share products and services wherever you can – like in the old days with the collective baking ovens” (FOEN 2013).
The Netherlands: as a CE hotspot is home to many clean tech, green business, ngo initiatives (Circle Economy, Metabolic...). Approaching CE from both top down and bottom up both at the national level and regional level. Four city level circular economy case studies will be introduced later and they are all from Dutch cities.

On the business level, innovative circular business models have been emerging which often overlaps with service economy, sharing economy and eco-design principles. Examples are numerous but not clearly defined and scattered all over the spectrum of sustainability concepts. Overall, existing circular economy practices so far have been presented as “scattered consciousness, ... implemented fragmentarily on the levels from single product supply chains to waste sector” (Kalmykova, 2015). Elements of the circular economy principles were adopted when convenient without striving for a real closed loop. Therefore, it’s urgent to put developing systematic and comprehensive circular economy implementation approaches aimed at closing the loop at a promising scale, the urban scale on top of the global sustainable development agenda.

2.3 Evaluation of the Existing Approaches to Urban Circular Economy

2.3.1 Evaluation Criteria

2.3.1.1 Regarding the approach itself

The approach to achieve circular economy at the urban scale can be evaluated from two aspects. One aspect is to evaluate the approach itself from a methodological point of view. A good approach for urban circular economy should be systemic, meaning that it is comprehensive to all resources in the city to a high level of detail, and can be adapted to be used in different types of cities; it also needs to take into consideration of the urban resource flow characteristics: for example, cities are usually intensive areas of consumption, have large resource stocks and potential leakages to the natural environment. Last but not least, life cycle thinking should be applied to avoid outsourcing the environmental damage to other parts of the world. In summary, the evaluation criteria of the approaches are:

- Is it systematic?
    - Is it comprehensive? Can it potentially consider all resource flows in the city?
    - To what level of detail of the resource flow can it reach?
    - Is it adaptable for any city in any country?
- Is it tailored to address urban resource flows?
    - Does it consider city as a main resource consumer?
    - Does it consider the urban resource stock?
    - Does it consider leakage points to nature from the cities?
- Does it apply life cycle thinking?
    - Does it consider the life cycle phases of the products?
    - Does it consider the lifespan of the products?
    - Does it consider beyond the urban boundary for the production and waste phase of the products?

2.3.1.2 Circular economy vision outcome

Such approaches should lead to the generation of strategies to achieve circular economy at the urban scale so the strategies need to be evaluated to see how well they could help achieve the desired vision. Ellen Macarthur Foundation provided an overview of the characteristics of a circular economy, which as previously discussed describes the most desirable vision. The five characteristics (Circular Economy Overview) and relevant enabling factors (EEA Report, 2016) are presented below:

- Design out waste (designed by intention to fit within a cycle, or to a lesser degree: Optimise exploitation of raw materials to deliver more with less input)
    - The biological materials are non-toxic and can be simply composted.
    - Technical materials (polymers, alloys and other man-made compounds) are designed to have longer life span and to be reused, refurbished, repaired, remanufactured with minimal energy and highest quality retention, if cannot be replaced by biological material.
    - Substitute hazardous substance.

- Build resilience through diversity
    - Modularity, versatility, and adaptability.
    - Balance efficiency with resilience
    - Replace virgin materials with recycled materials.

- Work towards energy from renewable sources
    - Systems should ultimately aim to run on renewable energy
    - Reduce the need for fossil-fuel and capture more of the energy value of by-products and manures.

- Think in systems (understand how parts influence one another within a whole, and the relationship of the whole to the parts)
    - Elements are considered in relation to their environmental and social contexts:
        - Economic incentives (internalization of environmental cost, deposit system, extended producer responsibility, tax on natural resources and pollution).
        - Business models (service and towards collaborative).
        - Technological and social innovation.
        - Governance, skills, knowledge and awareness.

- Think in cascades
    - extract additional value from products and materials by cascading them through other applications.
    - Recycling: avoid mixing and contamination, then used again as secondary material

2.3.2 Urban Scale Circular Economy Case Study Evaluation

There has been no shortage of environmental strategies at the city level, however recently several cities took it to the next level and initiated efforts to develop a circular economy vision at the urban scale. For example, Singapore has a Punggol Eco-Town, that hosts a “living laboratory” for sustainable public housing where water from the sinks is reused to flush the toilets, and residents are encouraged to recycle and solar panels are let and maintained by a private company for profit. The LED lights are installed and maintained by Philips, who charge only for the lighting service and then takes them back at the end of life to recycle and upgrade for reuse. Detroit has set up the “Reuse Opportunity Collaboratory” as a platform for entrepreneurs, businesses and industries to co-create closed-loop systems in which one organisation’s waste becomes another’s raw materials.” (Go Green). However, the four most comprehensive circular economy studies found have been done for two Dutch cities, Rotterdam and Amsterdam. Here their approaches will be briefly summarized and evaluated with the criteria introduced previously.

2.3.2.1 Rotterdam

Rabobank

The Rotterdam and Delta region hosts Antwerp and Rotterdam ports, where many icons of industry and logistics reside to manage considerable flow of resources. The city recognized the importance of sustainability and aimed to develop circular economy. The municipality collaborated with Rabobank and many stakeholders to address the energy, metals, chemical, and agriculture sectors. These sectors were selected based on major local activities on agriculture, aquaculture, industries, logistics, resource flows, knowledge, infrastructure and finance.

A four step pathway models for circular economy transformation were proposed:

1. Business as usual
2. Recycling and alternatives take hold
3. New markets come up
4. Circular economy emerges

Chosen sectors/flows were evaluated for status quo and strategies were proposed based on 4 principles to achieve a more circular future:

- use less: minimises inputs and eliminates waste and pollution
- do more: maximises the value created at each stage
- manage resources: manages flows of bio based resources and back to biosphere; recovers and retains flows of non-renewables in closed loops
- work together: promotes mutually beneficial relationships between companies within each circular chain (Port of Rotterdam & Rabobank, 2012).

The main framework of the study is illustrated in the Figure 2. below.

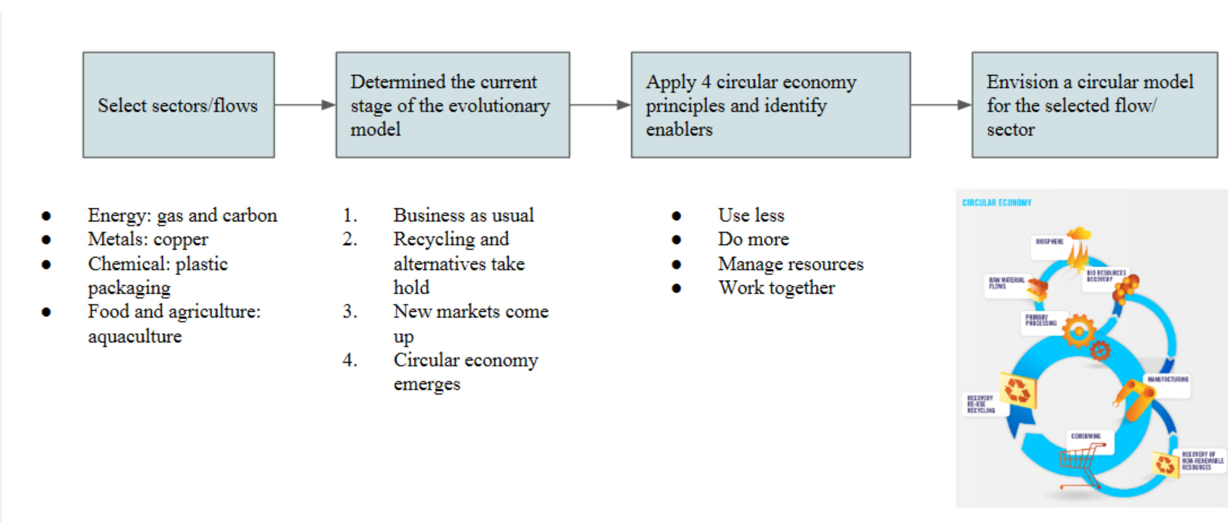

Figure 2. Conceptual illustration of Rotterdam Rabobank report. (Port of Rotterdam & Rabobank, 2012)

Evaluation

Evaluation criteria	
Methodological	
Is it systematic? Is it comprehensive? Can it potentially consider all resource flows in the city? How detailed is it/ to what level of detail of the resource can it reach? Is it adaptable for any city in any country?	The methodology is not systematic. The target flows are not unified but focused on a mix of sector (ie: energy & agriculture), product (ie: packaging), material (ie: copper) or unspecified (ie: aquaculture). The selection process is based on existing efforts therefore cannot be easily adapted to other cities or countries. It does not aim to be inclusive of the whole urban economy. The illustrated flows are also oversimplified and missing many components.
Is it tailored to address urban resource flows? Does it consider city as a main resource consumer? Does it consider the urban resource stock? Does it consider leakage points to nature from the cities?	The flows depicted seem to be mainly industrial process based, rather than urban living centred. Didn't mention the notion of "stock" and the related time scale is not taken into account. Emissions in general were considered.
Does it apply life cycle thinking? Does it consider the life cycle phase of the products? Does it consider the lifespan of the products? Does it consider beyond the urban boundary for the production and waste phase of the products?	Neither the life cycle phase nor the lifespan of the products were examined in detail. The exploitation of raw material and emission phase are partially or entirely left out of the scope. The resources input and output of the urban area were not balanced or justified.
Circular Economy Vision Outcome	
Design out waste (designed by intention to fit within a cycle, or to a lesser degree: Optimise exploitation of raw materials to deliver more with less input). The biological materials are non-toxic and can be simply composted. Technical materials (polymers, alloys and other man-made compounds) are designed to have longer life span and to be reused, refurbished, repaired, remanufactured with minimal energy and highest quality retention, if cannot be replaced by biological material. Substitute hazardous substance.	In terms of closing the loop for either the material flow or economic sector according to the real circular economy visions, the strategies proposed also failed. It is mostly because of a lack of life cycle thinking. Besides, waste has not been designed out but remains part of the system. The strategies did focus on maximizing material value mostly through better waste value recovery (higher carbon price, recycling, incineration) which only resulted in incremental improvements.
Build resilience through diversity. Modularity, versatility, and additivity. Balance efficiency with resilience. Replace virgin materials with recycled materials.	Multiple processes were proposed in the circular vision, especially in resource schemes but not enough details were provided.
Work towards energy from renewable sources. Systems should ultimately aim to run on renewable energy. Reduce the need for fossil-fuel and capture more of the energy value of by-products and manures.	The report proposed to promote bio-based economy however the result is still largely fossil based and renewable energy was not considered as priority. For a CE vision, fossil fuel use should not be merely reduced but mostly taken out of the system.

Think in systems (understand how parts influence one another within a whole, and the relationship of the whole to the parts) Elements are considered in relation to their environmental and social contexts: Economic incentives (internalization of environmental cost, deposit system, extended producer responsibility, tax on natural resources and pollution). Business models (service and towards collaborative).Technological and social innovation. Governance, skills, knowledge and awareness.	Many social sectors (business, governance, technology, knowledge...) were taken into consideration in the hope to collaborate, with the big focus on how companies can get on board and take actions.
Think in cascades extract additional value from products and materials by cascading them through other applications. Recycling: avoid mixing and contamination, then used again as secondary material	This has been done quite well in the study with the central principles being "do more with less"

International Architecture Biennale Rotterdam (IABR, 2014)

This development plan is unique in the way that it was proposed from the urban design and planning perspective. Therefore, it is quite conceptual, creative and different from other traditional urban resource flow studies. Urban metabolism tool was used to study the flows of 9 streams: goods, people, waste, biota (plants and animals), energy, food, fresh water, air, sand and clay. The selection was made based on the local features; material flows with the biggest impact was selected: An analysis of material flows in Amsterdam (Verstraeten, 2013) showed that the flows of goods, building materials, food and electricity production were the most relevant in the city (IABR, 2014).

Three general principles were introduced as “planning instruments”:

- Create cohesion between urban flows by designing and optimizing infrastructure to be aligned further with the flows they influence...
- Maximize positive effects on the quality of living environment by connecting flows with the help of urban metabolism data.
- Take advantage of urban landscape “spatial order” by paying attention to the location of infrastructures (mobility, utility, heat networks and etc) (IABR, 2014).

Additionally, two approaches to improve urban metabolism studies were reviewed. The first one is from the urban planning perspective where there are opportunities to “take advantage of the geographical proximity of material flows to create preconditions for synergies between different flows”. The second one is from the circular economy perspective where the production-consumption chain is considered for optimization using EMF’s “re-use, redesign, innovation and substitution” principles (IABR, 2014).

Four general strategies were proposed to be applied at both regional and city level to optimize selected flows:

1. Collecting resources—obtaining raw materials from waste and food

Regional level: aquaculture, horticulture and e-waste collection.
Aquafarming: harvesting lost nutrients from the sea
Biobased production for plastic, medicine, cosmetics…

City level: make separation and recycling easy for people

Phosphate recovery: from toilet etc.
Protein collectives: kitchen garburator etc; makes recycling household food waste easier so they can be used for insect breeding, urban farming etc.
Residue supermarket: use supermarkets as collection and exchange point

2. Creating biotopes-- improving urban nature by local use of fresh water, sand and clay
Regional: delta facing threat from silting and salinization
Ecological energy network: use space under high voltage power lines for biota
Water landscapes: water storage for dry period

City level: dredging sedimentation from the port is very costly, should use them locally
Sedimentation banks and land farming.
Water storage instead of drainage

3. Channelling energy waste: the use of by-products of energy extraction
Regional: use waste heat and excess CO_2 by expanding existing heat network; collect carbon from power plant and send them to greenhouses
Heating network for geothermal heat
Organic CO_2 for assimilation of plants

City:
Constructing geothermal heat hubs

4. Catalysing reindustrialization: boost the quality of flows, people and air

Region: new manufacturing industry for added value; better public transportation for better mobility of people, ie light rail ring

City: new form of manufacturing and crafts; optimization of logistics
Electrical-loop for logistics
Reindustrialization boulevard (IABR, 2014).

The four strategies and their application to flows are illustrated in the Figure 3. below

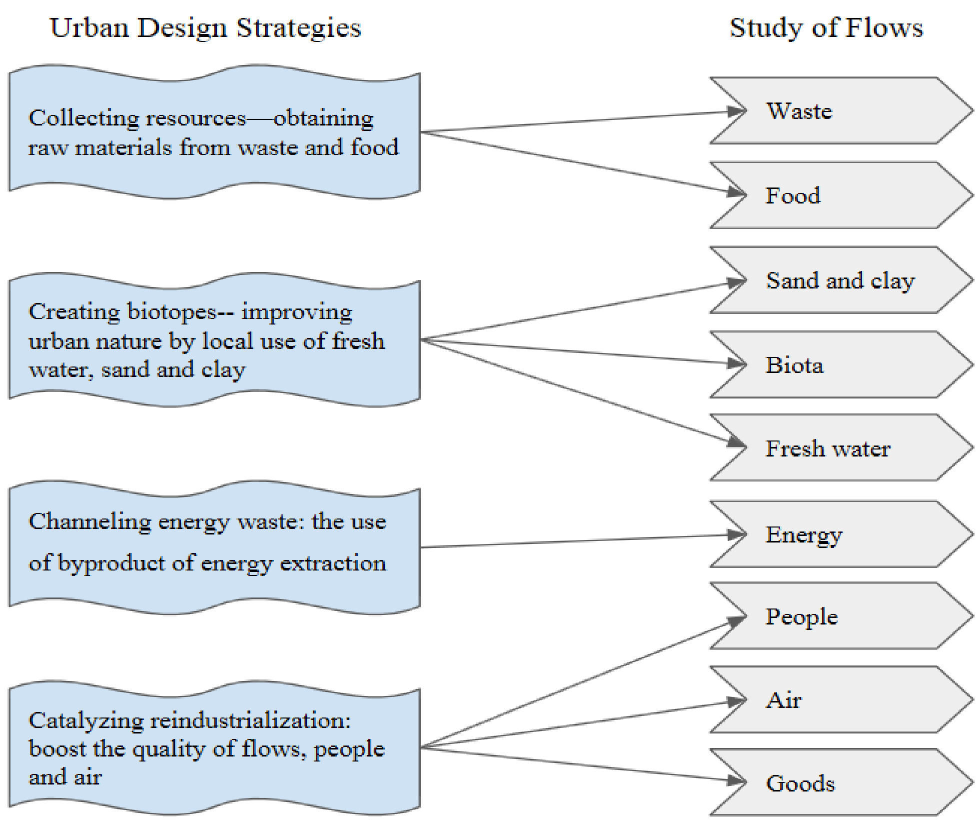

Figure 3. Conceptual illustration of Rotterdam IBAR report. (IBAR, 2014)

Evaluation

Evaluation criteria	
Methodological	
Is it systematic? Is it comprehensive? Can it potentially consider all resource flows in the city? How detailed is it/ to what level of detail of the resource can it reach? Is it adaptable for any city in any country?	The methodology is quite systematic and unique for it used an urban planning perspective. It first defined strategies and then applied them to selected flows. This report selected mainly substance flows (except for energy and people) because they are proven to have the biggest sustainability impact on the urban environment. The report itself is not yet comprehensive but the strategies have the potential to be if further developed.
Is it tailored to address urban resource flows? Does it consider city as a main resource consumer? Does it consider the urban resource stock? Does it consider leakage points to nature from the cities?	It is very much centred around the urban context. It considers many aspects of the city as a producer, consumer, space for activities etc. Many aspects of urban residents' lives, urban dynamic, the economics were taken into consideration and the urban spatial features were discussed for forming more linkages

	between substance flows. It considered the city as a system of people and resources hub, with interaction with the natural surroundings, though the notions of stock and leakage weren't specially discussed
Does it apply life cycle thinking? Does it consider the life cycle phase of the products? Does it consider the lifespan of the products? Does it consider beyond the urban boundary for the production and waste phase of the products?	The life cycle phase and lifespan are not directly considered. However, the study did take both city level and regional level into account and viewed the city as an dynamic system while showing some consideration for the life cycle stages of products (local food production & using local construction materials).
Circular Economy Vision Outcome	
Design out waste (designed by intention to fit within a cycle, or to a lesser degree: Optimise exploitation of raw materials to deliver more with less input). The biological materials are non-toxic and can be simply composted. Technical materials (polymers, alloys and other man-made compounds) are designed to have longer life span and to be reused, refurbished, repaired, remanufactured with minimal energy and highest quality retention, if cannot be replaced by biological material. Substitute hazardous substance.	It was not the aim of the study to close the loop but to find opportunities to improve the flows. Urban metabolism was used only to optimize fragments of certain materialistic or abstract flows. The mix of the flows are not necessarily material based so aren't specifically classified into toxic, biological or technical. The design aspect of systems and infrastructure arrangement was considered as powerful tool to optimize the flows.
Build resilience through diversity. Modularity, versatility, and adaptability. Balance efficiency with resilience. Replace virgin materials with recycled materials.	Strategy Two took natural resilience into account, proposed ways to better the biota with environmental engineering methods that can contribute to restorative system. However, from a systems perspective, the innovative strategies don't necessarily contribute to a more resilience system.
Work towards energy from renewable sources. Systems should ultimately aim to run on renewable energy. Reduce the need for fossil-fuel and capture more of the energy value of by-products and manures.	The strategies paid special attention to mainly using renewable energies (wind turbines & geothermal) even though the primary energy source is still fossil. Switching to bio-based production was only briefly mentioned.
Think in systems (understand how parts influence one another within a whole, and the relationship of the whole to the parts). Elements are considered in relation to their environmental and social contexts: Economic incentives (internalization of environmental cost, deposit system, extended producer responsibility, tax on natural resources and pollution). Business models (service and towards collaborative).Technological and social innovation. Governance, skills, knowledge and awareness.	Various aspect of urban living and production systems are taken into account. Despite the lack of detailed plans, specific strategies proposed are conceptual and often involve and benefit multiple flows and economic sector. The report also called for not only urban designers and planners, but also companies, investors, administrators and concerned citizens to participate.

Think in cascades extract additional value from products and materials by cascading them through other applications. Recycling: avoid mixing and contamination, then used again as secondary material	The utilization of waste has been mentioned a few times: e waste, nutrients in waste, heat and excess CO2 from the energy sector, food waste, manure and etc

2.3.1.2 Amsterdam

Towards the Amsterdam circular economy

Amsterdam municipality organized a Workforce Sustainability meeting in 2010 where everyone presented their own project in the theme of a cycle. Various cycles were observed to be intersected or interlinked and involves shifting of actors, scales, insights and processes. Two years later this report was produced to evaluate the current and desirable future cycles for food, phosphate, waste, water, electricity and heat. Overall the report covers many relevant aspects of circular economy however not very in depth.

The cycles have been depicted on the scale of global, the Netherlands, the Amsterdam Metropolitan Area, the city of Amsterdam, one district and one neighbourhood, all the way down to the individual dwelling, as seen in Figure 4. The study attempted to quantify the impacts of the flows at various scales to identify some main issues and action points embedded in the system. The methodology itself doesn't seem to aim for comprehensibility was but largely based on the existing knowledge of the municipal departments (City of Amsterdam, 2012)

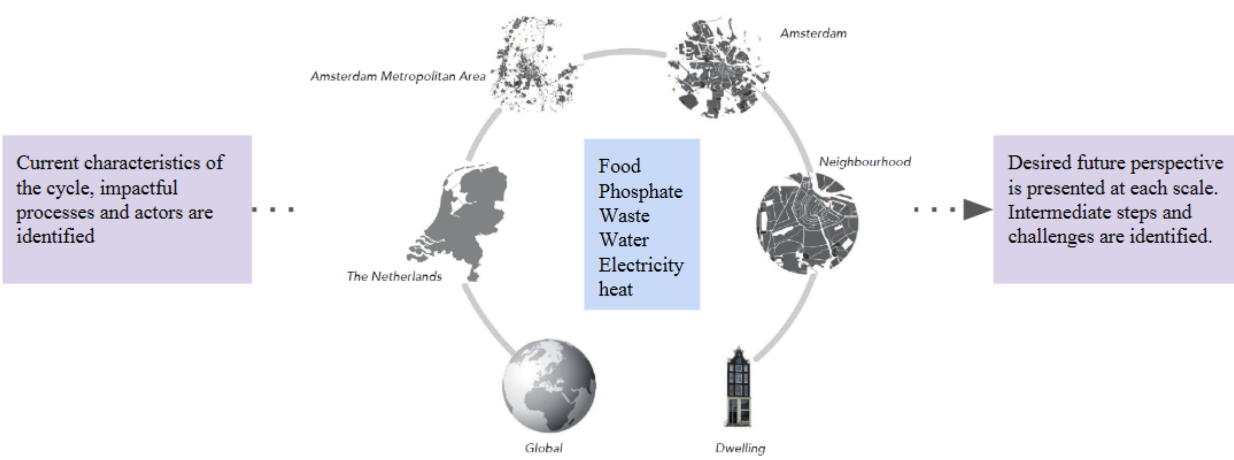

Figure 4. Conceptual illustration of "towards the circular Amsterdam" report. (City of Amsterdam, 2012)

Evaluation

Evaluation criteria	
Methodological	

Is it systematic? Is it comprehensive? Can it potentially consider all resource flows in the city? How detailed is it/ to what level of detail of the resource can it reach? Is it adaptable for any city in any country?	There isn't really an established methodology aiming for full circularity. The strategies were largely based on previously existing knowledge of various municipal departments. The flows selected were a mix of sectors, materials, substances and energy; the method is not easily extendable to include the missing flows. With each selected flow, plenty of details were included however it doesn't propose a transferable or adaptable strategy for action. The level of details and focus points vary between each flow, possibly because the study was divided to be done by different parties.
Is it tailored to address urban resource flows? Does it consider city as a main resource consumer? Does it consider the urban resource stock? Does it consider leakage points to nature from the cities?	The study was very much based on the urban context since it was initiated by the municipality. It has also notably explored the city's relation to other scales, ie the macro global scale. However, it missed the urban stocks and the leakage to nature when looking at the interactions between flows at various scales.
Does it apply life cycle thinking? Does it consider the life cycle phase of the products? Does it consider the lifespan of the products? Does it consider beyond the urban boundary for the production and waste phase of the products?	There are signs of life cycle thinking in the study since multiple scales were considered along with the life cycles of the flows. For example, food is produced elsewhere in the world, imported to the country, consumed and becomes waste at the residential and individual scale. These processes may be oversimplified but at least they were included in the scope.
Circular Economy Vision Outcome	
Design out waste (designed by intention to fit within a cycle, or to a lesser degree: Optimise exploitation of raw materials to deliver more with less input). The biological materials are non-toxic and can be simply composted. Technical materials (polymers, alloys and other man-made compounds) are designed to have longer life span and to be reused, refurbished, repaired, remanufactured with minimal energy and highest quality retention, if cannot be replaced by biological material. Substitute hazardous substance.	The powers of design of a system is visible in some areas (Urban food production and nutrient recovery). However, it didn't seem to have the ambition of closing the loop for the resources but only to add on known existing sustainable strategies. Moreover, the selected flows were not very representative of main urban resource flows. For example, no technical product flows, which should be an important aspect of urban living were selected.
Build resilience through diversity. Modularity, versatility, and adaptability. Balance efficiency with resilience. Replace virgin materials with recycled materials.	The report does propose versatility in terms of the supply aspect of food, water, energy etc.; technical materials couldn't not be evaluated since they were largely missing from the study.
Work towards energy from renewable sources. Systems should ultimately aim to run on renewable energy. Reduce the need for fossil-fuel and capture more of the	Switching to renewable energies were not visible in the study of most flows except for the study of the flow of energy where sustainable energy sources were added.

energy value of by-products and manures.	In fact, energy system is still relying on fossil fuels even in the future vision.
Think in systems (understand how parts influence one another within a whole, and the relationship of the whole to the parts). Elements are considered in relation to their environmental and social contexts: Economic incentives (internalization of environmental cost, deposit system, extended producer responsibility, tax on natural resources and pollution). Business models (service and towards collaborative).Technological and social innovation. Governance, skills, knowledge and awareness.	The study is not very systematic or detailed in terms of considering the interconnections of various aspects/activities/actors of the society. For some flows, various actors linked the city, enterprise, individuals were mentioned but in a sporadic way.
Think in cascades extract additional value from products and materials by cascading them through other applications. Recycling: avoid mixing and contamination, then used again as secondary material	Value maximization was done well for some flows, especially the waste sector. However, the study as a whole was too general covering too many flows. Many important components are missing so in the end it seems more like a presentation of existing knowledge, but not an exploratory study for bold solutions.

Circulair Amsterdam

The city of Amsterdam commissioned the study to explore its potential to achieve circular economy and invited stakeholders to join forces to speed up the process. This roadmap was built upon the many initiatives that have already been put in motion and done in collaboration with local stakeholders and existing local business opportunities.

It is the most extensive and practical on the strategy level and is possibly the first of its kind. The process went through 4 phases:
Phase 1. Charted the main material and energy flows and the value they could add at the city level.
Phase 2. Extensive analysis of the value chains in several sectors with criteria of ecological impact, economic importance of conservation and circular economy potential. A roundtable discussion with representatives from the municipality and local business lead to the selection of the construction and organic waste chains to be the most promising to achieve circularity.
Phase 3. Explored how the two value chains, the process of production, transport, consumption and waste, in an ideal circular future might function and how the value is being added or lost.
Phase 4. Created an action agenda and roadmap to achieve circularity in the two sectors. Also, barriers were mapped and actions were measured on (1) value, (2) CO_2 reduction, (3) material savings, and (4) jobs (Circulair Amsterdam, 2016).

The whole process is sketched in the Figure 5. Below and will be introduced in more details.

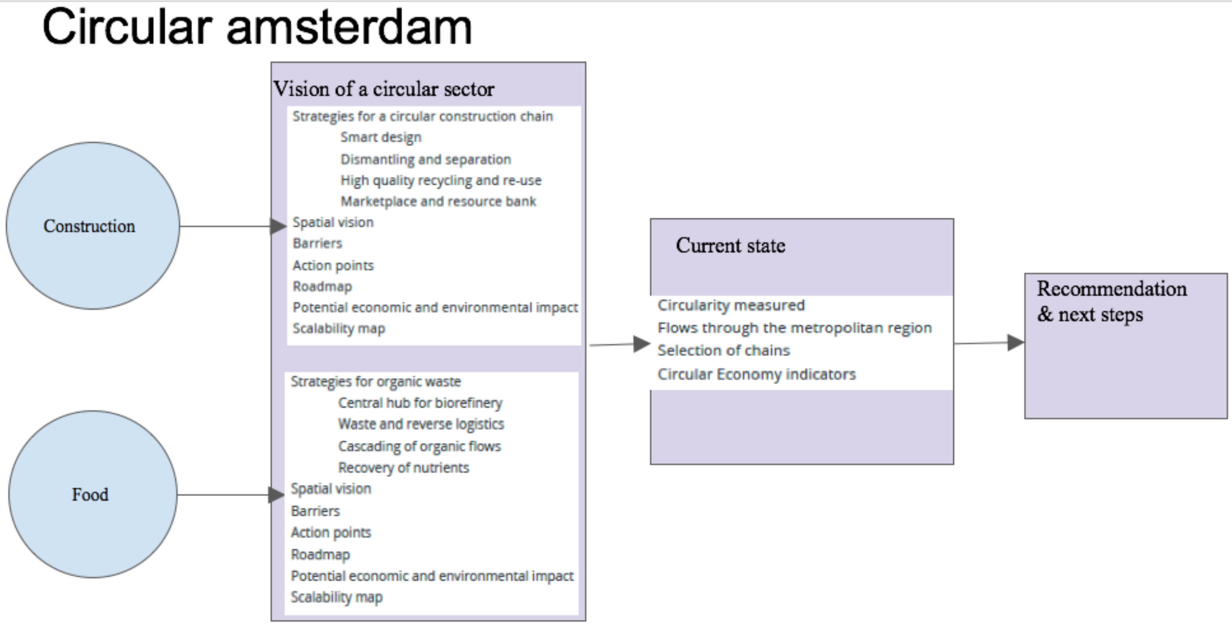

Figure 5. Conceptual illustration of “Circulair Amsterdam” report (Circulair Amsterdam, 2016)

Strategies

Construction Sector

Vision: In an ideal circular building chain are the buildings designed so that the materials get the longest possible service life by means of recycling or reuse. Four strategies were proposed to achieve the goal.
(1) Smart design of buildings aims to make buildings better suited for reuse and material recycling: modular and flexible design; 3D printing; bio-based materials and experimental space.
(2) Efficient dismantling and separating waste streams to make re-use possible: keep the design of buildings when decommissioning; hybrid waste management systems; systematic combine sorting methods.
(3) High recovery and reuse of materials and components: go beyond low-value recycling as gravel for roads but look for innovation and collaboration to get higher value.
(4) Sharing commodity among market participants: there is need for an integral (online) marketplace, supporting logistics system, as well as a physical storage location to facilitate the exchange of building materials between the demolition, construction and recycling companies (Circulair Amsterdam, 2016).

Barriers were identified in the following aspects:

- Laws and regulations: redefining waste by law.
- Culture: lack of inter-sector networks.
- Market: The existence of ‘split incentives’ and “knowledge asymmetry” among actors; the lack of externality pricing and the limited access to financing for circular initiatives.
- Technology: the up-scaling of a pilot to commercial scale, and the interdependency and complexity of technologies.

Top3 actions were proposed for immediate actions:

1.Facilitating resource and material storage
2.Stimulating high-value reuse

3.Stimulating material passports (Circulair Amsterdam, 2016).

A detailed road map was also made to illustrate short term (1 year) and long term (20+ years) actions and barriers and the circular construction sector scenario was compared to an unchanged linear model in four aspects: value creation, job growth, material savings and CO2 emissions (details see Circulair Amsterdam, 2016).

Food Sector

Vision: In ideal circular future vision for food, the organic streams such as food and water are supplied to consumers at the highest quality. Organic residues are recovered at high rate and recycled into innovative applications. The core of this circular vision is formed by integral food production, food processing and biological processes, where nutrients and water flows efficiently, and waste streams are valorized. That leads to more varied downstream outlets for organic waste which require less energy, nutrients, water and raw materials. Thereby, significant economic, environmental and social gains can all be won. It is assumed to take 5-7 years to have a circular arrangement for organic residues consumed by 430,000 Amsterdam households. Again, four strategies were proposed:

(1) A central hub of bio-refinery will be established for the valorisation of organic residues derived from household and industrial wastes and residues from the industries. To optimize the cascades of the organic waste chain, the possibilities of further processing the waste streams into high-value products (proteins, bio-oil, building materials and etc) will the first be explored. To facilitate this initiative, a logistical hub will be required to transport large-scale bulk products, as well as congregated small local streams.

(2) Waste separation and return logistics will be needed to deploy logistics in a smart way to increase the value of waste streams. This strategy requires technological innovations, especially for existing household food waste separation and collection, as well as street smart containers. The fruit and vegetable waste will initially be used to produce gas and later this can serve as raw materials to produce biochemicals.

(3) Cascading organic streams: Organic waste products are processed in a clever way: High quality applications from extracting organic waste can be explored (wastewater for algae and mushroom). High quality protein can be produced from insect farming with food waste. Public place can be utilized for urban farming.

(4) Recovery of nutrients: Essential nutrients are recovered to close the nutrient cycle. There are many large-scale food processors in the Amsterdam port area and the residues of these companies can be used in the production of fertilizers. Human waste is also full of nutrients and should be recovered more efficiently. Decentralized processing installations could be developed at the local pilot scales to recover nutrients (Circulair Amsterdam, 2016) …

Barriers were identified in the following aspects :

- Laws and regulations: redefining "waste" by law.
- Culture: lack of inter-sector networks could be obstacles to form cooperation.
- Market: The existence of 'split incentives' and "knowledge asymmetry" among actors; the lack of externality pricing and the limited access to financing for circular initiatives.
- Technology: the up-scaling of pilots to commercial scale, and the interdependency and complexity of technologies (Circulair Amsterdam, 2016) …

Top3 actions were then proposed for immediate actions:

1.Publicly accessible virtual resource platform of regional geo-data of supply and demand of organic residue streams

2.Circular free-zone biorefinery

3.Launching customers to develop local biomass purchase criteria (Circulair Amsterdam, 2016).

In the end, a detailed road map was made to illustrate short term (1 year) and long term (20+ years) actions and barriers (p69) and the circular construction sector scenario were compared to an unchanged linear model in four aspects: value creation, job growth, material savings and CO_2 emissions (Circulair Amsterdam, 2016).

Evaluation

Evaluation criteria	
Methodological	
Is it systematic? Is it comprehensive? Can it potentially consider all resource flows in the city? How detailed is it/ to what level of detail of the resource can it reach? Is it adaptable for any city in any country?	The approach is not a systematic approach but is very focused and extensive on two economic sectors: the construction and food sector. The details that was paid attention to is not on specific materials but on the stakeholders of the processes of the economic activities. For the two specific sectors, proposed strategies can potentially be adaptable to other cities.
Is it tailored to address urban resource flows? Does it consider city as a main resource consumer? Does it consider the urban resource stock? Does it consider leakage points to nature from the cities?	It is very much focused on the city level, specifically the city of Amsterdam. The flows of the two sectors were presented very thoroughly. The city of Amsterdam was seen as a resource stock, as well as consumer. In the ambitious circular vision, there was no leakage point to nature from the city.
Does it apply life cycle thinking? Does it consider the life cycle phase of the products? Does it consider the lifespan of the products? Does it consider beyond the urban boundary for the production and waste phase of the products?	Within the urban boundary, the loops seem to be circular however, what happens beyond the urban boundary (import& export balance) was not considered. The life cycle of product was given too little consideration.
Circular Economy Vision Outcome	
Design out waste (designed by intention to fit within a cycle, or to a lesser degree: Optimise exploitation of raw materials to deliver more with less input) The biological materials are non-toxic and can be simply composted. Technical materials (polymers, alloys and other man-made compounds) are designed to have longer life span and to be reused, refurbished, repaired, remanufactured with minimal energy and highest quality retention, if cannot be replaced by biological material. Substitute hazardous substance.	The suggested strategies highlighted some aspects of designing out waste with systemic, smart and modular design. However, it was still mostly focused on the waste streams for maximum value recovery. Hazardous materials in the construction sector were not addressed.
Build resilience through diversity. Modularity, versatility, and adaptability. Balance efficiency with resilience. Replace virgin materials with recycled	From the map of the circular vision, much diversity of processes can be found. Resilience was not specifically addressed but efficiency was.

materials.	
Work towards energy from renewable sources. Systems should ultimately aim to run on renewable energy. Reduce the need for fossil-fuel and capture more of the energy value of by-products and manures.	Renewable energy integration was not really considered.
Think in systems (understand how parts influence one another within a whole, and the relationship of the whole to the parts) Elements are considered in relation to their environmental and social contexts: Economic incentives (internalization of environmental cost, deposit system, extended producer responsibility, tax on natural resources and pollution). Business models (service and towards collaborative). Technological and social innovation. Governance, skills, knowledge and awareness.	The social, cultural, legal, technological background were analysed and barriers were identified. The study was very inclusive in terms of all element of the society, for example economic incentives, consumer culture and existing legislation were all considered as part of the study. Relevant and active stakeholders were also highlighted.
Think in cascades extract additional value from products and materials by cascading them through other applications. Recycling: avoid mixing and contamination, then used again as secondary material	The key focus of the study was about cascading of materials and top actions suggested establishing biorefinery, information platforms for residues and marketplaces for secondary construction materials. A lot of thoughts has been put on value maximization of waste streams

2.4 Identified Gaps

Reviewing four case studies and examining their approaches and the envisioned circular economy outcome, many gaps were identified and are presented below by criteria.

Evaluation criteria	
Methodological	
Is it systematic? Is it comprehensive? Can it potentially consider all resource flows in the city? How detailed is it/ to what level of detail of the resource can it reach? Is it adaptable for any city in any country?	The selection of flows was mostly arbitrary and based on existing efforts. There was a lack of unified systematic comprehensive approach that can potentially be upscaled to take all resource flows in the city into consideration with certain level of details. Reviewed methods were heavily based on the one city but with little adaptability to be used for other cities. Existing approaches were also predominantly qualitative.
Is it tailored to address urban resource flows? Does it consider city as a main resource consumer? Does it	Not all reviewed studies were focused on the urban context. City's role in resource consumption, resource

consider the urban resource stock? Does it consider leakage points to nature from the cities?	stock could be better recognized. The major leakage/emission points from the city to nature could be more clearly identified.
Does it apply life cycle thinking? Does it consider the life cycle phase of the products? Does it consider the lifespan of the products? Does it consider beyond the urban boundary for the production and waste phase of the products?	Life cycle thinking was not given much attention in the reviewed studies. There were some signs of life cycle phases being considered however the exploitation of raw material and emissions beyond the urban boundary were commonly out of scope. Not much study had a focus on technical product so the idea of lifespan has not been thoroughly examined. Considerations beyond the urban boundary could to be further addressed and discussed.
Circular Economy Vision Outcome	
Design out waste (designed by intention to fit within a cycle, or to a lesser degree: Optimise exploitation of raw materials to deliver more with less input) The biological materials are non-toxic and can be simply composted. Technical materials (polymers, alloys and other man-made compounds) are designed to have longer life span and to be reused, refurbished, repaired, remanufactured with minimal energy and highest quality retention, if cannot be replaced by biological material. Substitute hazardous substance.	Due to the limitation of flow selection, the design aspect for different materials (technical, biological and toxic) has not been fully explored. All reviewed studies put considerable effort into extracting value from waste/secondary material but much less on the design of the product, let alone analysing the whole system. As a result, in most cases, even the ideal circular vision proposed in the studies were far from “closing the loop”.
Build resilience through diversity. Modularity, versatility, and adaptability. Balance efficiency with resilience. Replace virgin materials with recycled materials.	The idea of building resilience through diversity and balancing it with efficiency appeared to be a too abstract and advanced concept for circular economy. Some studies had ideas that could contribute to it (improve biota, system diversity...) but haven't been fully explored
Work towards energy from renewable sources. Systems should ultimately aim to run on renewable energy. Reduce the need for fossil-fuel and capture more of the energy value of by-products and manures.	Renewable energy integration was not a key consideration in the reviewed studies. Only one or two studies briefly mentioned switching more to biobased materials or using more renewables
Think in systems (understand how parts influence one another within a whole, and the relationship of the whole to the parts) Elements are considered in relation to their environmental and social contexts: Economic incentives (internalization of environmental cost, deposit system, extended producer responsibility, tax on natural resources and pollution). Business models (service and towards collaborative).Technological and social innovation. Governance, skills, knowledge and awareness.	Thinking in systems was present in many studies where various sectors of the society (business, governance, technology, culture) were taken into consideration and their relations and possible cooperation opportunities were explored. The main economic, cultural, legislative and technological barriers can be identified and relevant key stakeholders were highlighted though not all actors could be clearly identified if not already active.

Think in cascades extract additional value from products and materials by cascading them through other applications. Recycling: avoid mixing and contamination, then used again as secondary material	Extracting value from waste was done best compared to other criteria in all reviewed studies. It might be the best economically incentivized, understood, and most experimented component of circular economy. However overall the focus was too concentrated on waste management to present the full potential of circular economy.

3. Theoretical Background of Proposed Approaches

3.1 Urban Metabolism Analyst Model

The metaphor of urban metabolism was first proposed by Abel Wolmann in 1965 when he calculated the demand of fossil fuel, food and water, as well as balanced emission of sewage, wastes, air pollutants of a hypothetical American city with a population of one million (Schulz, 2005). The idea was that cities resemble living organisms in the way that they interact with their environment: transforming and consuming resources and eventually excreting wastes (Kennedy et al, 2011). In practice, urban metabolism is "a field of research of resource consumption of cities in a systematic way" (Kalmykova et al, 2015). While urban metabolism studies had ups and downs over the past half a century, it has accelerated in the last decade and its practical applications are emerging and having more applications as guidance to urban planning (Kennedy et al, 2011).

A unified methodology is much needed in the field of study but has been lacking until the introduction of the UMAn, a new methodological framework to urban material flows and stocks accounting based on Eurostat economy-wide MFA. It addressed several major gaps in the urban metabolism studies field by providing a unified methodology to categorize material types, understand the origin, destination and related economic activities of materials, and quantify dynamic material flow and stock at urban level. It does so by providing a standard protocol for assembling statistically reported data at the urban level. The mechanisms of the model is illustrated in Figure 6. below and can be found in the original paper (Rosado et al, 2014).

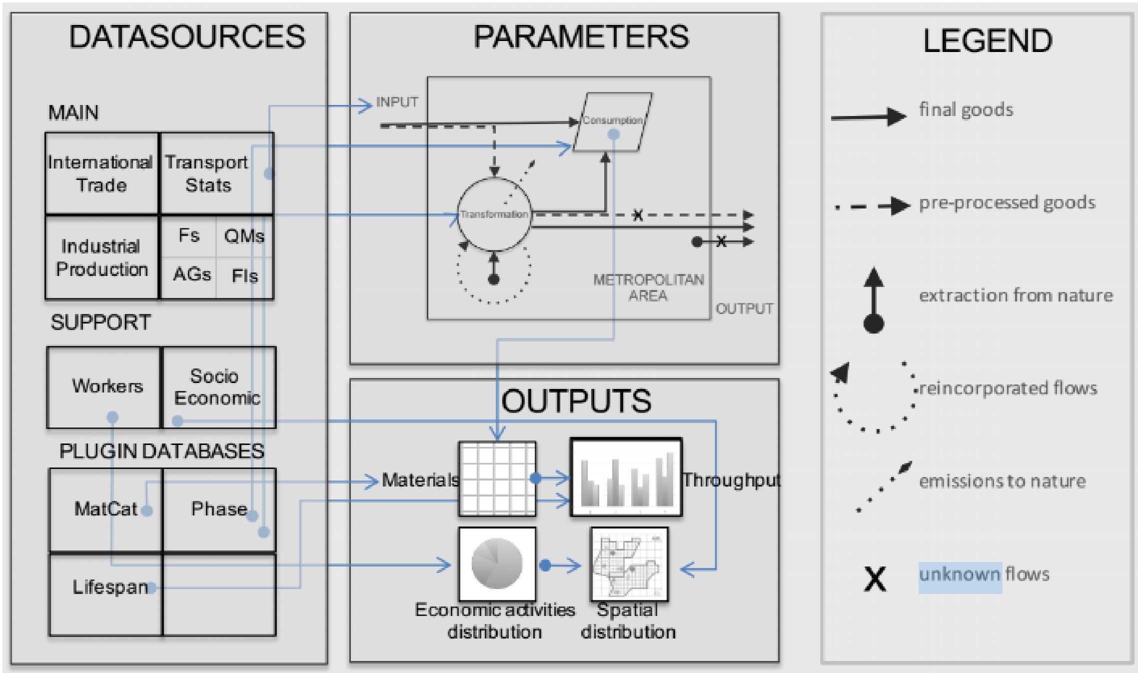

Figure 6. Mechanism of the UMAn model (Rosado et al, 2014).

This study relies on the output of the UMAn model with the relevant input data of Gothenburg from 1996 to 2011 (More on data source see Kalmykova, 2015) and the inherent link between resources flows (in CN codes) and economic activities (in NACE codes).

NACE stands for "Nomenclature Générale des Activités Économiques dans les Communautés Européennes". A Classification method imposed within all EU member states. According to the official document, economic activities are defined as transforming resources like capital, labour technology into final goods or services. The classification of a unit is mainly based on the total value added by the activity. When such information is unavailable, substitute criteria based on either output value or input labour can be used instead[*]. (Eurostat, 2016). Both NACE and CN are part of the large integrated international system of economic classifications. Their relationship is illustrated as Figure 7 below. At EU level, NACE codes is linked to CPA (European Classification of Products by Activity), which is linked to PRODCOM (EU classification of goods used for industrial production) that CN is also linked to by conversion table (as shown in Figure 7 below).

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[*] Note: The code used for input data of the city of Gothenburg is originally based on Swedish standard code, SNI 2002 (Swedish Standard Industrial Classification), which is primarily an activity classification and in fact based on NACE Rev. 1.1 (Statistics Sweden, 2013). In this study, results were with SNI codes whose correspondent NACE Rev.1.1 codes and detailed description were found in the Eurostat working paper (Eurostat, 2016).
CN stands for "Combined Nomenclature", which is the classification used within the EU for the purposes of foreign trade custom tariffs and statistics. Imported and exported goods have to be declared at customs stating which subheading of the nomenclature they fall, which determines their rate of duty. CN is based on Harmonized System nomenclature which is run by the World Customs Organisation and the basis for international trade negotiations. CN also has further subdivisions up to the 8-digit level (The Combined Nomenclature).

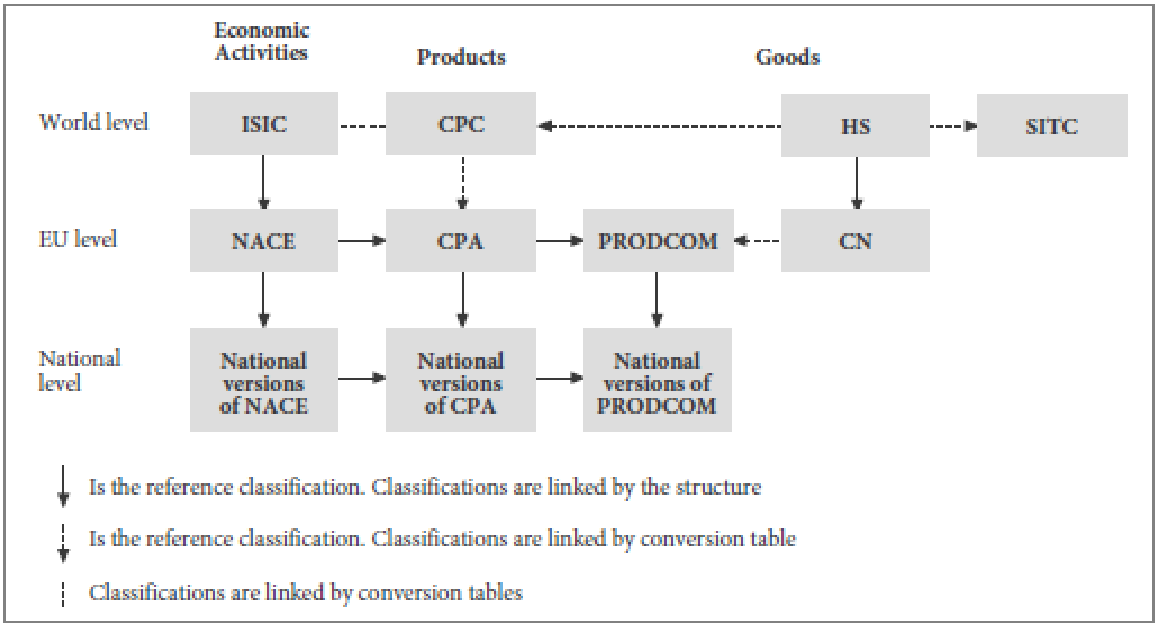

Figure 7. NACE & CN connection (The Combined Nomenclature, 2001).

Based on this interconnection between economic activities (NACE) and product (CN) flows, two approaches will be proposed as new perspectives to study urban resource consumption and as a basis for proposing circular economy strategies at the city level. After proposing the general framework of the approaches, they will be applied to the city of Gothenburg with 13 years of city resource flow data as support.3.3 Circular Vision and Strategy Generation

3.3.1 Scope

A product's traditional linear life cycle can be most generally described as "take-make-dispose" (EMF, 2013). "Take" usually refers to the manufacture phase of the product, which is often out of the urban boundary therefore is out of the scope of this study. "Dispose", referring to waste management, recycling, energy/nutrient recovery of various products, which is a frequently explored, and has a vast field of expertise on its own. At this stage, the value of the product is mostly lost which is too late for an optimal circular economy's vision. Therefore, this study aims to optimize the use phase of the product. The goal is to keep the product (technical) in the loop and maintain its maximum value for as long as possible. The key factors to consider are for the use phase of the product: the product's life span and product-user relationship.

3.3.2 Product life span

The life span of the product depends not only on the nature of its material (biological or technical), but also on the context of the product's function. When the target product functions as part of a larger product, it can lose its function due to various reasons or go into obsolescence very quickly. For example, nylon as a synthetic material has a very long life span, but when becomes a piece of clothing, its lifespan is shortened significantly to only 1-3 years on average (IFI). Therefore, the bigger picture needs to be taken into account when determining the product's lifespan in the specific NACE sector and in this study. The final product, of which the target product is a part, is considered when determining its lifespan.

Based on circular economy principles (EMF, 2013), three types of materials require different strategies: toxic, technical and biological. When using the UMAn model based on EUROSTAT, it is possible to make such classification systematically based on the CN codes:

- CN codes for toxic products (Statistics Sweden):
  - 2620
  - 8548
  - 2710
  - 2713
  - 3825
- CN codes for biological products (CN, 2002):
  - 0101
  - 2403
  - 4101
  - 5311
- CN codes for technical products: the rest

Ellen Macarthur Foundation also has some general circular economy principles for these three groups of materials as shown in Figure 8 the butterfly chart below, as well as in more detail in their (EMF, 2013) reports.

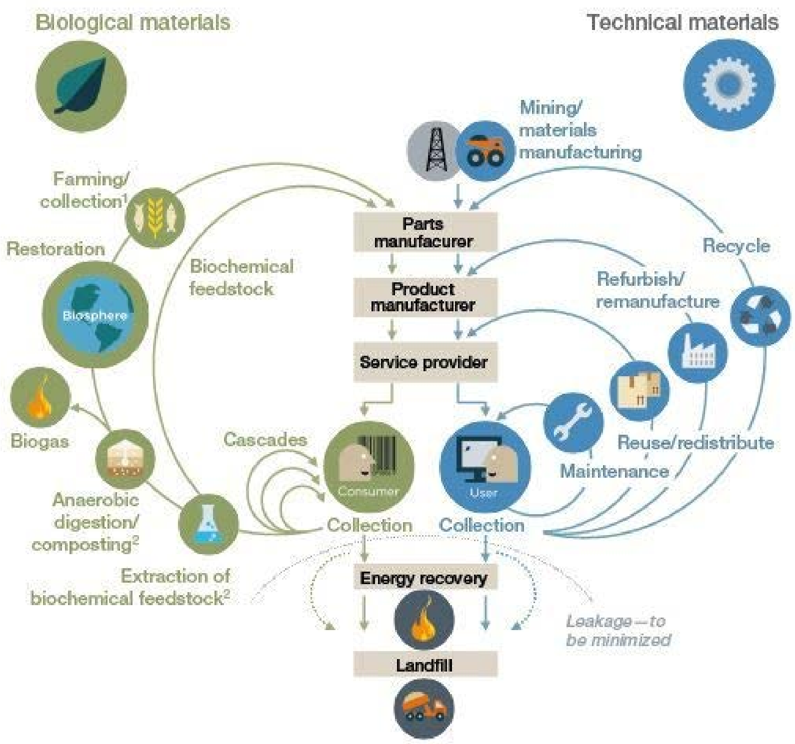

Figure 8. Butterfly Chart: General circular economy strategies for different material properties. (EMF)

These strategies can be summarized as below:

- Avoid using toxic materials by looking for alternatives.

- For the circularity of technical products, the goal is to keep them circulating in the loop by:
    - Maintenance
    - Reuse and redistribution
    - refurbish and remanufacture
    - end of life collection and recycle
- For the circularity of biological products, the goal is to expand their service time, then extract as much value as possible then return them safely to the biosphere. Strategies for this aim are:
    - Extraction of biochemical feedstock
    - Anaerobic digestion and composting
    - Production of biogas
    - Restoration
    - Farming/ collection

Cascading 3.3.3 Product-user relationship

This study combined two different approaches to investigate the product-user relationship: market perspective and Product-Service System (PPS)

- **Market perspective** classifies goods based on their customer's buying behaviour and perspective:
    - convenience goods: customers buy often but without much thoughts or planning (ie, candy)
    - Shopping: customers need a lot of considerations of price, quality and value for products. Heavy advertising and sales people can influence consumers' choices (clothing, appliance...)
    - Specialty goods: customers spend more time considering brands and the brand identity to decide (ie, car).
    - Unsought goods: customers don't put much thought into it and generally don't have compelling impulse to buy (batteries or life insurance) (Dye, unknown date).

- One simple way to define **PSS** is that "it consists of tangible products and intangible services, designed and combined so that they are jointly capable of fulfilling specific customer needs" (Brandstötter et al, 2003). And the studies of PSS has been claimed to be a means to achieve consumption reduction. Its objective is to transform the business models to make them more competitive and profitable while reorienting the current consumption and production patterns (Beuren et al, 2013). Tukker (2004) further proposed eight types of PSS as shown in the Figure 9 below. There is a range of value content which varies from value mainly in the product itself as a consumable product to value in the service where the very product is not essential at all but can easily be replaced as long as it serves the desired function.

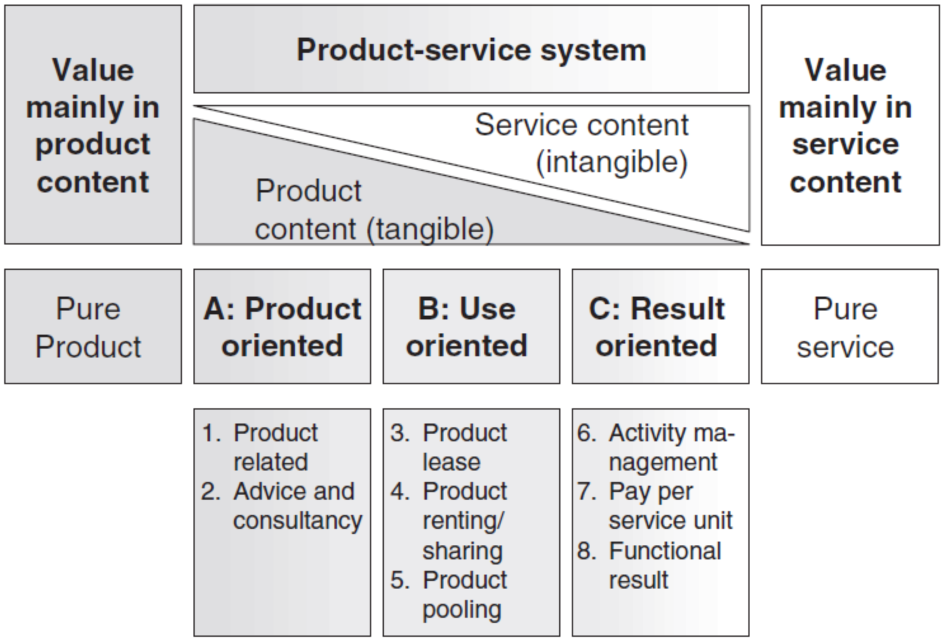

Figure 9. Main and Subcategories of PSS (Tukker, 2004)

As shown above, PSS provided a spectrum which ranges from pure product to pure service. “Product oriented”, “use oriented” and “result oriented” were in between the two extremes.

3.3.5 Novel circular economy strategy map scaled by PSS and lifespan

Inspired by the market classification and PSS, various economic sectors where the target product produces value to its users can be put on a scale describing the value content of the product (Tukker, 2004). The scale ranges from tangible product value content to intangible services value content. To further group the products along this scale, they can then be further divided into mainly 5 categories, inspired by the market perspective classification (convenience, shopping, specialty and unsought goods). For this study, special considerations were made for the product’s lifespan. In the end, a new classification of products was formed and explained below:

- Consumables: disposables, one time use items.
- Household: shopping products and appliances.
- Specialized equipment: machineries and motors (specialty goods).
- Industrial assembly lines: products that have specific functions in industrial environments.
- Infrastructure: products that are built in infrastructures.

The economic activities/product can be plotted on the scale of the product’s lifespan (Y axis) and its PSS (X axis) as shown in Figure 10. A selection of circular economy strategies (Wii; EEA, 2016; EMF 2013; Tukker 2004) can also be placed on the plot depending on its relevance to each PSS category and product lifespan. The presented strategies are not conclusive but can be adjusted depending on the context.

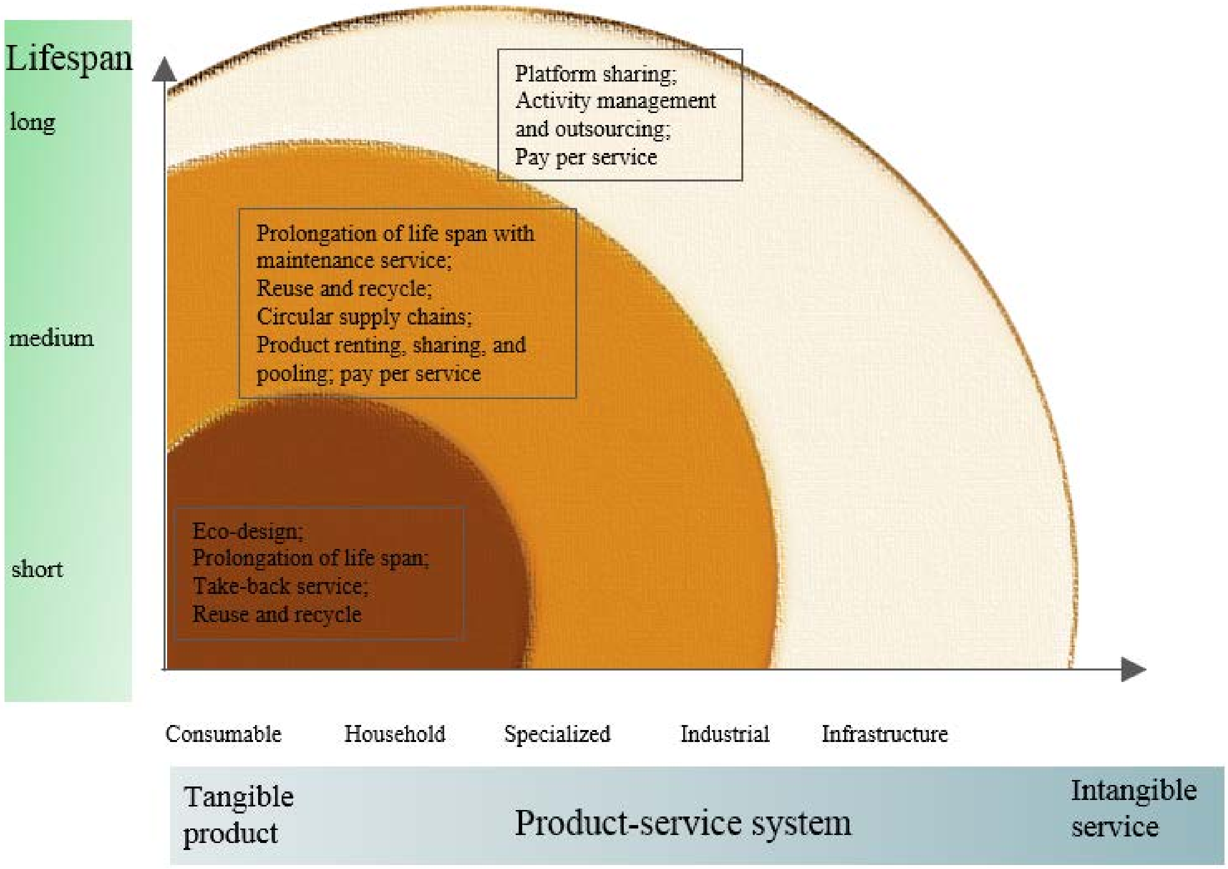

Figure 10 Circular economy strategy map on the scale of PSS&lifespan (Wiig; Tukker, 2004)

For products with value in their consumption, besides prolonging its durability and lifetime through service models, eco design is crucial to ensure the safe return of their composing materials to biosphere or easy disassembly and recyclability. For products with longer lifespans, there is more potential for renting, sharing, pooling and pay-per-use beyond repair, reuse and recycle. For products with long lifespans, i.e. infrastructures, initial capital investment and the amount of materials involved are possibly very large. Therefore, the focus should be on getting the most value out of their lifetime through expanding its accessibility to more people through active management or innovative business models.

4. Methodology

4.1 Study Area: City of Gothenburg

The two approaches proposed can be applied in any country that follows the CN and NACE nomenclatures in their statistical data. For the purposed of the illustration of the approaches, data from a Swedish city Gothenburg was used in this thesis.

Gothenburg is the second largest city in Sweden spanning over 13 municipalities with the population of 1.1 million. It is located at the epicentre of Scandinavia and the Baltic States with 70% of Scandinavia's total industrial capacity within the 500 km radius of the region. The port of Gothenburg, the largest port in Scandinavia is where 30% of the Swedish foreign trade passes through (Facts & Figures). The service sector employs most of the work force (77%) with the industrial and construction sectors take only 16% and 7% respectively (Kalmykova et al, 2015).

4.2 Product approach

The main idea of the product approach is to trace one or more products through their paths in the city and to identify the economic activities they are involved in with the goal to optimize use of one or more products within the urban context. This chapter describes this process step-by-step.

4.2.1 To select a target product at CN 4-digit level

4.2.2 To produce a list of economic activities related to target product.

The UMAn model presents all the NACE sectors (at 4 digits "class" level) that the target product flows through annually. There sectors then can be ranked by the respective product weight share, i.e. % of all the target products related to each economic sector. Then the top sectors are selected to include at least 95% of total product flow in the study. This process was illustrated in Figure 11 below.

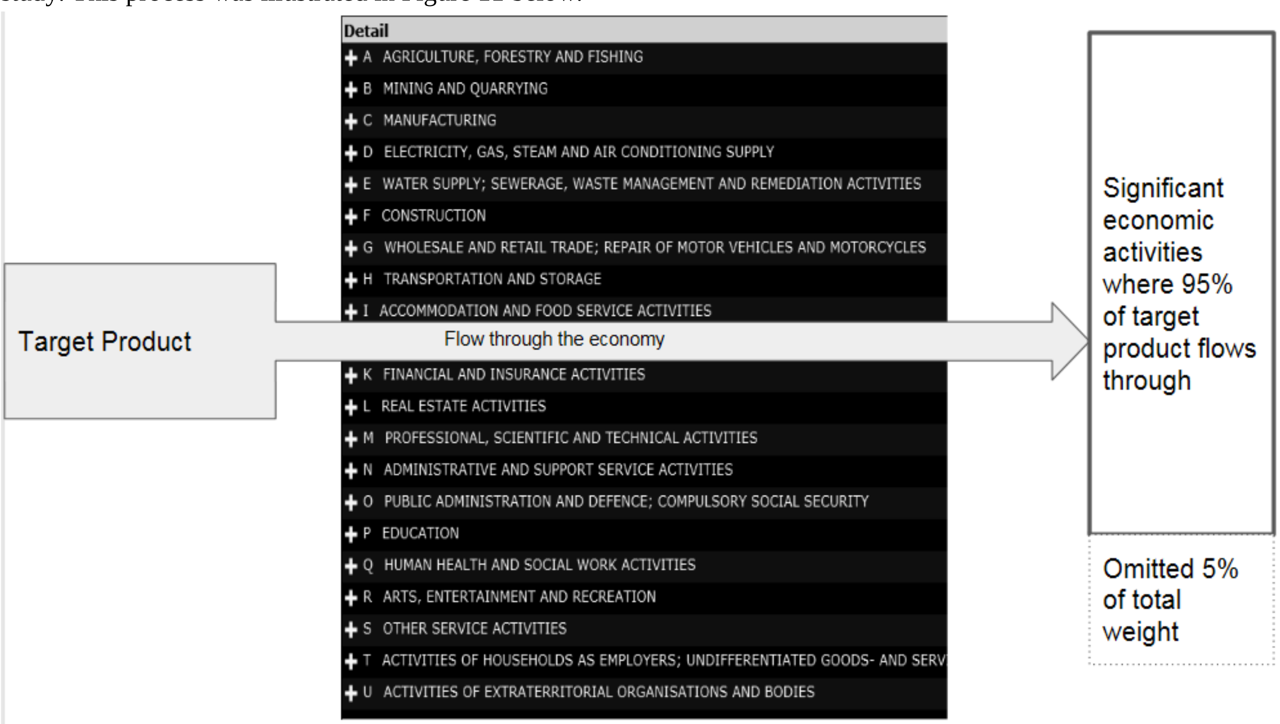

Figure 11. The selection of significant economic activities related to the target product.

4.2.3 To narrow down to a list of key economic activities relevant to the final use phase of the target product

It is important to understand that the UMAn model provides a snapshot of annual material flows, which means that it is likely the dynamic flow of goods was captured at several different life cycle stages. The target product, at different life cycle stages can have very different roles in the economic activities it is linked to: it can be the **product** of the manufacture activities, or be **sold** in the sales activities or be **used** in a variety of other economic activities. For example, a motor vehicle at different life cycle stages can be identified in very different economic activities: "Manufacture of motor vehicles", "Retail of motor vehicles" and "passenger transportation". The life stages of the same motor vehicle, ie being manufactured, sold and used are all captured by the UMAn model, which could exaggerate the presence of motor vehicles in the economy due to this triple counting.

The scope of this study has a focus on the final use phase of the product, but not how it is produced or sold as an intermediate product considering the urban context. In addition, the double counting (ie. Counting the target product at the manufacture stage as a semi-product then again at the use stage as a final product) needs to be considered to avoid overestimation. Therefore, an analysis of the list of economic activities should be done to transform it into a list relevant only to the final use phase of the product and without the overlapping with intermediate products.

The economic activities can be firstly divided into three big categories by the nature of the activity ("Manufacture", "Sales" and "Other activities") based on their NACE codes descriptions. However, the target product's roles can still be complicated and unclear within the same category. More details from external sources are needed to fully understand or to make the best judgement on what role the target product plays, more specifically whether it plays the role of the final product or not. And then subcategories can be made as described and illustrated below (Figure 12)

- Manufacture activities can be divided into three subcategories: "Manufacture of the target product" (motor vehicle in "manufacture of motor vehicle"), "Manufacture of other products which contains target product" (motor in "manufacture of motor vehicle") and "Manufacture of other products, the processes of which use target product" (assembly machineries in "manufacture of motor vehicles").
- Sales related activities can be divided into two sub categories: "Wholesales, retails and agents involved with sales where target product is sold as (part of) a product" (motor vehicle in "sales of motor vehicle") and "Wholesales, retails and agents involved with sales where target product is used as final product to aid the activity" (clothes hangers in "sales of apparels")

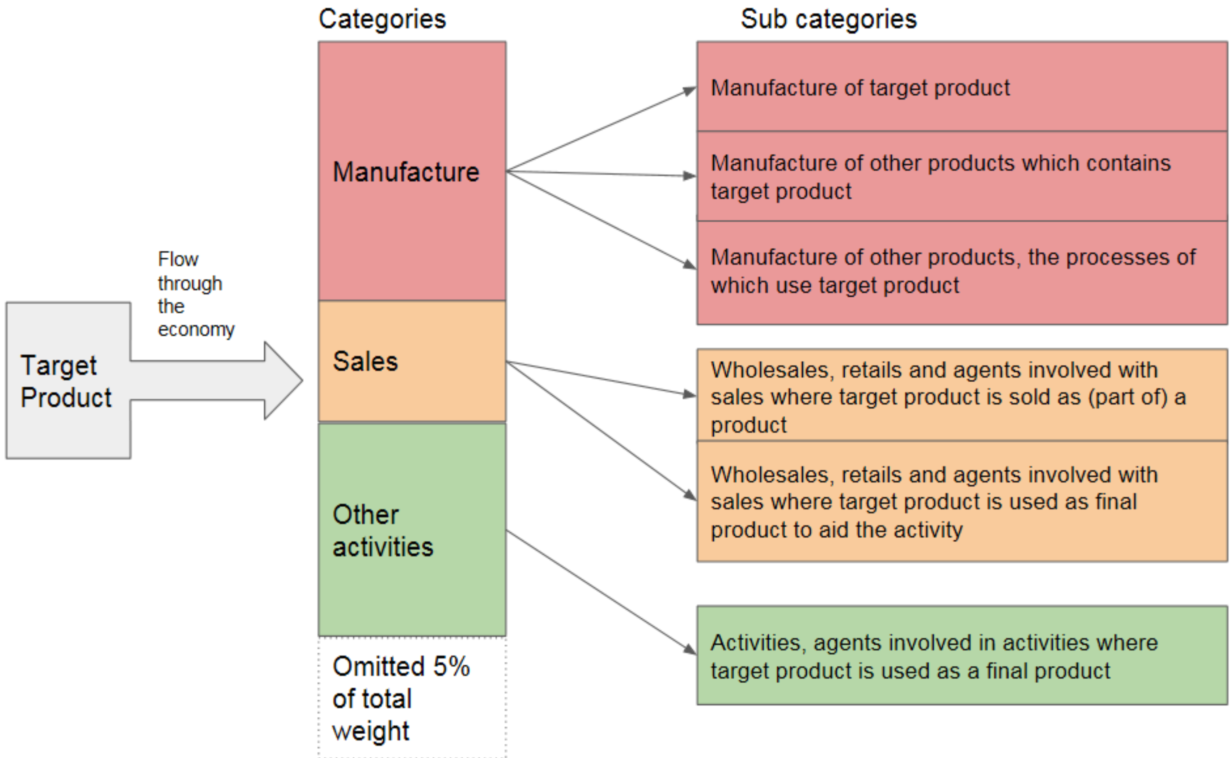

Figure 12. Illustration of categorization of NACE sectors.

To generate a final NACE list of economic activities where the target product is used as a final product, one need to examine the subcategories one by one. The best order is to start from “Other Activities”, to “Sales” and finally to “Manufacture”, detailed as in Figure 13.

- Other Activities: The economic activities listed under the “Other Activities” category all used the target product as a final product to provide goods or services.
- Sales:
  - When the target product is used to aid the sales process of other products (ie, dispensing machine, clothes hanger and etc), it is considered used as a final product and the sales activity can be added to the final NACE list.
  - When the target product is sold as (part of) goods as a “Sales” activity, it is not considered to be final product. However, it is possible that the use phase of this goods is missing from the “Other Activities” category, therefore such activities can be recreated/renamed and added to the NACE list, unless such activities are already present in the “Other Activities”. For example, “sales of explosives” may be added to the final list as “use of explosives” if “use of explosives” is originally missing from the “other activities” category.
- For “Manufacture”:
  - The target product can be used as a final product to aid the manufacture process of other products (i.e., machineries used in the production line…) and can be added to the NACE list.
  - When the target product is part of the manufactured goods, it is considered to be intermediate product. However, if this product’s final use phase is missing from “Sales” and “Other Activities”, the manufacture activity can be recreated/renamed and added to the final NACE list. For example, sector 3917 2461 “Manufacture of explosives” can be

added to the final list despite it being a “manufacture” sector because the use of explosives was not present in the “Other Activities” sectors.

- When the manufacture activity produces exactly the target product, it is considered to be intermediate product whose final use phase has been covered through the process above.

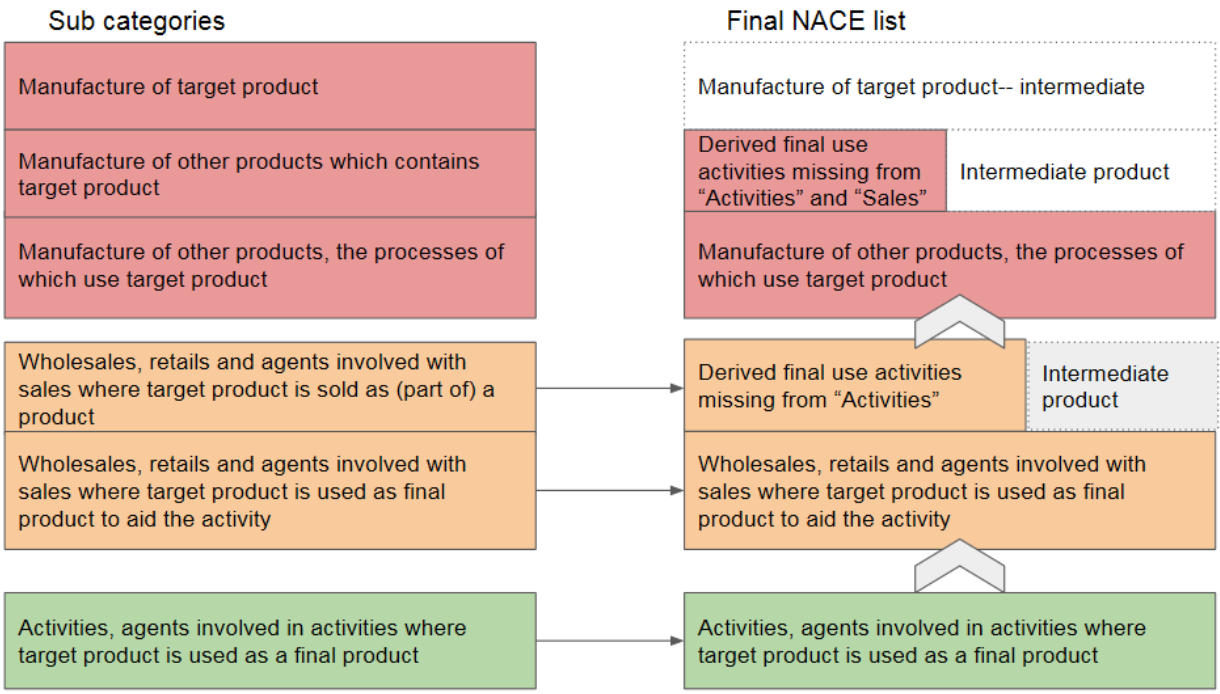

Figure 13. Illustration of narrowing down to “final-use phase” NACE sectors.

The column on the right shows the process of narrowing down the NACE list to the highlighted economic activities where the target product produces value as a final product. With the final NACE list, the weight share of each economic activity can then be adjusted with the total weight share of the final NACE list as 100%.

4.2.4 To analyse the final NACE sectors for circular economy strategy creation

With the final NACE list, which only includes economic activities where the target product functions as a final product, one can investigate strategies to “close the loop” at the systems level. These NACE sectors can be plotted on the circular economy strategy map as introduced earlier, clusters can then be identified and corresponding strategies can be adapted.

4.3 Sector Approach

The idea of the sector approach is to track down all the products entering one or more economic sectors with the goal to optimize the use of products. Tis chapter describes the step-by-step process of this approach.

4.3.1 To select a target NACE sector at NACE 4-digit level

4.3.2 To produce a list of all the products that goes into the target sector.

The UMAn model shows all CN products (at 4 digit level) that go into the target sector and only those appeared every year for 13 years were manually selected. What's to be noted is that unlike for the product approach, the first prioritization is not done by weight for the sector approach. For the "product approach", the list of sectors can be ranked by the weight of target product that goes through each one to determine each sector's relative importance to achieving more sustainable use of the target product. However, the sector approach works with different products whose criticality to sustainability cannot be determined simply by the weight share of the product. An inert product could have a dominant weight share out of all product input to the target sector, however its environmental impact may be neglectable; while a relatively small amount of a highly hazardous product can be serious harmful if not handled with priority. Therefore, it is better to study the complete list of product inputs of the target sector.

4.3.3 To divide products into two categories

It is important to understand how each product functions within the target sector. As noted previously, an economic activity is essentially an input of resources, a production process and an output of goods or services. It is obvious that part of the input of resources will go through a production process and become the output product. However, what can be easily neglected is that part of the input resources is consumed or used as tools by the employees of the industry. This is especially important for closing the loop in the service industry which focuses on the human capital instead of relying on the transformation of materials. Therefore, input products can be divided into two categories:

- Final use products - products to be consumed or used in the economic activity
- Intermediate use products - products to be transformed and to become a sector's output (as illustrated in Figure 14).

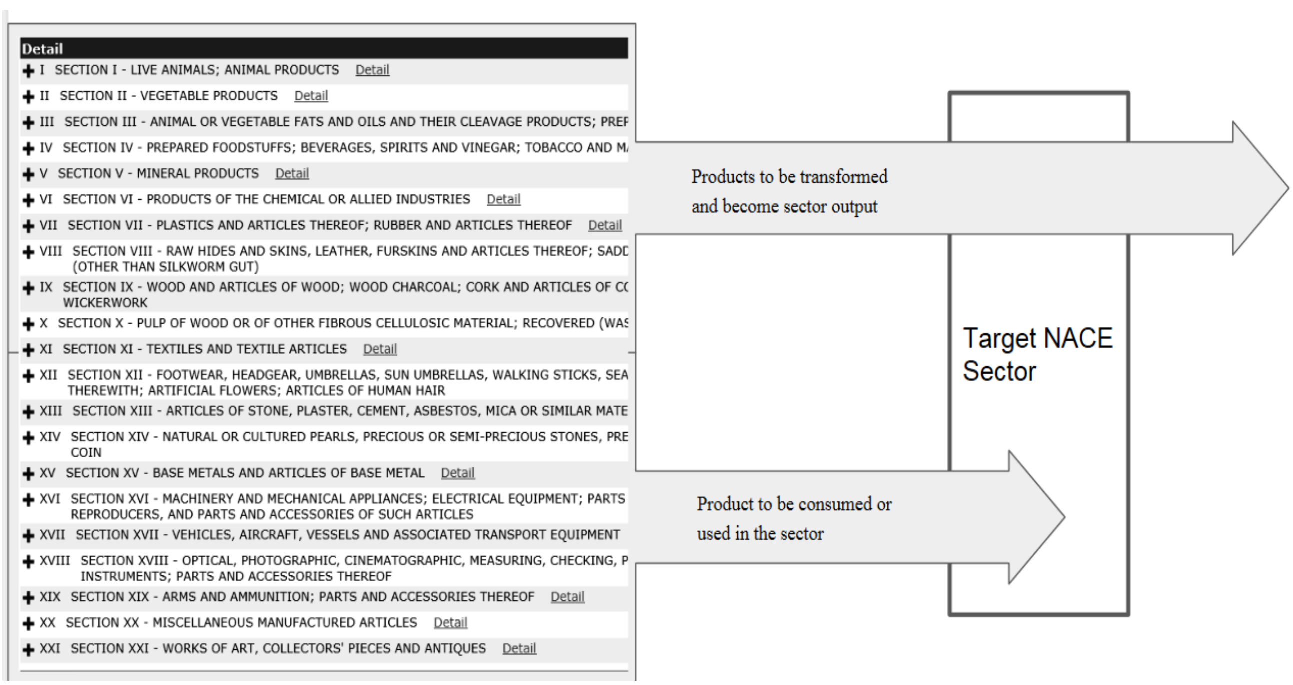

Figure 14. Illustration of dividing input products into two categories.

4.3.4 To develop circular economy strategies for two categories of products

4.3.4.1 Strategies for products to be consumed or used in the sector

The life stage of these products is the final-use phase. Therefore, the “circular economy strategy map on the scale of PSS& lifespan strategies” used for the “product approach” can be applied similarly here. Such a plot can provide valuable insights on the target NACE sector:

- Providing an overview of how various products produce value in this sector and identifying the main types of product use.
- Identifying opportunities to switch to the service model instead of putting the value on products
- Identifying key actors in the sector who have influence over the flow of the products (ie, purchase, utility time, disposal etc)

*The main difference from the “product approach” in this step is that

- As the product-user relationship plot is important for both approaches, the sector approach plotted the various products used by one NACE sector, while the product approach studied various NACE sectors that use the same product.
- The weight share of various products doesn’t play an important role in the sector approach as for any economic activity, the environmental impact of various products involved don’t necessarily depend on their mass.

4.3.4.2 Strategies for products to be transformed and become sector output

Developing circular economy strategies for products to be transformed in an economic sector is especially relevant to the production activities (eg. manufacturing, agriculture and construction sectors) for their economic value is not based on intangible services but on producing and selling tangible goods. The material inputs to the production of such goods can be classified into three categories based on the material property: toxic, technical and biological (see Figure 15). As briefly introduced before, some CN codes would already reveal the properties of products therefore making this step more systematic.

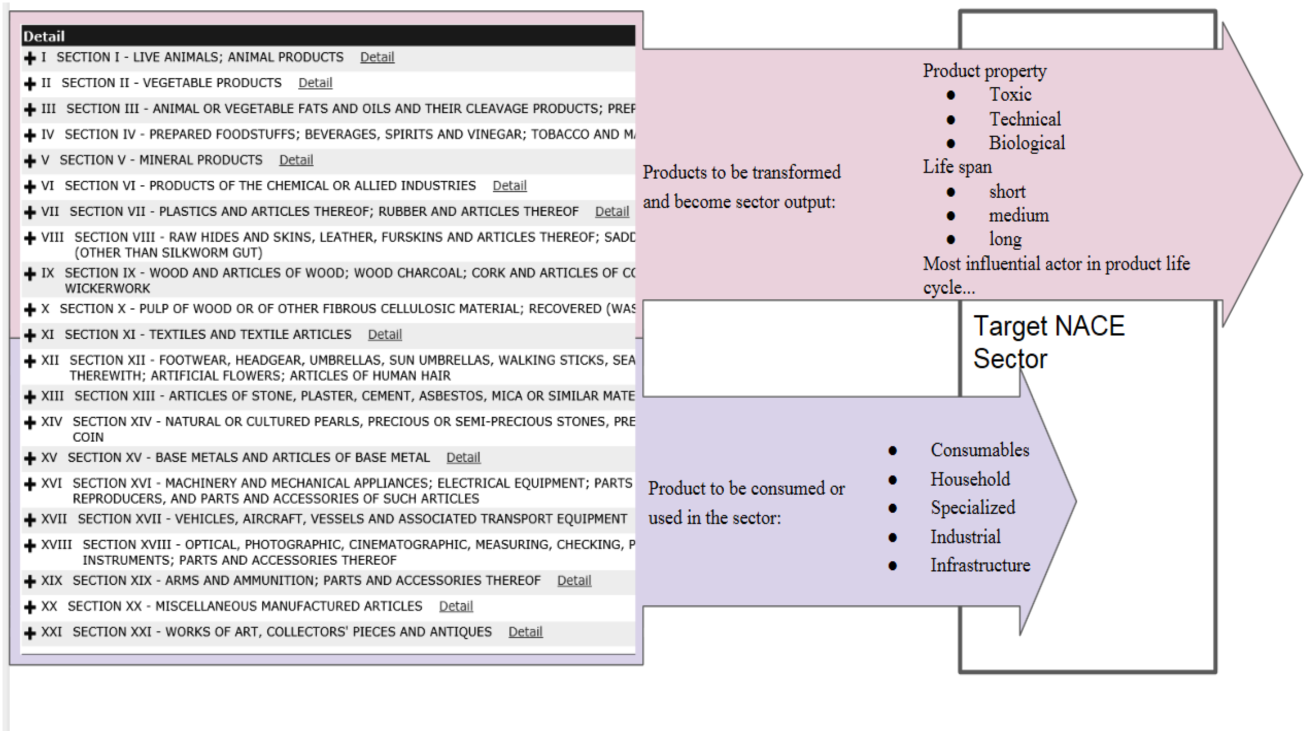

Figure 15. Sector approach strategy overview. General circular economy strategies for each class of materials have been previously introduced in the theoretical background section, illustrated here and will be explored further in the application section.

As illustrated, products in the category of “being transformed to become sector output” can be studied by the material property and lifespan for circular economy strategies. As for the category of “products to be consumed in the sector”, previously discussed PSS model can be used to further classify the products and help finding best strategies to close the material loops.

4.3.5 Influential actors

It is important to recognize the influential actors in each NACE sector, which is not always straightforward as often a crucial group of actors in the economic activities could get overlooked. For example, when discussing resource management in the construction sector, what first comes to mind is certainly secondary materials handling after demolition. However, the most influential actors, the architects who have initially decided how much of which material would be put in the building are usually not so visible in circular strategy generation. The often-overlooked process of “Service planning” or “Product Design” that occurs before the target sector activities, are in fact the most influential stages to focus on to harvest the power of design and to achieve the circular economy vision. It is because decisions like “what materials to use”, “how the product is assembled”, and “how it can be taken apart at the end of life” are usually made at the initial processes of these economic activities.

5. Results

5.1 Application of the Product Approach:

5.1.1 Target product selected at CN 4-digit level:

CN code: VII 3917 Tubes, pipes and hoses, and fittings thereof (for example, joints, elbows, flanges), of plastics.

5.1.1.1 Reasons for choosing VII 3917:

Plastics has an incredible wide range of applications and are used in huge volumes (311 million metric tonnes production in 2014) for its versatility, lightweight and other advantageous properties (Opsomer and Pennington, 2016). However, such a modern classic technical material group generally has a very long lifespan and its current usage cycle only utilizes very little of its inherent value. As a result of the linear economic model and poor end of life management, plastics are now leaking into the environment in large volumes, exerting profound environmental and socio-economic impacts. Therefore, there is huge economic and environmental potential in making plastics flow in a more circular manner (Mckinsey&Company, 2016)

5.1.1.2 Description of the target product

The CN catalogue gave a detailed description on what exactly is classified under the heading 3917:

> "the expression 'tubes, pipes and hoses' means hollow products, whether semi–manufactured or finished products, of a kind generally used for conveying, conducting or distributing gases or liquids (for example, ribbed garden hose, perforated tubes). This expression also includes sausage casings and other lay–flat tubing. However, except for the last mentioned, those having an internal cross–section other than round, oval, rectangular (in which the length does not exceed one–and–a–half times the width) or in the shape of a regular polygon are not to be regarded as tubes, pipes and hoses but as profile shapes." (Combined Nomenclature 2002, 2001).

In fact, VII3917 is a product group consisting of 9 6-digits product sub-groups which the have 34 even more detailed 8-digit product groups sitting under it including various materials: artificial guts, poly-ethylene, poly-propylene, poly-vinyl chloride, and other plastics; as well as various forms: rigid, flexible, reinforced, not reinforced, and fittings. Detailed listing of the product can be seen in Appendix-5 (Combined Nomenclature 2002, 2001).

Real life application of this product group is very broad. Information regarding the role and function of plastic tubing can be best extracted from the producers and wholesaler's commercial catalogues which can be summarized below:

- Fluid or gas flow systems (pneumatic, hydraulic, process, medical…)
- Structural systems
- Sheathing for electrical systems
- Insulation for heating assemblies (IEEE, n.d.)

To provide a better context of how VII 3917 functions in the industries and markets, the specific markets and industries where VII 3917 is commonly used are listed below:

- “Automotive: in fuel, air and windshield applications
- Industrial: a wide array of low-pressure vacuum, gas, and fluidic applications
- Food and beverage: manufacturing to packaging and processing.
- Laboratory and research facilities: laboratory components and fittings...including engineering prototyping, pharmaceuticals, biomedical and basic laboratory R&D.
- Maintenance and repair: vacuum, gas, air and fluid flow control components
- Medical: medical flow control parts
- Small engine: outdoor power equipment, power sports, marine and other small engine applications.
- Technology: pneumatic and fluidic flow control components” (ISM, n.d.)

5.1.2 List of significant economic activities for VII 3917

The UMAn model produced a list of NACE sectors (at 4 digits “class” level) where the target product flows through annually for 13 years, with the weight share of the product (at 8-digit level) for each sector (Rosado 2016, personal communication). The 83 NACE sectors that appeared in all 13 years from the model output were first selected for the long list.

The sectors in the long list were then rank by the weight share (%) and the top 62 sectors that represents 99.97% of the total weight of VII 3917 in the economy in Gothenburg were then kept for the short list. List of significant (by weight) economic activities related to target product with NACE codes and brief descriptions can be found in Appendix 2.

5.1.3 Narrow down to a final NACE list of economic activities relevant to the final use phase of the target product

The 62 economic activities were divided into three big categories by the nature of the activity: “Manufacture”, 31; “Sales”, 18; and “Other activities”, 13 based on their NACE codes descriptions (For full list ranked by weight share see Appendix 2).

As mentioned before, CN 3917 is a complex product group which includes various materials and forms of plastic tubing. Therefore, to understand the product’s role in each economic sector requires detailed analysis of its NACE description, breakdown of the 8-digits product weight share, as well as additional external sources such as plastic tubing manufacturer catalogs. Only then should the best judgement be made on which subcategory the economic activities belong to. The reasoning and results of subcategorization are presented in the Tables below

  - Manufacture: Table 1

Subcategories	NACE	Reasons	Sources
Manufacture of target product	2521 Manufacture of plastic plates, sheets, tubes and profiles	Target product 3917 is the major (component of the) output of these manufacture processes	(NACE Rev. 2, 2008)
	2913 Manufacture of taps and valves		
	3130 Manufacture of insulated wire and cable		
	2524 Manufacture of other plastic products		
	2416 Manufacture of plastics in primary forms		
Manufacture of other products	2875 28751 Manufacture of sinks, sanitary ware etc. of metal for construction purposes; 28759 Manufacture of various other fabricated metal products n.e.c.	Target product 3917 seems to be	

which contains target product	2811 Manufacture of metal structures and parts of structures	part of the products of the manufacture activities, as plastic pipes, tubes, fittings, electric wirings and etc	(NACE Rev. 2, 2008) (FreelinWade)
	3410 Manufacture of motor vehicles		
	3120 Manufacture of electricity distribution and control apparatus		
	2523 Manufacture of builders' ware of plastic		
	3310 33101 Manufacture of medical and surgical quipment and ortopaedic applicances except artificial teeth, dentures etc.; 33102 Manufacture of artificial teeth, dentures, dental plates etc.		
	2924 Manufacture of other general purpose machinery n.c.e.		
	3430 Manufacture of parts and accessories for motor vehicles and their engines		
	2442 Manufacture of pharmaceutical preparations		
	2952 Manufacture of machinery for mining, quarrying and construction		
	2912 Manufacture of pumps and compressors		
	2923 Manufacture of non-domestic cooling and ventilation equipment		
	3420 Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers		
	2932 Manufacture of other agricultural and forestry machinery		
	3614 Manufacture of other furniture		
	2030 20301 Manufacture of prefabricated wooden buildings; 20302 Manufacture of other builders' carpentry and joinery		
	2971 29711 Manufacture of refrigerators, freezers, washing machines and dishwashers; 29719 Manufacture of other electric domestic appliances		
	2461 Manufacture of explosives		
	29561 Manufacture of machinery for plastic and rubber processing; 29569 Manufacture of various other special purpose machinery n.e.c.		
	2522 Manufacture of plastic packing goods		
Manufacture of other products, the processes of which use target product	2722 Manufacture of steel tubes	Product of the manufacture activities doesnt seem to contain any (noticable amount of) target product	(NACE Rev. 2, 2008) (FreelinWade)
	2661 26611 Manufacture of light concrete products; 26619 Manufacture of other concrete products for construction purposes		
	2112 21121 Manufacture of newsprint; 21122 Manufacture of other printing paper; 21123 Manufacture of kraft paper and paperboard; 21129 Manufacture of other paper and paperboard		
	2513 Manufacture of other rubber products		
	1598 Production of mineral waters and soft drinks		
	2430 Manufacture of paints, varnishes and similar coatings, printing ink and mastics		

- Sales: Table 2

Subcategories	NACE	Reasons	Sources
Wholesales, retails and agents involved with sales where target product is sold as (part of) a product	5154 51541 Wholesale of hardware; 51542 Wholesale of plumbing and heating equipment	Target product is a major component of what's being sold	(NACE Rev. 2, 2008) (FreelinWade)
	5156 51561 Wholesale of industry supplies; 51562 Wholesale of packaging materials; 51569 Wholesale of intermediate products n.e.c.		
	5246 52461 Retail sale of hardware, plumbing and building materials; 52462 Retail sale of paint		
	5147 51471 Wholesale of furniture fittings; 51472 Wholesale of sports and leisure goods; 51473 Wholesale of stationery and other office supplies; 51479 Wholesale of household goods n.e.c.		

	5143 51431 Wholesale of electrical household appliances; 51432 Wholesale of radio and television goods; 51433 Wholesale of gramophone records, tapes, CSs, DVDs and video tapes; 51434 Wholesale of electrical and lighting equipment		
	5153 Wholesale of wood, construction materials and sanitary equipment		
	5114 51141 Agents involved in the sale of machinery, industrial equipment, ships and aircraft, except office machinery and computer equipment; 51142 Agents involved in the sale of office machinery and computer equipment (kind of sales activity)		
	5141 Wholesale of textiles		
	5030 50301 Wholesale of motor vehicle parts and accessories; 50302 Retail sale of motor vehicle parts and accessories		
	5146 Wholesale of pharmaceutical goods		
	5144 Wholesale of china and glassware, wallpaper and cleaning materials		
	5261 52611 Non-specialized retail sale via mail order Houses; 52612 Retail sale of textiles and clothing via mail order houses; 52613 Retail sale of sports and leisure goods via mail order houses; 52614 Retail sale of books and other media goods via mail order houses; 52615 Retail sale of household goods via mail order houses; 52616 Other retail sale via mail order houses; 52617 Non-specialized retail sale via internet; 52618 Retail sale of books, media goods and computer equipment via internet; 52619 Other retail sale via internet		
	5010 50101 Sale of lorries, buses and specialized motor vehicles; 50102 Sale of passenger motor vehicles; 50103 Sales of caravans, motorhomes, trailers and semi-trailers		
	5118 Agents specializing in the sale of particular products or ranges of products n.e.c		
Wholesales, retails and agents involved with sales where target product is used as final product to aid the activity	5155 Wholesale of chemical products	Target product functions to aid the sales activities, as liquid transfering, packaging, storage and etc	(NACE Rev. 2, 2008) (FreelinWade)
	5211 52111 Retail sale in department stores and the like with food, beverages and tabacco predominating; 52112 Retail sale in other non-specialized stores with food, beverages and tobacco predominating		
	5119 Agents involved in the sale of a variety of goods		
	5138 Wholesale of other food including fish, crustaceans and molluscs		

- Activities: Table 3

Subcategories	NACE	Reasons	Sources
Activities, agents involved in activities where target product is used as a final product	7420 74201 Architectural activities; 74202 Construction and other engineering activities	Product 3917 serves as final product in this economic activity	(NACE Rev. 2, 2008) (FreelinWade)
	4523 Construction of motorways, roads, airfields and sport facilities		
	4533 45331 Installation of heating and sanitary equipment; 45332 Installation of ventilation equipment; 45333 Installation of refrigeration and freezing equipemnt; 45339 Other plumbing		
	4521 45211 General construction of buildings 45212 General construction of civil engineering works		
	6340 Activities of other transport agencies		
	4511 Demolition and wrecking of buildings; earth moving		
	6312 Storage and warehousing		
	7310 73101 Research and development on natural Sciences; 73102 Research and development on engineering and technology; 73103 Research and development on medical and pharmaceutical sciences; 73104 Research and development on agricultural sciences; 73105		

	Interdisciplinary research and development, predominantly on natural sciences and engineering		
	7132 Renting of construction and civil engineering machinery and equipment		
	7020 70201 Letting of dwellings; 70202 Letting of industrial premises; 70203 Letting of other premises; 70204 Property management of tenant-owners' associations; 70209 Letting of other property		
	2852 General mechanical engineering		
	7430 Technical testing and analysis		
	4525 Other construction work involving special trades		

The next step is to generate a final NACE list of economic activities where VII 3917 is used as a final product, starting from "Activities", to "Sales" and finally to "Manufacture". Details of the selection for each category are presented in Table 4 "activities", Table 5 "sales", and Table 6 "manufacture".

> Note: As describe previously, this step is to exclude the sectors where VII is used as a semi-final product. The final list economic activities added up to be only 12.8% of total weight of the original list which included semi-final VII 3917. Therefore, the weight share of VII 3917 used as final product was then adjusted to 100% for easier conceptualisation, and the weight share of each NACE sector in the final list was upscaled proportionally

- For "Other Activities": The economic activities listed under the "Other Activities" category all used the target product as a final product to generate goods or services.

Table 4. Activities NACE final list

Subcategories	NACE	Share
Activities, agents involved in activities where target product is used as a final product	7420 74201 Architectural activities; 74202 Construction and other engineering activities	12,94%
	4523 Construction of motorways, roads, airfields and sport facilities	7,14%
	4533 45331 Installation of heating and sanitary equipment; 45332 Installation of ventilation equipment; 45333 Installation of refrigeration and freezing equipemnt; 45339 Other plumbing	5,93%
	4521 45211 General construction of buildings 45212 General construction of civil engineering works	2,20%
	6340 Activities of other transport agencies	0,56%
	4511 Demolition and wrecking of buildings; earth moving	0,51%
	6312 Storage and warehousing	0,34%
	7310 73101 Research and development on natural Sciences; 73102 Research and development on engineering and technology; 73103 Research and development on medical and pharmaceutical sciences; 73104 Research and development on agricultural sciences; 73105 Interdisciplinary research and development, predominantly on natural sciences and engineering	0,34%
	7132 Renting of construction and civil engineering machinery and equipment	0,27%
	7020 70201 Letting of dwellings; 70202 Letting of industrial premises; 70203 Letting of other premises; 70204 Property management of tenant-owners' associations; 70209 Letting of other property	0,12%
	2852 General mechanical engineering	0,11%
	7430 Technical testing and analysis	0,08%
	4525 Other construction work involving special trades	0,07%

- For “Sales”:

Only when the target product is used to aid the sales process of other products (ie, dispensing machine, clothes hanger and etc), it is considered to be used as a final product and can be added to the final NACE list. For example, “5155 wholesale of chemical products”, plastic tubes are not the items being sold but being used in the sales activities as part of the dispensing apparatus, therefore the target product here is not intermediate but final product, therefore this NACE can be included to the final list.

Table 5a. Sales NACE final list

Subcategories	NACE	Share
Wholesales, retails and agents involved with sales where target product is used as final product to aid the activity	5155 Wholesale of chemical products	34,22%
	5211 52111 Retail sale in department stores and the like with food, beverages and tabacco predominating; 52112 Retail sale in other non-specialized stores with food, beverages and tobacco predominating	0,52%
	5119 Agents involved in the sale of a variety of goods	0,43%
	5138 Wholesale of other food including fish, crustaceans and molluscs	0,30%

- When the target product is sold as (part of) goods as a “Sales” activity, it is not considered to be final product. However, it is possible that the use phase of this goods is missing from the “Other Activities” category, therefore such activities can be modified (renamed) and added to the final NACE list, unless such activities are already present in the “Other Activities” as "final use derived from sales". For example, in the table below, “51479 wholesale of household goods” is a sector where target products are being sold possibly as part of the household appliance, ie as the wiring component of electric appliances. Considering the use of household products is missing from “Table 4 Activities”, this sales item can be transferred to “activities” in order to fill the blank of the use of household products (where VII 3917 is used as a final product).

Table 5b. Sales NACE final list

Subcategories	NACE	Share
Wholesales, retails and agents involved with sales where target product is sold as (part of) a product	5147 51471 Wholesale of furniture fittings; 51472 Wholesale of sports and leisure goods; 51473 Wholesale of stationery and other office supplies; 51479 Wholesale of household goods n.e.c.	7,47%
	5143 51431 Wholesale of electrical household appliances; 51432 Wholesale of radio and television goods; 51433 Wholesale of gramophone records, tapes, CSs, DVDs and video tapes; 51434 Wholesale of electrical and lighting equipment	5,90%
	5114 51141 Agents involved in the sale of machinery, industrial equipment, ships and aircraft, except office machinery and computer equipment; 51142 Agents involved in the sale of office machinery and computer equipment (kind of sales activity)	3,43%
	5141 Wholesale of textiles	0,63%
	5030 50301 Wholesale of motor vehicle parts and accessories; 50302 Retail sale of motor vehicle parts and accessories	0,50%
	5146 Wholesale of pharmaceutical goods	0,24%
	5144 Wholesale of china and glassware, wallpaper and cleaning materials	0,11%

	5261 52611 Non-specialized retail sale via mail order Houses; 52612 Retail sale of textiles and clothing via mail order houses; 52613 Retail sale of sports and leisure goods via mail order houses; 52614 Retail sale of books and other media goods via mail order houses; 52615 Retail sale of household goods via mail order houses; 52616 Other retail sale via mail order houses; 52617 Non-specialized retail sale via internet; 52618 Retail sale of books, media goods and computer equipment via internet; 52619 Other retail sale via internet	0,07%
	5010 50101 Sale of lorries, buses and specialized motor vehicles; 50102 Sale of passenger motor vehicles; 50103 Sales of caravans, motorhomes, trailers and semi-trailers	0,06%
	5118 Agents specializing in the sale of particular products or ranges of products n.e.c	0,04%

- For “Manufacture”:
  - The target product can be used as a final product to aid the manufacture process of other products (ie, machineries used in the production line…) and can be added to the final list. For example, for manufacture of steel tubes, target product “plastic tubes” are not what’s being manufactured as intermediate product but used in the production process of other products, ie “steel tubes”, therefore target product here can be considered as being used as final products.

Table 6a. Manufacture NACE final list

Subcategories	NACE	Share
Manufacture of other products, the processes of which use target product	2722 Manufacture of steel tubes	12,38%
	2661 26611 Manufacture of light concrete products; 26619 Manufacture of other concrete products for construction purposes	0,93%
	2112 21121 Manufacture of newsprint; 21122 Manufacture of other printing paper; 21123 Manufacture of kraft paper and paperboard; 21129 Manufacture of other paper and paperboard	0,63%
	2513 Manufacture of other rubber products	0,54%
	1598 Production of mineral waters and soft drinks	0,10%
	2430 Manufacture of paints, varnishes and similar coatings, printing ink and mastics	0,04%

  - When the target product is part of the manufactured goods, it is considered to be intermediate product. However, if this product’s final use phase is missing from “Sales” and “other Activities”, the manufacture activity can be recreated/renamed and added to the final NACE list as “final use derived from manufacture”. For example, for “2461 Manufacture of explosives”, target products are likely to be the wiring component of the explosives, therefore could be considered as part of the intermediate products. However, as neither the sales or the use of explosives had been listed, this manufacture item can be transferred to “activities” to fill the missing NACE activities involving explosives.

Table 6b. Manufacture NACE final list

Subcategories	NACE	Share
Manufacture of other products which contains target product	3310 33101 Manufacture of medical and surgical quipment and ortopaedic applicances except artificial teeth, dentures etc.; 33102 Manufacture of artificial teeth, dentures, dental plates etc.	0,63%
	2932 Manufacture of other agricultural and forestry machinery	0,15%
	2461 Manufacture of explosives	0,08%

- When the manufacture activity produces exactly the target product, it is considered to be intermediate product whose final use phase has been covered through the process above hence wouldn't be included in the final list.

Figure 16. below gives an overview of the final count of NACE sectors by three categories, divided into whether the target product appeared to be a final product or intermediate.

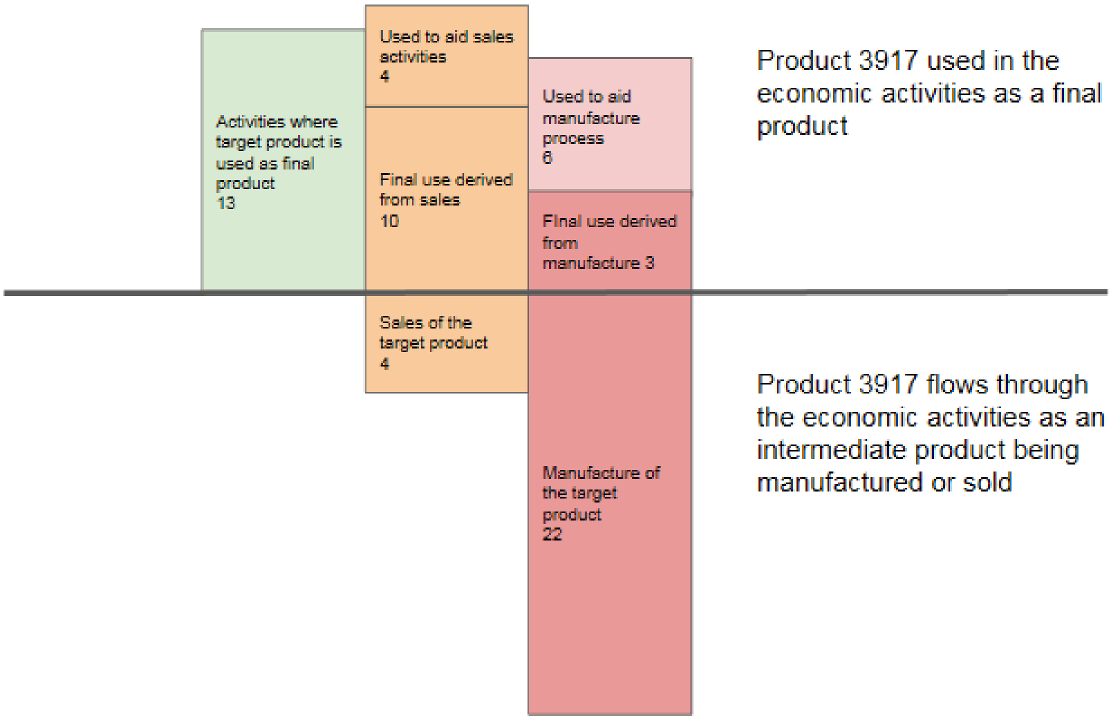

Figure 16. Breakdown of NACE sectors by three categories and final vs intermediate

5.1.4 Final NACE list analysis for CE strategy creation

The list of economic activities where the target products produce value as final products can be analysed by the investigating both the life span of the final product and the product-user relationship. A bubble graph can be made to provide an overview (Figure 17).

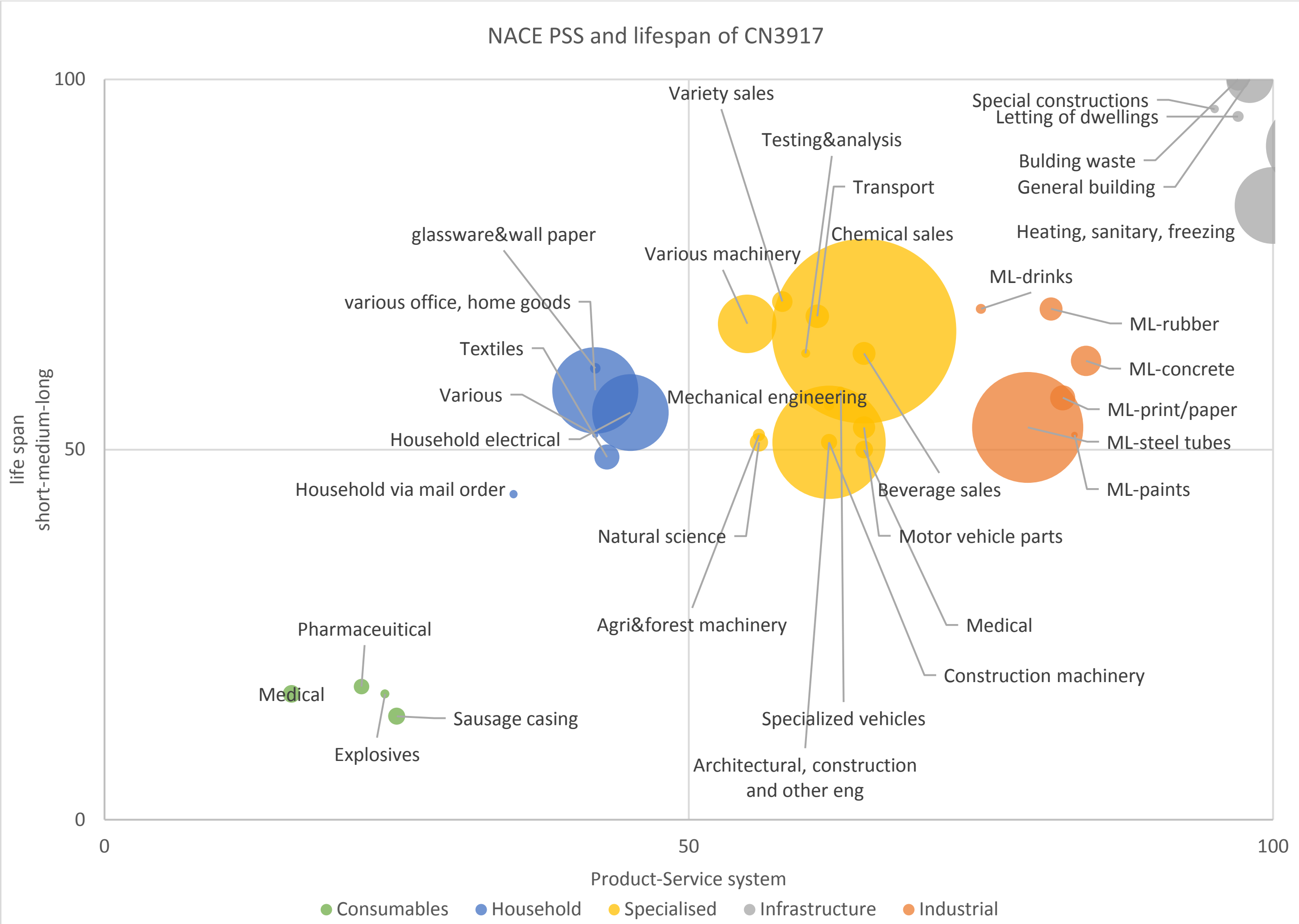

Figure 17. Bubble graph breakdown of final use NACE sectors across lifespan and PSS

X axis: PSS ranging from product value content to service value content. From left to right and coded by different colors:

- Consumables (“randbetween 15-25”)
- Household (“randbetween 35-45”)
- Specialized equipment (“randbetween 55-65”)
- Industrial assembly lines (“randbetween 75-85”)
- Infrastructure (“randbetween 95-105”)

The valuable content of each product (either product or service oriented) was determined through research and analysis. Once the category was determined, the "randombetween” function was used to assign a value within the range of the category. For example, “medical” was determined to be “consumable”, so it was assigned a value between 15 to 25 in the table to plot it on the bubble graph.
Y axis: Lifespan of the final product qualitatively: short, up to a year; medium, a few years; long, decades to centuries…

Size of the bubbles: weight share of target product (used as final product) in that economic activity.

5.1.5 Insights and Strategies

This approach allows for clear insights of how to best promote circularity for the target products in the city. The insights and strategies are listed below with application to a specific example:

- Identify clusters where the target product produces value in the economy as hotspots for actions and developing fitting strategies for products/ sectors of various lifespan and PSS

For example, “specialized equipment” is observably be the largest cluster of the target products. Therefore we arrive at the insight that most of the target products (by weight share) function as part of a specialized equipment, more specifically, mainly in the “chemical sales activity” to provide value in the economy, therefore it would be reasonable to take these products as a hotspot for actions for the biggest impact.

- Identify influential actors and possible networks

Once having selected target products to focus on, we will be able to identify influential actors and possible networks surrounding plastic tubes in the chemical sales activities. The influential actors also have a wide spread across the economy, as producers, users, maintainers and etc in a complex network. In this case, producers refer to the producers of chemical dispensing machines, assembly lines and instruments; users are chemical salesmen; and finally maintainers of these equipment are specialized mechanics or engineers.

- Identify the main urban stocks of the products (long life span) to plan for their end of life management

The main urban stocks of the chemical sales equipment should have a medium to long lifespan, especially considering that the plastic tube is a fossil fuel based material that can last for forever. Strategies should focus on long term planning of the products to make it stay in the economy through maintenance and reuse for as long as possible. Considerable amount of the product is most likely to be in long term stock and should be the focus area for end of life management.

- Identify potentials for standardization, sharing and cascading mechanisms of the target product

For chemical dispensing equipment, there is a lot of potential for standardization, especially considering the reality is that plastic tubing is known for its diversity to accommodate for a wide variety of applications. Big producers like FreelinWade advertises the options they provide in customizing their product to meet consumers’ demands. They are able to produce plastic tubing with limitless options of colours, shapes, pressure ratings, bend radius, temperature ranges, strength, spark resistances, sterilisable, cutting, forming, coiling, bonding depending on material construction (FreelinWade). Such a variety makes reusing of the material rather challenging and should be the key focus point to achieve circularity of the target product. The producer has the most power to design and regulate the product’s’ life cycle. Therefore, the producers and designers have opportunity to implement standardization of the target product. Besides, the network of actors also has the possibility to collaborate and explore opportunities to share, reuse and cascade recycle the equipment in their own applications.

- Identify the leakage points of the target product in the economy

The prominent leakage point for the system where VII 3917 has a short life span, observably in the medical, explosives, and pharmaceutical sectors. Biodegradable alternative options would be the best to explore for these applications.

5.2 Application of the Sector Approach

5.2.1 Select a target economic activity sector at NACE 4-digit level

5.2.1.1 Target sector description

Target sector is the General construction sector, with the NACE code 4521:

1. It includes the construction of residential (all type: single-family house, multi-family house, including high-rise buildings) and non-residential buildings (ie. buildings for industrial production like factories, workshops, assembly plants, hospitals, schools, hotels, stores, shopping malls, restaurants, airports, indoor sports facilities, parking garages, warehouses, religious buildings and etc). Assembly and erection of prefabricated constructions, remodelling and renovating existing structures are also included. Outsourcing parts or even the whole construction process is also included. However, architectural and engineering activities, project management for construction, demolition, site preparation and waste management are excluded.

2. It also includes the general construction for civil engineering objects, including new works, repair, additions and alterations. The erection of pre-fabricated structure on site, temporary construction, as well as heavy construction of motorways, streets, bridges, tunnels, railways, airfields, harbours, other water projects, irrigation systems, sewerage systems, industrial facilities, pipelines and electric lines, outdoor sports facilities are also included. Outsourcing of portions or the whole practical work is possible (NACE Rev. 2., 2008).
The construction sector was chosen because it is the most relevant to the urban environment, which is the central scope of this study. It also has very high impact both environmentally and economically.

5.2.2 List of all the products that goes into the target sector

The UMAn model produces all CN products (at 4 digits level) that go into the target sector for 13 years. And a total of 114 CN products at 4-digits level were presented by the model to present 100% of the total product input. The list, their official CN descriptions and weight share can be seen in Appendix 3 (Rosado 2016, personal communication).

5.2.3 Divide products into two major categories

All input products are then divided into two categories: for use and as sector output.

- Products to be consumed or used in the sector (final use products)

The general construction sector workers use a wide variety of tools in routine work conditions, and consume household products like clothing, printed matters etc. Fifty Products in total are in this category, see Table 7. (Rosado 2016, personal communication).

- Product to be transformed and become sector output (intermediate use products).

There are a wide variety of construction materials going into the sector and be transformed or assembled to become the sector’s output (ie materials in buildings, roads, bridges and etc).

5.2.4 Insights and Strategies

5.2.4.1. For products to be consumed or used in the sector

These products are in their final-use phase so can simply be grouped by their lifespans (Table 7), which indirectly indicates their general value content, being either product or service content oriented. Overall for the construction sector, there are relatively few consumables and household products which are mainly for the construction workers onsite. However, there are large amounts of specialized equipment like machinery and tools involved in the construction activities. Products in this category are listed in Table 7 below.

Table 7.

Lifespan	Products
Short	Newspapers
	Printed books, brochures, leaflets and similar printed matter
Medium	T–shirts, singlets and other vests, knitted or crocheted
	Printed matter
	Collectors' pieces
	Suits
	Other headgear
	Gloves, mittens and mitts
	Articles of apparel and clothing accessories, of leather
Long	Machines and mechanical appliances
	Bulldozers and angledozers
	Cranes
	Special purpose motor vehicles
	Pulley tackle and hoists
	Machinery, for earth, minerals or ores
	Machinery for earth, stone, ores or other mineral substances
	Other lifting, handling, loading or unloading machinery
	Trailers and semi–trailers
	Motor cars for persons
	Seats
	Parts for machinery
	Interchangeable tools for hand tools
	Containers for carriage by transport
	Pumps for liquid
	Machinery, plant or laboratory equipment for the treatment of materials by change of temperature
	Hand tools not elsewhere specified or included
	Motor vehicles for the transport of goods
	Air or vacuum pumps
	Centrifuges, including centrifugal dryers
	Other agricultural, horticultural, forestry, poultry–keeping or bee–keeping machinery
	Mechanical appliances for fire extinguishing
	Reservoirs, tanks for any material
	Tools for Pneumatic
	Brazing or soldering machines and apparatus
	Parts of the motor vehicles
	Automatic data–processing machines
	Automatic regulating or controlling instruments and apparatus
	Measuring or checking instruments
	Instruments and apparatus for physical or chemical analysis

	Electrical machines and apparatus
	Parts and accessories of heading Nos 8456 to 8465
	Parts and accessories of vehicles of headings 8711 to 8713
	Hydrometers, thermometers, pyrometers, barometers etc
	Primary cells and primary batteries
	Transmission shafts and cranks; bearing; gears ; crews (including universal joints)
	Geo surveying instruments and appliances
	Electric motors and generators
	Parts suitable for apparatus of headings 8525 to 8528
	Portable electric lamps designed to function by their own source of energy
	Parts and accessories for machines of headings 8469 to 8472

Similarly, such an overview can provide valuable insights on the target NACE sector's resource use thus inspire relevant strategies:

- Overview how various products produce value in this sector and identify the main type of product use.

Most of machineries are used, while some household products (mostly clothing or print related) are consumed by the workers in this sector. Three clusters of products can be clearly identified and similar strategies provided from Figure 10 Circular economy strategy map on the scale of PSS& can be applied here. For example, for the short-living consumables, strategies like eco-design and take back service can be effective; as for the long life spanned machineries, having a service sharing platform can have a bigger effect.

- Identify opportunities to outsource for services instead of owning products

There is great opportunity to implement the "outsourcing" and "pay per service" strategies here for the machineries. In fact, it is already being done to a great extent in Sweden. As machineries are high value products, there are great incentives to maintain the machineries for their maximum value and lifespan whether their owners being the construction sector itself or external business who lease these machineries out as a service. And this great opportunity for service economy (renting, sharing and pooling of resources) is already very much in. There are many companies that provide such machinery pooling services to the construction sector though it largely depends on the machinery type (Hedberg, 2016).

- Identify key actors in the sector who has influence over the flow of the products

Workers have control over the consumable and household products that they own, at least their maintenance and end of life. However, many products (gears and newspapers) could be purchased by the company in bulk, in which case sustainable purchase decisions can be made to buy greener products or use external services to outsource ownership so that other parties can take responsibility of managing these products for maximum value and lifespan.

5.2.4.2 Strategies for products to be transformed and become sector output

The output of construction sector is buildings, bridges and other infrastructures, which can be seen both as goods and service. The products in this category can then be roughly classified by their material properties (toxic, technical and biological) as explained in 3.3.2. Full list see Appendix 3.

<u>Count of Toxic product groups: 3</u>

*Note: The obviously toxic products identified here are:

- 3824: Prepared binders for foundry moulds or cores; chemical products and preparations of the chemical or allied industries (including those consisting of mixtures of natural products), not elsewhere specified or included

- 6806: Slag wool, rock wool and similar mineral wools; exfoliated vermiculite, expanded clays, foamed slag and similar expanded mineral materials; mixtures and articles of heat–insulating, sound–insulating or sound–absorbing mineral materials, other than those of heading 6811 or 6812 or of Chapter 69
- 3506: Prepared glues and other prepared adhesives, not elsewhere specified or included; products suitable for use as glues or adhesives, put up for retail sale as glues or adhesives, not exceeding a net weight of 1 kg

Above were identified according to the Swedish Construction Federation's list of hazardous wastes which is based on substances, ranging from aerosols in spray cans to heavy metals, from all kinds of plastics to oils (Kretsloppsrådet's guidelines, 2015). The list was made primarily for pre-demolition audit, in order to protect the demolition worker's health, but not to guide material recycling. However, this list exposed the problem that toxicity of a product is usually substance based, which cannot be captured in the CN codes which is centred around commercial products but not classified by the substance they contain. Therefore, this approach will need further improvement to better identify hazardous or toxic products in a systematic way.

Strategy: Avoid using toxic materials by looking for alternatives.

Real life experiences: Looking for alternative sources to replace toxic materials has long been a focus for the construction sector. Many previously used toxic products have been phased out, such like lead, PCBs and asbestos (Bagley, 2013). However, the reality is that the more environmental friendly construction materials have higher price initially therefore who should pay that price has been the issue in the construction field (Hedberg, 2016).

<u>Count of Technical product groups: 54</u>

*Note: Stones and cement have dominant weight share among all product input to the construction sector (87%).

Strategies: For the circularity of technical products, the goal is keep them circulating in the loop. The proposed approach identifies these products to look out for when developing strategies for

- modular design,
- standardization across the industry for reusability,
- repair and refurbish accessibility,
- plan for end of life separation and collection, then reuse or recycle.

Real life experiences:

- modular design

This strategy is also suggested by the Circular Amsterdam study: smart design should be done to make the buildings more suitable for repurposing and reuse of materials (2016). However, the challenge is that architects, especially when design the exterior of the buildings look at special materials of a certain form or color for visual appeals. Without the end of life in mind, it is hard to plan the recycling of these special materials (Hedberg, 2016).

- standardization across the industry for reusability

The current construction sector fulfils this criterion in some parts, especially when it comes to the smaller components of a building. However, the challenge is the long lifespan of buildings, which means many of the materials used in old buildings may contain toxic materials, or that certain parts of the old buildings doesn't fit current energy efficiency standards which creates a barrier for reuse.

- repair and refurbish accessibility

Infrastructure generally has long lifespan and renovation is commonly done.

- plan for end of life separation and collection, then reuse or recycle.

Pre-construction waste planning has been strongly recommended by the federation, however not yet in any legislation. To make economic sense, the amount of material being recycled needs to reach big enough volume and mass, and easy to aggregate for treatment (Hedberg, 2016).

Count of Biological product groups: 7

*Note: The line between technical and biological products is also somewhat blurred because the method is based on product, not material. When biological material like wood is processed, and preserved, its lifespan gets extended considerably and it because of the preservatives and other chemical additives, it becomes questionable if it can still be treated as biological product and returned safely to nature at its end of life.

Strategies:
For the circularity of biological products, the goal is to expand their service time, then extract as much value as possible then return them safely to the biosphere. Identifying these products in the sector helps for the planning for their

- Maintenance
- Collection and separation
- Treatment and maximum value recovery

Real life experiences: For construction material, as the distinction between biological and technical is rather blurred, strategies for biological materials like timber can be similar to strategies for technical materials in some respects, for example, further prolonging the lifespan. In addition, the biological aspect of timber should also be considered at its end of use, ie biological treatment or value recovery.

5.2.5 Influential actors

As previously discussed, architect can play can play an important role in the material composition of a building for they have the power of design, which is the most crucial for a circular system. Smart and modular design makes it possible to prolong the building's lifespan and to reuse the materials.

The contractors of construction projects can also play an important role. Investing in biological and non-toxic materials, developing a waste plan before construction, and doing a pre-demolition material audit all contribute to a more circular sector.

The commissioners and final users of construction projects can choose green procurement and demand better material management to be implemented in their purchasing decisions, which can be a key driver to move the sector towards circularity from the demand side.

6. Discussion

The proposed approaches filled many gaps identified in the state of art in urban circular economy implementation. For example, the product approach identifies the clusters of urban stock leakage points and where most of the target products produce value in the economy as hotspots for actions; having an overview of the products in the city also makes it possible to develop a set of strategies for products/sectors of various lifespans in a more systematic way. Moreover, it also scans the whole urban flow to identify influential actors and possible networks for efforts of standardization, sharing, cascading mechanisms of the target products. However, despite the advantages added by these urban metabolism based approaches, there are still limitations that require future studies. The criteria, existing gaps, improvements and further studies are organized in the table below for clarification.

Evaluation criteria	Gaps	Improvements made by proposed approaches	Further studies needed
Methodological			
Is it systematic? Is it comprehensive? Can it potentially consider all resource flows in the city? How detailed is it/ to what level of detail of the resource can it reach? Is it adaptable for any city in any country?	The selection of flows was mostly arbitrary and based on existing efforts. There was a lack of unified systematic comprehensive approach that can potentially be upscaled to take all resource flows in the city into consideration with certain level of details. Reviewed methods were heavily based on the one city but with little adaptability to be used for other cities. Existing approaches were also predominantly qualitative.	This study provided approaches that are systematically based on Eurostat classification of products and economic activities, which means they can be used in other European cities, and even globally with some modification, providing standards and comparability. These approaches are also more comprehensive because CN and NACE classification includes all the products and activities in the economy so it could be upscaled to cover all the flows in any given city. These approaches also went beyond the existing efforts but has the potential to realize the ambition of circularising even the obscure flows in the city. The level of details can be flexible depending on which level of classification was chosen (product: up to the 8 digit level, activity: up to the 6 digit level). These approaches also went beyond a mere qualitative study but are relatively accurate quantitative.	The study was done at the 4 digit level, trying 2 or 8 digit level could potentially yield other interesting insights. The CN classification doesn't exactly distinguish toxic, technical or biological materials.
Is it tailored to address urban resource flows? Does it consider city as a main resource consumer? Does it consider the urban resource stock? Does it consider leakage points to nature from the cities?	Not all reviewed studies were focused on the urban context. City's role in resource consumption, resource stock could be better recognized. The major leakage/emission points from the city to nature could be more clearly identified.	The approaches are very much tailored to the city context because of the UMAn model has a clear scope on the urban scale. The target products are those at the final consumption phase in the city and the lifespans are taken into consideration in order to identify urban stocks and quick leakages. While the target economic activities take into account all the products input at their use phase as well as their lifespans to identify urban stocks and leakage point to nature.	The manufacture and agriculture NACE sectors' relevance to urban scale are not clear and largely depending on the individual city scale and industry typology.

Does it apply life cycle thinking? Does it consider the life cycle phase of the products? Does it consider the lifespan of the products? Does it consider beyond the urban boundary for the production and waste phase of the products?	Life cycle thinking was not given much attention in the reviewed studies. There were some signs of life cycle phases being considered however the exploitation of raw material and emissions beyond the urban boundary were commonly out of scope. Not much study had a focus on technical product so the idea of lifespan has not been thoroughly examined. Considerations beyond the urban boundary could to be further addressed and discussed.	The approaches integrated life cycle thinking. For the product approach, the lifespan and life phase of the products were both considered. However the agriculture and industrial production phase was not discussed in details due to the urban scope. For the sector approach, how various products are used in a chosen activity (to provide a service as final products or to be transformed to a good) determines whether the focus of the strategy is on sustainable consumption or production. Moreover, the nature of the activity great affects the focus of the strategies. For example, for a manufacture natured economic activity, the end of life phase of the produced goods needs to be planned from the production or even design phase of this very activity, while for a service activity with no output of goods, sustainable consumption is the only concern. In terms of thinking beyond the urban boundary, the goal of the strategies is to keep the technical materials in the economy without leaking to nature. The approach can also identify most prominent leakage points based on the lifespan of the products.	Considerations beyond the urban boundary regarding the production phase of the products needs to be further addressed.
Circular Economy Vision Outcome			
Design out waste (designed by intention to fit within a cycle, or to a lesser degree: Optimise exploitation of raw materials to deliver more with less input) The biological materials are non-toxic and can be simply composted. Technical materials (polymers, alloys and other man-made compounds) are	Due to the limitation of flow selection, the design aspect for different materials (technical, biological and toxic) has not been fully explored. All reviewed studies put considerable effort into extracting value from waste/secondary material but much less on the design of the product, let alone analysing the	Eliminate the concept of waste through design is the most powerful therefore priority strategy. The product approach also provides opportunities to identify potentials for standardization, establishing partnership, and transitioning into a service-based economy. The nature of material was also taken into account: for each target economic sector, toxic materials should be avoided while modular design, standardization for reusability, repair and refurbishment accessibility and plan for end of life reuse should be especially investigated for technical materials.	

designed to have longer life span and to be reused, refurbished, repaired, remanufactured with minimal energy and highest quality retention, if cannot be replaced by biological material. Substitute hazardous substance.	whole system. As a result, in most cases, even the ideal circular vision proposed in the studies were far from "closing the loop".		
Build resilience through diversity. Modularity, versatility, and adaptability. Balance efficiency with resilience. Replace virgin materials with recycled materials.	The idea of building resilience through diversity and balancing it with efficiency appeared to be a too abstract and advanced concept for circular economy. Some studies had ideas that could contribute to it (improve biota, system diversity...) but haven't been fully explored	For the product approach, balance of the system was taken into consideration. Suggestions were made regarding diversifying the business models towards service and sharing economy, as well as modularity and standardization which could increase system resilience. For products consumed in the target economic activity sector, diversifying business models can be also applied to improve the resilience of the system. For the products to be transformed as sector output (in any production natured activity), modularity, versatility and adaptivity potentials can be further explored.	
Work towards energy from renewable sources. Systems should ultimately aim to run on renewable energy. Reduce the need for fossil-fuel and capture more of the energy value of by-products and manures.	Renewable energy integration was not a key consideration in the reviewed studies. Only one or two studies briefly mentioned switching more to biobased materials or using more renewables	Energy is out of scope since the focus is on resources	Different studies with a focus on energy can be done
Think in systems (understand how parts influence one another within a whole, and	Thinking in systems was present in many studies where various sectors of the society (business,	A systematic picture of the whole urban economy relevant to the target products can be provide by identifying all applications of the products, along with various relevant actors playing different roles.	

the relationship of the whole to the parts) Elements are considered in relation to their environmental and social contexts: Economic incentives (internalization of environmental cost, deposit system, extended producer responsibility, tax on natural resources and pollution). Business models (service and towards collaborative).Technological and social innovation. Governance, skills, knowledge and awareness.	governance, technology, culture) were taken into consideration and their relations and possible cooperation opportunities were explored. The main economic, cultural, legislative and technological barriers can be identified and relevant key stakeholders were highlighted though not all actors could be clearly identified if not already active.	Most influential actors for the target sector can also be identified and analysed by their respective influence over listed products of different categories. These approaches made achieving a truly circular vision more tangible.	
Think in cascades extract additional value from products and materials by cascading them through other applications. Recycling: avoid mixing and contamination, then used again as secondary material	Extracting value from waste was done best compared to other criteria in all reviewed studies. It might be the best economically incentivized, understood, and most experimented component of circular economy. However overall the focus was too concentrated on waste management to present the full potential of circular economy.	By means of these approaches, thinking in cascade can be done in a more comprehensive way that switches attention from waste management to earlier life cycle stage management. Various product applications can be identified and grouped based on the respective product lifespans which derives more fitting strategies for their end of life planning. However, waste management is not the key focus since this area has been quite well investigated. As for the sector approach, the products consumed in the sector can be studied in a similar manner: use life span and PSS to derive strategies to prolong their lifespan and to develop better end of life management strategies. For the products transformed in the sector, where their end of life reusing/recycling can also be planned ahead of time, preferably in the designing phase.	

7. Conclusion

This study started with investigating the two emerging global megatrends, rapid urbanisation and unsustainable resource use and discovered an opportunity to alleviating problems raised by both, which is achieving circular economy in the urban environment. Early research on existing international efforts towards circular economy give rise to a set of criteria for measuring true circularity. Additional criteria for evaluating the methods of achieving urban circular economy was also established.

Four existing cases of cities that have been making an effort towards circularity were then found and evaluated against the developed criteria. Many gaps in both the method and the envisioned circularity were then identified and it was apparent that more work is needed for the mission of achieving urban circular economy.

Two new systematic approaches based on an urban metabolism model (UMAn) were then introduced in attempt to fill these gaps. The logic, operation mechanism, and matching strategies of the model was introduced then applied to urban metabolism data of the Swedish city Gothenburg to test. The two approaches (the product approach and the sector approach) were tested on the resource flows of one product (CN code 3917: tubes, pipes and hose of plastic) and one sector (NACE code 4521: general construction).

These approaches were then also examined by the previously introduced criteria to see to what extent they can fill the existing gaps in the methodology as well as the urban circular visions. And it was discovered that the proposed approaches made advancements as they are more systemic and can be adaptable to many different (European) cities due to the use of standard database providing possibilities of comparison in a quantitative measure. They are also more specific to the urban context by focusing the “final use” aspect of the products and can identify hotspots for action and influential stakeholders. They are also more comprehensive in the targeting of products, activities and actors as they do not depend on existing efforts, or arbitrarily chosen sectors but can be much more inclusive to all. Last but not least, they provided opportunities to switch the attention of sustainable development from waste management to the earlier life cycle stages of products highlighting the power of design.

On the other hand, no perfect solution could be promised yet as there are still limitations regarding the novel approaches: They didn't not address energy but only focused on materials; simplified the urban context as if production only happens outside of cities; and only tested product groups at 4 digit CN level.
Therefore, further studies are needed mainly on incorporating the energy aspect into the urban circular economy vision; finding a way to better define the relationship between urban context and the production sector; testing the approach at 2 or 8 CN digit level for additional insights.

This study has been an initial attempt to systematically building an urban circular economy vision. Despite some progress made, further studies on this topic and applications are fervently needed for a truly circular future.

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Appendix

Appendix 1 Circular Economy Definitions

Circular Economy is “described as an industrial economy in which material flows keep circulating at a high rate (in terms of quality, property, function, range of use) without the material entering the biosphere, unless they are biological nutrients.” “a system which is restorative by design” (EMF, 2013)

“A circular economy is a living system which creates value based on usage, instead of consumption. Durability of products and resources is key. Basic principles of the circular economy are using pure and non-toxic products, design for disassembly and use only renewable energy” (EMF, 2013).

“A circular economy is a restorative industrial economy in which materials flows are of two types: biological nutrients, designed to re-enter the biosphere safely, and technical nutrients (non-biological materials), which are designed to circulate at high quality, with their economic value preserved or enhanced.” (Aldersgate, 2012)

“A circular economy is an industrial economy, which has resilience as intention and replaces usage by using. The circular economy is based on closing loops and (where possible, infinitely) extending cycles.” (OPAi & MVO Nederland, 2014)

Appendix 2 Selected 65 NACE sectors for target product VII 3917

65 selected NACE sectors	NACE code	Weight share
2521 Manufacture of plastic plates, sheets, tubes and profiles	2521	43,93%
5154 51541 Wholesale of hardware; 51542 Wholesale of plumbing and heating equipment	5154	35,35%
5155 Wholesale of chemical products	5155	4,17%
5156 51561 Wholesale of industry supplies; 51562 Wholesale of packaging materials; 51569 Wholesale of intermediate products n.e.c.	5156	1,58%
7420 74201 Architectural activities; 74202 Construction and other engineering activities	7420	1,58%
2722 Manufacture of steel tubes	2722	1,51%
2913 Manufacture of taps and valves	2913	1,29%
5246 52461 Retail sale of hardware, plumbing and building materials; 52462 Retail sale of paint	5246	1,23%
5147 51471 Wholesale of furniture fittings; 51472 Wholesale of sports and leisure goods; 51473 Wholesale of stationery and other office supplies; 51479 Wholesale of household goods n.e.c.	5147	0,91%
4523 Construction of motorways, roads, airfields and sport facilities	4523	0,87%
3130 Manufacture of insulated wire and cable	3130	0,81%
4533 45331 Installation of heating and sanitary equipment; 45332 Installation of ventilation equipment; 45333 Installation of refrigeration and freezing equipemnt; 45339 Other plumbing	4533	0,72%
5143 51431 Wholesale of electrical household appliances; 51432 Wholesale of radio and television goods; 51433 Wholesale of gramophone records, tapes, CSs, DVDs and video tapes; 51434 Wholesale of electrical and lighting equipment	5143	0,72%
5153 Wholesale of wood, construction materials and sanitary equipment	5153	0,60%
2524 Manufacture of other plastic products	2524	0,55%
2875 28751 Manufacture of sinks, sanitary ware etc. of metal for construction purposes; 28759 Manufacture of various other fabricated metal products n.e.c.	2875	0,49%
2416 Manufacture of plastics in primary forms	2416	0,46%
2811 Manufacture of metal structures and parts of structures	2811	0,43%
5114 51141 Agents involved in the sale of machinery, industrial equipment, ships and aircraft, except office machinery and computer equipment; 51142 Agents involved in the sale of office machinery and computer equipment	5114	0,42%
3410 Manufacture of motor vehicles	3410	0,30%
4521 45211 General construction of buildings 45212 General construction of civil engineering works	4521	0,27%
3120 Manufacture of electricity distribution and control apparatus	3120	0,23%
2523 Manufacture of builders' ware of plastic	2523	0,19%
2661 26611 Manufacture of light concrete products; 26619 Manufacture of other concrete products for construction purposes	2661	0,11%
5141 Wholesale of textiles	5141	0,08%

2112 21121 Manufacture of newsprint; 21122 Manufacture of other printing paper; 21123 Manufacture of kraft paper and paperboard; 21129 Manufacture of other paper and paperboard	2112	0,08%
3310 33101 Manufacture of medical and surgical quipment and ortopaedic applicances except artificial teeth, dentures etc.; 33102 Manufacture of artificial teeth, dentures, dental plates etc.	3310	0,08%
6340 Activities of other transport agencies	6340	0,07%
2924 Manufacture of other general purpose machinery n.c.e.	2924	0,07%
2513 Manufacture of other rubber products	2513	0,07%
5211 52111 Retail sale in department stores and the like with food, beverages and tabacco predominating; 52112 Retail sale in other non-specialized stores with food, beverages and tobacco predominating	5211	0,06%
4511 Demolition and wrecking of buildings; earth moving	4511	0,06%
5030 50301 Wholesale of motor vehicle parts and accessories; 50302 Retail sale of motor vehicle parts and accessories	5030	0,06%
3430 Manufacture of parts and accessories for motor vehicles and their engines	3430	0,05%
5119 Agents involved in the sale of a variety of goods	5119	0,05%
6312 Storage and warehousing	6312	0,04%
7310 73101 Research and development on natural Sciences; 73102 Research and development on engineering and technology; 73103 Research and development on medical and pharmaceutical sciences; 73104 Research and development on agricultural sciences; 73105 Interdisciplinary research and development, predominantly on natural sciences and engineering	7310	0,04%
2442 Manufacture of pharmaceutical preparations	2442	0,04%
2952 Manufacture of machinery for mining, quarrying and construction	2952	0,04%
5138 Wholesale of other food including fish, crustaceans and molluscs	5138	0,04%
2912 Manufacture of pumps and compressors	2912	0,04%
7132 Renting of construction and civil engineering machinery and equipment	7132	0,03%
2923 Manufacture of non-domestic cooling and ventilation equipment	2923	0,03%
5146 Wholesale of pharmaceutical goods	5146	0,03%
3420 Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers	3420	0,02%
2932 Manufacture of other agricultural and forestry machinery	2932	0,02%
3614 Manufacture of other furniture	3614	0,02%
7020 70201 Letting of dwellings; 70202 Letting of industrial premises; 70203 Letting of other premises; 70204 Property management of tenant-owners' associations; 70209 Letting of other property	7020	0,01%
2030 20301 Manufacture of prefabricated wooden buildings; 20302 Manufacture of other builders' carpentry and joinery	2030	0,01%
2852 General mechanical engineering	2852	0,01%
5144 Wholesale of china and glassware, wallpaper and cleaning materials	5144	0,01%
1598 Production of mineral waters and soft drinks	1598	0,01%
7430 Technical testing and analysis	7430	0,01%
2971 29711 Manufacture of refrigerators, freezers, washing machines and dishwashers; 29719 Manufacture of other electric domestic appliances	2971	0,01%

2461 Manufacture of explosives	2461	0,01%
4525 Other construction work involving special trades	4525	0,01%
5261 52611 Non-specialized retail sale via mail order Houses; 52612 Retail sale of textiles and clothing via mail order houses; 52613 Retail sale of sports and leisure goods via mail order houses; 52614 Retail sale of books and other media goods via mail order houses; 52615 Retail sale of household goods via mail order houses; 52616 Other retail sale via mail order houses; 52617 Non-specialized retail sale via internet; 52618 Retail sale of books, media goods and computer equipment via internet; 52619 Other retail sale via internet	5261	0,01%
5010 50101 Sale of lorries, buses and specialized motor vehicles; 50102 Sale of passenger motor vehicles; 50103 Sales of caravans, motorhomes, trailers and semi-trailers	5010	0,01%
29561 Manufacture of machinery for plastic and rubber processing; 29569 Manufacture of various other special purpose machinery n.e.c.	2956	0,01%
2522 Manufacture of plastic packing goods	2522	0,01%
2430 Manufacture of paints, varnishes and similar coatings, printing ink and mastics	2430	0,01%
5118 Agents specializing in the sale of particular products or ranges of products n.e.c	5118	0,01%

Appendix 3 Selected CN products for target sector: General Construction

Product description	CN code	Weight share
Pebbles, gravel, broken or crushed stone, of a kind commonly used for concrete aggregates, for road metalling or for railway or other ballast, shingle and flint, whether or not heat–treated; macadam of slag, dross or similar industrial waste, whether or not incorporating the materials cited in the first part of the heading; tarred macadam; granules, chippings and powder, of stones of heading 2515 or 2516, whether or not heat–treated	2517	82,3%
Prepared binders for foundry moulds or cores; chemical products and preparations of the chemical or allied industries (including those consisting of mixtures of natural products), not elsewhere specified or included	3824	15,1%
Articles of cement, of concrete or of artificial stone, whether or not reinforced : – Tiles, flagstones, bricks and similar articles	6810	2,3%
Prefabricated buildings	9406	0,1%
Builders’ joinery and carpentry of wood, including cellular wood panels, assembled parquet panels, shingles and shakes	4418	0,0%
Structures (excluding prefabricated buildings of heading 9406) and parts of structures (for example, bridges and bridge–sections, lock–gates, towers, lattice masts, roofs, roofing frameworks, doors and windows and their frames and thresholds for doors, shutters, balustrades, pillars and columns), of iron or steel; plates, rods, angles, shapes, sections, tubes and the like, prepared for use in structures, of iron or steel	7308	0,0%
Other articles of iron or steel : – Forged or stamped, but not further worked	7326	0,0%
Ceramic building bricks, flooring blocks, support or filler tiles and the like	6904	0,0%
Machines and mechanical appliances having individual functions, not specified or included elsewhere in this chapter	8479	0,0%

Aluminium structures (excluding prefabricated buildings of heading No 9406) and parts of structures (for example, bridges and bridge–sections, towers, lattice masts, roofs, roofing frameworks, doors and windows and their frames and thresholds for doors, balustrades, pillars and columns); aluminium plates, rods, profiles, tubes and the like, prepared for use in structures	7610	0,0%
Tube or pipe fittings (for example, couplings, elbows, sleeves), of iron or steel :– Cast fittings	7307	0,0%
Builders' ware of plastics, not elsewhere specified or included	3925	0,0%
Multiple–walled insulating units of glass	7008	0,0%
Other furniture and parts thereof	9403	0,0%
Other cast articles of iron or steel	7325	0,0%
Glaziers' putty, grafting putty, resin cements, caulking compounds and other mastics; painters' fillings; non–refractory surfacing preparations for façades, indoor walls, floors, ceilings or the like	3214	0,0%
Other tubes, pipes and hollow profiles (for example, open seam or welded, riveted or similarly closed), of iron or steel	7306	0,0%
Articles of plaster or of compositions based on plaster : – Boards, sheets, panels, tiles and similar articles, not ornamented	6809	0,0%
Refractory cements, mortars, concretes and similar compositions, other than products of heading	3816	0,0%
Self–propelled bulldozers, angledozers, graders, levellers, scrapers, mechanical shovels, excavators, shovel loaders, tamping machines and road rollers :– Bulldozers and angledozers	8429	0,0%
Particle board and similar board (for example, oriented strand board and waferboard) of wood or other ligneous materials, whether or not agglomerated with resins or other organic binding substances : – Oriented strand board and waferboard, of wood :	4410	0,0%
Other tubes and pipes (for example, welded, riveted or similarly closed), having circular cross–sections, the external diameter of which exceeds 406,4 mm, of iron or steel : – Line pipe of a kind used for oil or gas pipelines	7305	0,0%
Ships' derricks; cranes, including cable cranes; mobile lifting frames, straddle carriers and works trucks fitted with a crane : – Overhead travelling cranes, transporter cranes, gantry cranes, bridge cranes, mobile lifting frames and straddle carriers :	8426	0,0%
Special purpose motor vehicles, other than those principally designed for the transport of persons or goods (for example, breakdown lorries, crane lorries, fire–fighting vehicles, concrete–mixer lorries, road sweeper lorries, spraying lorries, mobile workshops, mobile radiological units)	8705	0,0%
Pulley tackle and hoists other than skip hoists; winches and capstans; jacks : – Pulley tackle and hoists other than skip hoists or hoists of a kind used for raising vehicles	8425	0,0%
Worked monumental or building stone (except slate) and articles thereof, other than goods of heading 6801; mosaic cubes and the like, of natural stone (including slate), whether or not on a backing; artificially coloured granules, chippings and powder, of natural stone (including slate)	6802	0,0%
Other live plants (including their roots), cuttings and slips; mushroom spawn	602	0,0%
Other moving, grading, levelling, scraping, excavating, tamping, compacting, extracting or boring machinery, for earth, minerals or ores; piledrivers and pile–extractors; snowploughs and snow–blowers	8430	0,0%
Wood sawn or chipped lengthwise, sliced or peeled, whether or not planed, sanded or end–jointed, of a thickness exceeding 6 mm	4407	0,0%

Machinery for sorting, screening, separating, washing, crushing, grinding, mixing or kneading earth, stone, ores or other mineral substances, in solid (including powder or paste) form; machinery for agglomerating, shaping or moulding solid mineral fuels, ceramic paste, unhardened cements, plastering materials or other mineral products in powder or paste form; machines for forming foundry moulds of sand	8474	0,0%
Other lifting, handling, loading or unloading machinery (for example, lifts, escalators, conveyors, teleferics)	8428	0,0%
Glazed ceramic flags and paving, hearth or wall tiles; glazed ceramic mosaic cubes and the like, whether or not on a backing	6908	0,0%
Electrical apparatus for switching or protecting electrical circuits, or for making connections to or in electrical circuits (for example, switches, fuses, lightning arresters, voltage limiters, surge suppressors, plugs, junction boxes), for a voltage exceeding 1 000 V	8535	0,0%
Wood (including strips and friezes for parquet flooring, not assembled) continuously shaped (tongued, grooved, rebated, chamfered, V–jointed, beaded, moulded, rounded or the like) along any of its edges, ends or faces, whether or not planed, sanded or end–jointed	4409	0,0%
Insulated (including enamelled or anodised) wire, cable (including coaxial cable) and other insulated electric conductors, whether or not fitted with connectors; optical fibre cables, made–up of individually sheathed fibres, whether or not assembled with electric conductors or fitted with connectors : – Winding wire	8544	0,0%
Tubes, pipes and hoses, and fittings therefor (for example, joints, elbows, flanges), of plastics	3917	0,0%
Fibreboard of wood or other ligneous materials, whether or not bonded with resins or other organic substances	4411	0,0%
Trailers and semi–trailers; other vehicles, not mechanically propelled; parts thereof	8716	0,0%
Other articles of plastics and articles of other materials of headings 3901 to 3914	3926	0,0%
Screws, bolts, nuts, coach screws, screw hooks, rivets, cotters, cotter–pins, washers (including spring washers) and similar articles, of iron or steel : – Threaded articles	7318	0,0%
Motor cars and other motor vehicles principally designed for the transport of persons (other than those of heading 8702), including station wagons and racing cars	8703	0,0%
Other articles of vulcanised rubber other than hard rubber	4016	0,0%
Seats (other than those of heading 9402), whether or not convertible into beds, and parts thereof	9401	0,0%
Parts suitable for use solely or principally with the machinery of headings 8425 to 8430	8431	0,0%
Other articles of wood	4421	0,0%
Slag wool, rock wool and similar mineral wools; exfoliated vermiculite, expanded clays, foamed slag and similar expanded mineral materials; mixtures and articles of heat–insulating, sound–insulating or sound–absorbing mineral materials, other thanthose of heading 6811 or 6812 or of Chapter 69	6806	0,0%
Interchangeable tools for hand tools, whether or not power–operated, or for machine–tools (for example, for pressing, stamping, punching, tapping, threading, drilling, boring, broaching, milling, turning or screw driving), including dies for drawing or extruding metal, and rock drilling or earth boring tools : – Rock drilling or earth boring tools	8207	0,0%
Stranded wire, ropes, cables, plaited bands, slings and the like, of iron or steel, not electrically insulated	7312	0,0%
Taps, cocks, valves and similar appliances for pipes, boiler shells, tanks, vats or the like, including pressure–reducing valves and thermostatically controlled valves :	8481	0,0%

Glass fibres (including glass wool) and articles thereof (for example, yarn, woven fabrics) :– Slivers, rovings, yarn and chopped strands	7019	0,0%
Containers (including containers for the transport of fluids) specially designed and equipped for carriage by one or more modes of transport	8609	0,0%
Safety glass, consisting of toughened (tempered) or laminated glass : – Toughened (tempered) safety glass	7007	0,0%
Pumps for liquids, whether or not fitted with a measuring device; liquid elevators : – Pumps fitted or designed to be fitted with a measuring device	8413	0,0%
Machinery, plant or laboratory equipment, whether or not electrically heated (excluding furnaces, ovens, and other equipment of heading 8514), for the treatment of materials by a process involving a change of temperature such as heating, cooking, roasting, distilling, rectifying, sterilizing, pasteurizing, steaming, drying, evaporating, vapourizing, condensing or cooling, other than machinery or plant of a kind used for domestic purposes; instantaneous or storage water heaters, non–electric :– Instantaneous or storage water heaters, non–electric	8419	0,0%
Hand tools (including glaziers' diamonds), not elsewhere specified or included; blow–lamps; vices, clamps and the like, other than accessories for and parts of, machine tools; anvils; portable forges; hand or pedal–operated grinding wheels with frameworks	8205	0,0%
Other articles of aluminium	7616	0,0%
Motor vehicles for the transport of goods	8704	0,0%
Air or vacuum pumps, air or other gas compressors and fans; ventilating or recycling hoods incorporating a fan, whether or not fitted with filters	8414	0,0%
Boards, panels, consoles, desks, cabinets and other bases, equipped with two or more apparatus of heading 8535 or 8536, for electric control or the distribution of electricity, including those incorporating instruments or apparatus of Chapter 90, and numerical control apparatus, other than switching apparatus of heading 8517	8537	0,0%
Electrical transformers, static converters (for example, rectifiers) and inductors	8504	0,0%
Parts suitable for use solely or principally with the apparatus of heading 8535, 8536 or 8537	8538	0,0%
Centrifuges, including centrifugal dryers; filtering or purifying machinery and apparatus, for liquids or gases : – Centrifuges, including centrifugal dryers	8421	0,0%
Aluminium plates, sheets and strip, of a thickness exceeding 0,2 mm : – Rectangular (including square)	7606	0,0%
Other agricultural, horticultural, forestry, poultry–keeping or bee–keeping machinery, including germination plant fitted with mechanical or thermal equipment; poultry incubators and brooders	8436	0,0%
Electrical apparatus for switching or protecting electrical circuits, or for making connections to or in electrical circuits (for example, switches, relays, fuses, surge suppressors, plugs, sockets, lamp–holders, junction boxes), for a voltage not exceeding 1 000 V	8536	0,0%
Mechanical appliances (whether or not hand–operated) for projecting, dispersing or spraying liquids or powders; fire extinguishers, whether or not charged; spray guns and similar appliances; steam or sandblasting machines and similar jet projecting machines	8424	0,0%

Electric instantaneous or storage water heaters and immersion heaters; electric space heating apparatus and soil heating apparatus; electrothermic hair–dressing apparatus (for example, hair dryers, hair curlers, curling tong heaters) and hand dryers; electric smoothing irons; other electrothermic appliances of a kind used for domestic purposes; electric heating resistors, other than those of heading 8545	8516	0,0%
Lamps and lighting fittings including searchlights and spotlights and parts thereof, not elsewhere specified or included; illuminated signs, illuminated name–plates and the like, having a permanently fixed light source, and parts thereof not elsewhere specified or included	9405	0,0%
Printed books, brochures, leaflets and similar printed matter, whether or not in single sheets	4901	0,0%
Cloth (including endless bands), grill, netting and fencing, of iron or steel wire; expanded metal of iron or steel : – Woven cloth	7314	0,0%
Articles and equipment for general physical exercise, gymnastics, athletics, other sports (including table–tennis) or outdoor games, not specified or included elsewhere in this chapter; swimming pools and paddling pools : – Snow–skis and other snow–ski equipment	9506	0,0%
Base metal mountings, fittings and similar articles suitable for furniture, doors, staircases, windows, blinds, coachwork, saddlery, trunks, chests, caskets or the like; base metal hat–racks, hat–pegs, brackets and similar fixtures; castors with mountings of base metal; automatic door closers of base metal	8302	0,0%
Tarpaulins, awnings and sunblinds; tents; sails for boats, sailboards or landcraft; camping goods :– Tarpaulins, awnings and sunblinds	6306	0,0%
Refrigerators, freezers and other refrigerating or freezing equipment, electric or other; heat pumps other than air–conditioning machines of heading No 8415	8418	0,0%
Reservoirs, tanks, vats and similar containers for any material (other than compressed or liquefied gas), of iron or steel, of a capacity exceeding 300 l, whether or not lined or heat–insulated, but not fitted with mechanical or thermal equipment	7309	0,0%
Tools for working in the hand, pneumatic, hydraulic or with self–contained electric or non–electric motor :– Pneumatic	8467	0,0%
Electric (including electrically heated gas), laser or other light or photon beam, ultrasonic, electron beam, magnetic pulse or plasma arc soldering, brazing or welding machines and apparatus, whether or not capable of cutting; electric machines and apparatus for hot spraying of metals or cermets : – Brazing or soldering machines and apparatus	8515	0,0%
T–shirts, singlets and other vests, knitted or crocheted	6109	0,0%
Parts and accessories of the motor vehicles of heading 8701 to 8705	8708	0,0%
Other printed matter, including printed pictures and photographs	4911	0,0%
Collections and collectors’ pieces of zoological, botanical, mineralogical, anatomical, historical, archaeological, palaeontological, ethnographic or numismatic interest	9705	0,0%
Automatic data–processing machines and units thereof; magnetic or optical readers, machines for transcribing data onto data media in coded form and machines for processing such data, not elsewhere specified or included	8471	0,0%
Tubes, pipes and hoses, of vulcanised rubber other than hard rubber, with or without their fittings (for example, joints, elbows, flanges)	4009	0,0%
Automatic regulating or controlling instruments and apparatus	9032	0,0%
Prepared glues and other prepared adhesives, not elsewhere specified or included; products suitable for use as glues or adhesives, put up for retail sale as glues or adhesives, not exceeding a net weight of 1 kg	3506	0,0%

Measuring or checking instruments, appliances and machines, not specified or included elsewhere in this chapter; profile projectors	9031	0,0%
Newspapers, journals and periodicals, whether or not illustrated or containing advertising material	4902	0,0%
Gaskets and similar joints of metal sheeting combined with other material or of two or more layers of metal; sets or assortments of gaskets and similar joints, dissimilar in composition, put up in pouches, envelopes or similar packings; mechanical seals	8484	0,0%
Instruments and apparatus for physical or chemical analysis (for example, polarimeters, refractometers, spectrometers, gas or smoke analysis apparatus); instruments and apparatus for measuring or checking viscosity, porosity, expansion, surface tension or the like; instruments and apparatus for measuring or checking quantities of heat, sound or light (including exposure meters); microtomes	9027	0,0%
Electrical machines and apparatus, having individual functions, not specified or included elsewhere in this chapter : – Particle accelerators :	8543	0,0%
Aluminium bars, rods and profiles :	7604	0,0%
Gas, liquid or electricity supply or production meters, including calibrating meters therefor	9028	0,0%
Parts and accessories suitable for use solely or principally with the machines of heading Nos 8456 to 8465, including work or tool holders, self–opening dieheads, dividing heads and other special attachments for machine–tools; tool holders for any type of tool for working in the hand	8466	0,0%
Instruments and apparatus for measuring or checking the flow, level, pressure or other variables of liquids or gases (for example, flow meters, level gauges, manometers, heat meters), excluding instruments and apparatus of heading 9014, 9015, 9028 or 9032	9026	0,0%
Chain and parts thereof, of iron or steel : – Articulated link chain and parts thereof	7315	0,0%
Electric filament or discharge lamps, including sealed–beam lamp units and ultraviolet or infrared lamps; arc–lamps	8539	0,0%
Parts and accessories of vehicles of headings 8711 to 8713 : – Of motor–cycles (including mopeds)	8714	0,0%
Electrical apparatus for line telephony or line telegraphy, including line telephone sets with cordless handsets and telecommunication apparatus for carrier–current line systems or for digital line systems; videophones : – Telephone sets; videophones	8517	0,0%
Other headgear, whether or not lined or trimmed	6506	0,0%
Hydrometers and similar floating instruments, thermometers, pyrometers, barometers, hygrometers and psychrometers, recording or not, and any combination of these instruments : – Thermometers and pyrometers, not combined with other instruments	9025	0,0%
Primary cells and primary batteries	8506	0,0%
Transmission shafts (including cam shafts and crank shafts) and cranks; bearing housings and plain shaft bearings; gears and gearing; ball or roller screws; gear boxes and other speed changers, including torque converters; flywheels and pulleys, including pulley blocks; clutches and shaft couplings (including universal joints)	8483	0,0%

Articles of apparel and clothing accessories (including gloves, mittens and mitts), for all purposes, of vulcanised rubber other than hard rubber : – Gloves, mittens and mitts	4015	0,0%
Other articles of glass	7020	0,0%
Men’s or boys’ suits, ensembles, jackets, blazers, trousers, bib and brace overalls, breeches and shorts (other than swimwear) : – Suits	6203	0,0%
Articles of apparel and clothing accessories, of leather or of composition leather	4203	0,0%
Surveying (including photogrammetrical surveying), hydrographic, oceanographic, hydrological, meteorological or geophysical instruments and appliances, excluding compasses; rangefinders	9015	0,0%
Electric motors and generators (excluding generating sets)	8501	0,0%
Parts suitable for use solely or principally with the apparatus of headings 8525 to 8528	8529	0,0%
Portable electric lamps designed to function by their own source of energy (for example, dry batteries, accumulators, magnetos), other than lighting equipment of heading 8512	8513	0,0%
Parts and accessories (other than covers, carrying cases and the like) suitable for use solely or principally with machines of headings 8469 to 8472	8473	0,0%
Transmission apparatus for radio–telephony, radio–telegraphy, radio–broadcasting or television, whether or not incorporating reception apparatus or sound recording or reproducing apparatus; television cameras; still image video cameras and other video camera recorders; digital cameras	8525	0,0%
Padlocks and locks (key, combination or electrically operated), of base metal; clasps and frames with clasps, incorporating locks, of base metal; keys for any of the foregoing articles, of base metal	8301	0,0%
Copper tube or pipe fittings (for example, couplings, elbows, sleeves)	7412	0,0%
Live horses, asses, mules and hinnies	101	0,0%
Peat (including peat litter), whether or not agglomerated	2703	0,0%
Lubricating preparations (including cutting–oil preparations, bolt or nut release preparations, anti–rust or anti–corrosion preparations and mould release preparations, based on lubricants) and preparations of a kind used for the oil or grease treatment of textile materials, leather, furskins or other materials, but excluding preparations containing, as basic constituents, 70 % or more by weight of petroleum oils or of oils obtained from bituminous minerals	3403	0,0%
Other plates, sheets, film, foil and strip, of plastics	3921	0,0%
Plates, sheets, strip, rods and profile shapes, of vulcanised rubber other than hard rubber	4008	0,0%
Float glass and surface ground or polished glass, in sheets, whether or not having an absorbent, reflecting or non–reflecting layer, but not otherwise worked	7005	0,0%
Electrical capacitors, fixed, variable or adjustable (pre–set)	8532	0,0%
Electrical resistors (including rheostats and potentiometers), other than heating resistors :	8533	0,0%