



POTENTIAL FOR DENMARK AS A CIRCULAR ECONOMY
A CASE STUDY FROM: DELIVERING THE CIRCULAR
ECONOMY - A TOOLKIT FOR POLICY MAKERS

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This report presents findings from a Denmark case study, undertaken as part of developing a methodology for circular economy policymaking. The findings, identifying circular economy opportunities, barriers and policy options, were first presented in the report *Delivering the circular economy – a toolkit for policymakers* by the Ellen MacArthur Foundation. They may be of special interest to Danish stakeholders, although this report does not recommend any specific policy intervention to Denmark or any other country. While the findings cannot be directly transposed to other countries, they might serve as a source of inspiration.



Readers who are interested in further material around the circular economy, and the methodology used in this case study, are encouraged to read the full toolkit report, as well as other Ellen MacArthur Foundation publications. These can be downloaded from the Ellen MacArthur Foundation website:

www.ellenmacarthurfoundation.org/books-and-reports

CONTENTS

List of figures	4
Foreword	7
Acknowledgements	10
Executive Summary	14
Introduction	25
1 National perspective	26
2 Food & Beverage	44
3 Construction & Real Estate	53
4 Machinery	66
5 Packaging	73
6 Hospitals	83
Appendix	93
About the Ellen MacArthur Foundation	132

LIST OF FIGURES

Figure A: 10 circular economy opportunities in the Denmark case study	15
Figur A: 10 muligheder i den cirkulære økonomi i case studiet af Danmark	20
Figure 1: Circularity baselining in the Denmark pilot	27
Figure 2: Policy landscape in the Denmark pilot	29
Figure 3: Results of sector prioritisation in Denmark pilot	30
Figure 4: The ReSOLVE framework: six action areas for businesses and countries wanting to move towards the circular economy	32
Figure 5: Qualitative opportunity prioritisation of focus sectors in the Denmark pilot	33
Figure 6: Ten circular economy opportunities in five focus sectors	34
Figure 7: Illustrative status of circular economy in Denmark today and potential by 2035	36
Figure 8: Short-term and long-term scenarios used in the Denmark pilot	35
Figure 9: Estimated potential impact of further transitioning to the circular economy in Denmark	38
Figure 10: Breakdown of potential economic impact by quantified opportunity	40
Figure 11: Barrier matrix for the ten prioritised opportunities in Denmark	42
Figure 12: Main sources of food waste in global food value chain – production and consumption	50
Figure 13: Examples of what remanufacturing and new business models could look like for pumps in Denmark	69
Figure 14: Estimated potential adoption rates and value creation in wind turbines and pumps in the Denmark pilot	70
Figure 15: Share of plastic packaging collected for recycling in Denmark	75
Figure 16: Share of purchased goods in Danish hospitals that could be covered by performance models	84

Figure A1: Summary of methods and data used in the sector selection in the Denmark pilot	95
Figure A2: Overview of scoring of 'Role in national economy' in the Denmark pilot	96
Figure A3: Overview of scoring of 'Circularity potential' in the Denmark pilot	97
Figure B1: Qualitative assessment of potential of opportunities for the Construction & Real Estate sector in the Denmark pilot	98
Figure B2: Schematic overview of sector-specific impact quantification	100
Figure B3: Value capture in cascading bio-refineries	102
Figure B4: Reduction of avoidable food waste	103
Figure B5: Industrialised production and 3D printing of building modules; reuse and high-value recycling of components and materials	104
Figure B6: Sharing and multi-purposing of buildings	105
Figure B7: Remanufacturing and new business models	106
Figure B8: Increased recycling of plastic packaging	107
Figure B9: Performance models in procurement in the hospital sector	107
Figure B10: Key sources for assumptions & estimates for each circular economy opportunity	108
Figure B11: Pork and Dairy – Price 'delta' per sector and waste stream	111
Figure B12: Pork and Dairy – volume allocation per sector and waste stream	111
Figure C1: Overview of a Computable general equilibrium (CGE) model	112
Figure C2: Sectoral and geographical aggregates in the CGE Model in the Denmark pilot	113
Figure C3: Generic structure of production functions in the CGE Model	114
Figure C4: Potential approaches and trade-offs for representing circularity within a CGE framework	115
Figure C5: Overview of a 'hybrid' CGE approach	116
Figure C6: Data sources used in the baseline calibration and CGE modelling in the Denmark pilot	118
Figure D1: Prioritisation of policy options – 'Value capture in cascading bio-refineries	120
Figure D2: Snapshot and description of the policy assessment tool	122
Figure D3: Worked example of the implementation of the scoring methodology.	123
Figure E1: Circular economy – an industrial system that is restorative and regenerative by design	126
Figure E2: The economic opportunity of the circular economy	128
Figure E3: Estimated potential contribution of the circular economy to economic growth, job creation and reduction of greenhouse gas emissions	130

FOREWORD

FROM DELIVERING THE CIRCULAR ECONOMY – A TOOLKIT FOR POLICYMAKERS

Flemming Besenbacher

Chairman of the Supervisory Board of Carlsberg A/S



How can we create prosperity for a growing world population while strengthening the systems that support us? How can we achieve continued economic development while preserving the resource base that is fuelling this economy? The growing interest around these questions suggests it is time to rethink the way we operate. The circular economy holds the promise of reconciling these seemingly opposing objectives and creating long-term value. It is my firm belief that the 'take-make-waste' economy is about to be replaced by a circular, restorative approach where we no longer consider anything to be 'waste'.

The circular economy is of particular interest to Carlsberg because our products depend on well-functioning natural systems and a stable supply of raw materials. We are working in this area through our partnership platform – the Carlsberg Circular Community – to develop innovations and practical solutions optimised for the circular economy.

This toolkit represents a valuable blueprint for policymakers who want to stimulate the progression from a linear to a circular economy. It rightfully positions the circular economy as a unique opportunity for dialogue and collaboration between private and public entities to achieve the common goal of long-term value creation.

I therefore encourage governments across the world to apply this toolkit and work closely with businesses to unleash the circular economy in their country and unlock its true potential. I also urge companies to continue to lead the way to a more resilient operating model, decoupled from resource constraints. Carlsberg is determined to do so.

A handwritten signature in blue ink, reading 'Flemming Besenbacher'. The signature is fluid and cursive, with the first name 'Flemming' being more prominent.

FLEMMING BESENBACHER
JUNE 2015

FORORD

Flemming Besenbacher
Bestyrelsesformand for Carlsberg A/S



Hvordan kan vi skabe velstand for en voksende global befolkning, mens vi samtidig styrker de systemer, som understøtter os? Hvordan kan vi opnå fortsat økonomisk udvikling, mens vi samtidig bevarer de ressourcer, der er grundlaget for vores økonomiske fremskridt? Den voksende interesse i disse spørgsmål indikerer, at det er tid til at tænke nye tanker om den måde, som tingene fungerer på. Den cirkulære økonomi giver løfter om at kunne forene disse tilsyneladende modsatrettede målsætninger og skabe værdi på langt sigt. Det er min faste overbevisning, at det er tid til at erstatte 'brug og smid-væk' økonomien med en cirkulær, genoprettende tilgang, hvor 'affald' som koncept ikke længere eksisterer.

Den cirkulære økonomi er af særlig interesse for Carlsberg, fordi vores produkter er afhængige af velfungerende systemer i naturen og en stabil forsyning af råvarer. Vi arbejder inden for dette område igennem vores partnerskabsplatform – the Carlsberg Circular Community – for at udvikle innovative og praktiske løsninger, der er optimeret til den cirkulære økonomi.

Dette 'toolkit' udgør en værdifuld formular for politikere, som ønsker at stimulere, at vi bevæger os fremad fra en lineær til en cirkulær økonomi. Det placerer med rette den cirkulære økonomi som en unik mulighed for dialog og samarbejde mellem private og offentlige virksomheder for at opnå et fælles mål om at skabe værdi på langt sigt.

Jeg opfordrer derfor regeringer verden rundt til at anvende dette 'toolkit' og arbejde tæt sammen med erhvervslivet for at få åbnet op for mulighederne i den cirkulære økonomi i deres lande og få låst op for det sande potentiale heri. Jeg opfordrer også virksomhederne til at føre an frem imod en mere modstandsdygtig model for den måde, vi gør tingene på, hvor vi ikke længere er begrænsede af ressourcemæssige hensyn. Carlsberg er fast besluttet på at gå denne vej.

FLEMMING BESENBACHER
JUNI 2015

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DISCLAIMER

This report has been produced by a team from the Ellen MacArthur Foundation, which takes full responsibility for the report's contents and conclusions. While the key contributors and contributors listed in the acknowledgements provided significant input to the development of this report, their participation does not necessarily equate to endorsement of the report's contents or conclusions. The McKinsey Center for Business and Environment provided analytical support. NERA Economic Consulting provided support for the macroeconomic and policy analysis for this report.

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EXECUTIVE SUMMARY

In its research to date, the Ellen MacArthur Foundation has demonstrated that the circular economy can be a significant value creation opportunity. As many policymakers and regulators become interested in this promising model, they look for concrete guidance on how to create enabling framework conditions and, as appropriate, set direction to unlock its economic and environmental opportunities. The Ellen MacArthur Foundation therefore developed the report *Delivering the circular economy – a toolkit for policymakers* – published in June 2015 – which takes a country and policymaker perspective, and aims at identifying circular economy opportunities, barriers, and policy interventions to overcome these barriers. In the context of this toolkit (referred to as the ‘toolkit report’ throughout the text), an extensive case study was performed in Denmark, which is the focus of this report.

Delivering the circular economy – a toolkit for policymakers is the result of a collaboration led by the Ellen MacArthur Foundation, with the Danish Business Authority and the Danish Environmental Protection Agency as key contributors. The toolkit report and the Denmark case study were developed in collaboration with Danish and international stakeholders, including leading policymakers, businesses and academics. The McKinsey Center for Business and Environment provided analytical support. NERA Economic Consulting provided support for the macroeconomic and policy analysis presented herein. The MAVA Foundation funded the project.

THE OPPORTUNITY FOR DENMARK

Denmark is internationally recognised for innovative initiatives in circular economy and sustainability. Yet, the pilot study identified significant opportunities to further the transition towards a circular economy.

Denmark has many leading companies pioneering circular economy solutions, a long and rich tradition of innovative policies that stimulate the circular economy, as well as a long-term strategic commitment to energy efficiency and renewable energy. Denmark outperforms EU28 on a majority of selected resource and innovation metrics, such as share of renewable energy or Eco-innovation index. Still, significant value is left on the table across the economy, which could be unlocked by, e.g. improved utilisation of assets and better use of waste or by-products as a resource. For example, one third of all waste is incinerated for heat and power generation before extracting its full potential value as a resource, and the materials that are looped back into the value chains are predominantly recycled for material value instead of being used in higher-value cycles, such as reuse or remanufacturing.

Even in a country with a starting position as advanced as Denmark’s, a transition towards the circular economy can bring about lasting benefits of a more innovative, resilient and productive economy. Modelling conducted in this study suggests that by 2035 it could lead to an increase in GDP by 0.8-1.4%, the creation of an additional 7,000-13,000 job equivalents, a 3-7% reduction in carbon footprint, 5-50% reduction in virgin resource consumption for selected materials and an increase in net exports by 3-6 %.






These positive effects on the Danish economy are based on five selected sectors, covering 25% of the economy. It is assumed in the modelling that the share of renewable energy in the circular economy scenario increases at the same pace as in the baseline scenario, meaning that no further shift towards renewable energy is included in the estimated benefits.

Ten circular economy opportunities were identified in five focus sectors, and the largest economic potential was found in Construction & Real Estate and in Food & Beverage.

The ten opportunities and their estimated economic impact by 2035 are shown in Figure A.¹ Summaries of ten circular economy opportunities, their key barriers and policy options identified, are given in the five sector boxes.

The economic impact of circular economy estimated for Denmark could, if the right enabling conditions are established, mostly be captured within the next 20 years. But even as circular economy opportunities take time to realise, it is estimated that up to 20% of the net value created by 2035 could be realised already by 2020.

Figure A: 10 circular economy opportunities in the Denmark case study

SECTOR	OPPORTUNITY	NET VALUE CREATED EUR MILLION, 2035
 FOOD AND BEVERAGE	1 Value capture in cascading bio-refineries	300 - 500
	2 Reduction of avoidable food waste	150 - 250
 CONSTRUCTION AND REAL ESTATE	3 Industrialised production and 3D printing of building modules	450 - 600
	4 Reuse and high-value recycling of components and materials	100 - 150
	5 Sharing and multi-purposing of buildings	300 - 450
 MACHINERY	6 Remanufacturing and new business models	150 - 250
 PLASTIC PACKAGING	7 Increased recycling of plastic packaging	Not assessed
	8 Bio-based packaging where beneficial	Not assessed
 HOSPITALS	9 Performance models in procurement	70 - 90
	10 Waste reduction and recycling	Not assessed

HOW POLICYMAKERS CAN ENABLE THE OPPORTUNITIES

While the majority of the ten circular economy opportunities identified in Denmark have a sound underlying profitability, there are often non-financial barriers limiting further scale-up or holding back development pace. Both policymakers and industry players can play important roles in helping businesses overcome these barriers. To this end, close collaboration is needed between governmental bodies, as well as with businesses and other society stakeholders.

The key barriers include unintended consequences of existing regulations (e.g. definitions of waste that hinder trade and transport of products for remanufacturing), social factors such as a lack of experience among companies and policymakers to detect and capture circular economy opportunities, and market failures such as imperfect information (e.g. for businesses to repair, disassemble and remanufacture products)

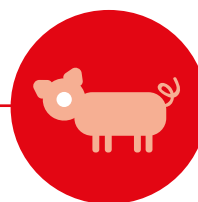
1 Three opportunities were not quantified economically due to lack of input data and high degrees of uncertainty. The sector-specific impact was used as input for a general equilibrium, macroeconomic model to assess the impact on the whole economy. It is therefore not directly comparable to the estimated economy-wide impact for Denmark.

and unaccounted, negative externalities (e.g. carbon emissions). In addition to creating enabling conditions, policymakers can, as appropriate, set direction for a transition to the circular economy.

As businesses are already starting the transition, the circular economy offers an opportunity for policymakers to collaborate with businesses. An important conclusion from the Denmark case study is that there is a need for cooperation between different government departments (including business/industry, finance and environment) so that no new unintended policy barriers are created and – like the business solution – the policy response is designed to maximise system effectiveness. Other society stakeholders, including citizens and consumers, labour unions, environmental organisations and the scientific and educational community, should also be engaged.

In several cases, EU-level policy interventions would need to complement national Danish policies, as the value chains of many sectors extend across borders.

Product policy and promoting the market for secondary raw materials are just two examples that could be coordinated at the European level in order to simplify and reduce the cost of doing (circular) business.



FOOD & BEVERAGE

Value capture in cascading bio-refineries, which extract a variety of nutraceutical and chemical products from by-product and waste streams, could lead to a net value of EUR 300–500 (50–80) million p.a. by 2035 (2020).

Key barriers include:

- access to capital to build and scale up capacity;
- availability of mature technology;
- unintended consequences of existing regulation.

Identified policy options include:

- setting long-term strategic targets for bio-refineries;
- supporting capacity building for existing technologies and create markets;
- supporting technological development.

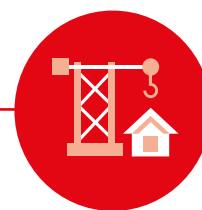
Reduction of avoidable food waste, by building awareness and knowledge for consumers, leveraging best practices for businesses, smart technologies and creating markets for second-tier foods, could lead to a net value of EUR 150–250 (30–40) million p.a. by 2035 (2020).

Key barriers include:

- consumers' custom and habit;
- businesses capabilities and skills;
- imperfect information;
- split incentives among players in the value chain.

Identified policy options include:

- informing and educating consumers;
- setting up quantitative food waste targets;
- support capability building;
- introducing fiscal incentives.



CONSTRUCTION & REAL ESTATE

Industrialised production and 3D printing of building modules, reducing time and material cost of construction and renovation, could lead to a net value of EUR 450–600 (40–60) million p.a. by 2035 (2020).

Key barriers include:

- inadequately defined legal frameworks;
- immature 3D printing technology;
- custom and habit and capabilities and skills in the industry.

Identified policy options include:

- augmenting building codes;
- supporting the development of module production facilities;
- setting a clear legal framework for 3D printing materials.

Reuse and high-value recycling of components and materials, enabled by, e.g., design for disassembly and new business models, could lead to a net value of EUR 100–150 (10–12) million p.a. by 2035 (2020).

Key barriers include:

- split incentives and lack of information across the construction value chain;

- custom and habit;
- capabilities and skills.

Identified policy options include:

- augmenting building codes;
- running industry-wide training programmes;
- creating support for material inventory software and databanks.

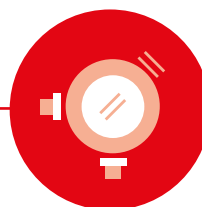
Sharing and multi-purposing of buildings to increase the utility of existing floor space could lead to a net value of EUR 300–450 (100–140) million p.a. by 2035 (2020).

Key barriers include:

- inadequately defined legal frameworks;
- unintended consequences of existing regulation.

Identified policy options include:

- clarifying the existing legislation;
- providing financial incentives or support to new business models;
- creating portals for public building availability.



MACHINERY

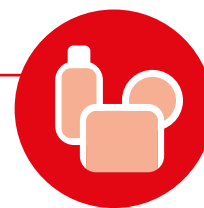
Remanufacturing and new business models based on performance contracts and reverse logistics could lead to a net value of EUR 150–200 (50–100) million p.a. by 2035 (2020). In addition, similar opportunities of EUR 100–400 (50–150) million p.a. could be captured in adjacent sectors through extrapolation of these activities.

Key barriers include

- lack of capabilities and skills;
- imperfect information about existing opportunities;
- unintended consequences of existing regulation.

Identified policy options include

- supporting remanufacturing pilots and conducting information campaigns;
- amending existing regulatory frameworks;
- adopting an overarching government strategy on remanufacturing.



PACKAGING

Increased recycling of plastic packaging, driven by better packaging design, higher collection rates, and improved separation technology, could lead to a reduction in the demand for virgin plastic material by 70-100 thousand tonnes p.a. by 2035.

Key barriers include:

- low profitability in the reverse value chain (driven by unaccounted externalities and price volatility);
- collection and separation technology;
- split incentives across the value chain.

Identified policy options include:

- improving the collection infrastructure;
- increasing national recycling targets;
- standardising collection and separation systems;
- increasing incineration taxes.

Bio-based packaging where beneficial, leading to an innovation-driven shift to from petro-based plastics to bio-based alternatives for selected packaging applications.

Key barriers include:

- technologic maturity
- profitability (driven by unaccounted externalities);
- inadequately defined legal frameworks.

Identified policy options include:

- funding of innovation and B2B collaboration;
- investing in improved end-of-use pathways of bio-based packaging;
- working to clarify the EU regulatory framework.



HOSPITALS

Performance models in procurement of hospital equipment, such as advanced diagnostic, IT or laboratory equipment, could lead to a net value of EUR 70-90 (10-15) million p.a. by 2035 (2020).

Key barriers include:

- insufficient capabilities and skills due to lack of experience;
- imperfect information;
- custom and habit in hospital operations.

Identified policy options include:

- setting up guidelines and targets;
- capability building;
- defining procurement rules.

Waste reduction and recycling in hospitals, through systematic and centrally managed initiatives.

Key barriers include:

- insufficient capabilities and skills due to lack of experience;
- custom and habit in hospital operations;
- imperfect information

Identified policy options include:

- piloting of waste reduction and recycling management integrated in staff training;
- setting waste minimisation and recycling targets;
- increasing fiscal incentives to avoid waste generation.

RESUMÉ

Ellen MacArthur Foundation har med sin forskning dokumenteret, at cirkulær økonomi har et stort potentiale for at skabe forretningsmæssig værdi i virksomheder. Flere og flere politikere og embedsmænd er interesserede i cirkulær økonomi og efterspørger konkret vejledning til, hvordan de kan skabe de rette rammevilkår, der muliggør en omstilling til cirkulær økonomi. Og til hvordan der opstilles en vision og en retning for at udnytte de økonomiske og miljømæssige muligheder, som cirkulær økonomi indeholder. Til dette formål har Ellen MacArthur Foundation udarbejdet rapporten *Delivering the circular economy - a toolkit for policymakers*, som blev offentliggjort i juni 2015. Rapportens perspektiv er på lande- og myndighedsniveau og sigter imod at identificere økonomiske muligheder og barrierer i den cirkulære økonomi samt politiske initiativer, der kan fjerne disse barrierer. Som en del af denne rapport (omtales i det følgende som 'toolkit-rapporten') er der udført et omfattende case studie i Danmark. Nærværende rapport fokuserer på dette case studie.

Rapporten *Delivering the circular economy - a toolkit for policymakers* er resultatet af et samarbejde under ledelse af Ellen MacArthur Foundation og med Erhvervsstyrelsen og Miljøstyrelsen som vigtige bidragsydere. Toolkit-rapporten og case studiet, der er lavet om Danmark, er udarbejdet med bidrag fra danske og udenlandske interessenter, herunder førende erhvervsfolk, embedsmænd og forskere. Endvidere har McKinsey Center for Business and Environment bidraget til analysen, og NERA Economic Consulting har bidraget til den makroøkonomiske analyse samt analysen af politiske virkemidler. MAVA Foundation har finansieret projektet.

MULIGHEDERNE FOR DANMARK

Danmark er internationalt anerkendt for innovative initiativer inden for cirkulær økonomi og bæredygtighed. Alligevel har case studiet af dansk økonomi påvist et betydeligt potentiale ved at tage yderligere skridt hen imod en cirkulær økonomi.

Danmark har mange virksomheder, der ligger i front med at udvikle løsninger inden for den cirkulære økonomi. Dette skyldes bl.a. en lang tradition for innovativ politikskabelse i Danmark, som stimulerer grøn omstilling, samt et langsigtet og strategisk engagement i at øge energieffektiviteten og producere vedvarende energi. Danmark præsterer bedre end EU28 på de fleste udvalgte ressource- og innovationsindikatorer, såsom andelen af vedvarende energi og eco-innovationsindekset. Alligevel er der stadig muligheder for at skabe betydelig værdi i økonomien, f.eks. ved at forbedre udnyttelsen af aktiver og skabe en bedre ressourceudnyttelse af affald og biprodukter. I Danmark, går en tredjedel af alt affald til forbrænding, hvorved der produceres varme og el, men dette sker, før den fulde værdi af affaldet er blevet udnyttet som en materialeresource. Når materialer tilbageføres i værdikæden, sker det primært ved genanvendelse, snarere end ved højere værdiudnyttelse, såsom ved genbrug eller genfremstilling.

Selvom Danmark har taget flere initiativer, som peger i retning af en omstilling til cirkulær økonomi, er der stadig et stort potentiale med varige effekter ved at skabe en mere innovativ, modstandsdygtig og produktiv økonomi. De modeller, der er anvendt i denne analyse, viser, at Danmark i 2035 kan opnå en stigning i BNP på 0,8-1,4 %, tillige med skabelse af, hvad der svarer til yderligere 7.000-13.000 job, 3-7 % reduktion i Danmarks CO2-aftryk, 5-50 % reduktion i forbruget af nye ressourcer for udvalgte materialer, samt en stigning i nettoeksporten på 3-6 %.

Disse positive effekter på den danske økonomi er baseret på fem udvalgte sektorer, som tilsammen dækker 25 % af økonomien. I modelleringen antages det, at andelen af vedvarende energi i et cirkulært scenarie stiger i samme takt som i baseline-scenariet,






dvs. at yderligere stigninger i andelen af vedvarende energi ikke er medregnet i resultaterne. Resultatet af denne analyse understøttes af et stigende antal internationale forskningsresultater, som ligeledes peger på, at effekten af en omstilling til en cirkulær økonomi sandsynligvis vil være positiv i forhold til økonomisk vækst, jobskabelse og miljøet.

Der er fundet ti særligt oplagte muligheder inden for den cirkulære økonomi i Danmark i fem sektorer; det største økonomiske potentiale er fundet inden for Byggeindustrien og Bygninger samlet set, samt inden for Fødevareindustrien.

De ti muligheder og deres beregnede økonomiske potentiale frem mod 2035 vises i figur A. De fem sektorbokse giver en opsummering af de ti muligheder inden for den cirkulære økonomi, de væsentligste barrierer samt mulige politiske virkemidler.

Det økonomiske potentiale af cirkulær økonomi, som beregnes for Danmark, kan i overvejende grad opnås inden for de næste 20 år, såfremt der skabes de rette rammevilkår. Det tager tid at realisere de muligheder, som en cirkulær økonomi giver, men det anslås, at op til 20 % af den nettoværdi, der vil være skabt i 2035, allerede vil kunne opnås i 2020.

Figur A: 10 muligheder i den cirkulære økonomi i case studiet af Danmark

SEKTOR	MULIGHED	POTENTIALE (NETTOVÆRDI) DKK MIA., 2035
 FØDEVARE-INDUSTRIEN	1 Øget kaskadeudnyttelse i bio-raffinaderier	2,3 - 3,8
	2 Reduktion af madspild	1,1 - 1,9
 BYGGE-INDUSTRIEN OG BYGNINGER	3 Industrialiseret produktion og 3D print af bygningsmoduler	3,4 - 4,5
	4 Genbrug og højværdi-genanvendelse af komponenter og materialer	0,8 - 1,1
	5 Deling og multi-brug af bygninger	2,3 - 3,4
 MASKIN-INDUSTRIEN	6 Genfremstilling og nye forretningsmodeller	1,1 - 1,9
 PLAST-EMBALLAGE	7 Øget genanvendelse af plastikemballage	Ikke vurderet
	8 Bio-baseret emballage	Ikke vurderet
 HOSPITALER	9 Servicebaserede modeller for indkøb	0,5 - 0,7
	10 Affaldsreduktion og genanvendelse	Ikke vurderet

HVORDAN POLITIKERNE KAN SIKRE UDNYTTELSE AF MULIGHEDERNE

Selv om de fleste af de ti særlige muligheder i den cirkulære økonomi, som er identificeret for Danmark, har en sund underliggende profitabilitet, så er der dog ofte ikke-finansielle barrierer, som begrænser større udbredelse eller bremser udviklingen. Både myndighederne og industrien kan spille en vigtig rolle, når det drejer sig om at fjerne barriererne for virksomhederne. Der er brug for et tæt samarbejde mellem forskellige offentlige myndigheder såvel som virksomheder og andre interessenter i samfundet.

De væsentligste barrierer omfatter utilsigtede konsekvenser af eksisterende regulering (f.eks. definitioner af affald, som hindrer handel og transport af produkter til genfremstilling), sociale faktorer, såsom mangel på erfaring blandt virksomheder og myndigheder, når det drejer sig om at opdage og udnytte muligheder i en cirkulær økonomi, samt markedsmæssige fejl, såsom ufuldstændig information (f.eks. til virksomheder om at reparere, adskille og genfremstille produkter), og ikke medregnede negative eksternaliteter (f.eks. drivhusgas-udledninger). Ud over at skabe de rette rammevilkår, kan politikerne via målsætninger sætte retning henimod en overgang til en cirkulær økonomi.

Da mange virksomheder allerede har påbegyndt omstillingen til en cirkulær økonomi, er der gode muligheder for, at myndighederne kan samarbejde med erhvervslivet på dette felt. En af de vigtige konklusioner fra det danske case studie er, at der er behov for at samarbejde mellem de forskellige ministerier (erhvervs- og vækst, finans og miljø- og fødevarer), så der ikke skabes nye utilsigtede barrierer, og således at styringsmidler – ligesom de forretningsmæssige løsninger – udformes til at maksimere systemets effektivitet. Andre samfundsaktører, såsom borgere og forbrugere, fagforeninger, miljøorganisationer samt forskere og uddannelsessektoren, bør også involveres.

I flere tilfælde vil der være behov for, at fælles EU politik supplerer de nationale virkemidler, da værdikæderne i mange sektorer går på tværs af lande.

Produktpolitik og fremme af markedet for sekundære råvarer er blot to eksempler, som kan koordineres på europæisk niveau for at forenkle og reducere omkostningerne ved at gøre (cirkulære) forretninger.

FØDEVAREINDUSTRIEN

Øget kaskadeudnyttelse i bio-raffinaderier, som udvinder en række nutraceutiske og kemiske produkter fra biprodukter og affald, kan medføre en nettoværdi på DKK 2,3 - 3,8 mia. (400 - 600 mio.) pr. år i 2035 (2020).

De væsentligste barrierer omfatter

- adgang til kapital til at bygge og opskalere kapacitet;
- tilgængelighed af moden teknologi;
- utilsigtede konsekvenser af nuværende regulering

Mulige politiske virkemidler omfatter:

- fastsættelse af langsigtede, strategiske mål for bio-raffinaderier;
- støtte til kapacitetsopbygning for eksisterende teknologier og skabelse af markeder;
- støtte til teknologisk udvikling

Reduktion af madspild, ved at opbygge bevidsthed og viden hos forbrugerne, udbrede best practice i virksomheder, anvende smart teknologi, samt skabe markeder for anden classes fødevarer, kan medføre en nettoværdi på DKK 1,1 - 1,9 mia. (200 - 300 mio.) pr. år i 2035 (2020).

De væsentligste barrierer omfatter:

- forbrugernes vaner og adfærd;
- erhvervslivets kapacitet og færdigheder;
- ufuldstændig information i værdikæden
- forskellige incitamenter blandt aktørerne i værdikæden

Mulige politiske virkemidler omfatter:

- information og uddannelse af forbrugerne;
- fastsættelse af kvantitative mål for madspild;
- støtte til kapacitetsopbygning;
- indførelse af økonomiske incitamenter



BYGGEINDUSTRIEN & BYGNINGER

Industrialiseret produktion og 3D print af bygningsmoduler, nedsættelse af tids- og materialeomkostninger ved byggeri og renovering, kan medføre en nettoværdi på DKK 3,4 – 4,5 mia. (300 – 500 mio.) pr. år i 2035 (2020).

De væsentligste barrierer omfatter:

- en utilstrækkeligt defineret lovgivningsmæssig ramme
- umoden teknologi
- vaner og adfærd samt industriens kapacitet
- evner og færdigheder.

Mulige politiske virkemidler omfatter:

- videreudvikling af byggeregulativer
- som støtter udvikling af modulproduktionsfaciliteter
- samt fastlæggelse af en tydelig lovgivningsmæssig ramme for brug af materialer til 3D printning.

Genbrug og højværdi-genanvendelse af komponenter og materialer, muliggjort f.eks. ved at designe med henblik på senere adskillelse, samt nye forretningsmodeller, kan medføre en nettoværdi på DKK 0,8 – 1,1 mia. (80 – 90 mio.) pr. år i 2035 (2020).

De væsentligste barrierer omfatter:

- forskellige incitamenter og mangel på information på tværs af værdikæden i byggeriet

- vaner og adfærd samt kapacitet
- evner og færdigheder.

Mulige politiske virkemidler omfatter:

- videreudvikling af byggeregulativer
- gennemførelse af uddannelsesprogrammer i hele branchen samt støtte til etablering af materialeopgørelser (software og databanker).

Deling og blandet brug af bygninger for at øge anvendeligheden af den nuværende bygningsmasse kan medføre en nettoværdi på DKK 2,3 – 3,4 mia. (800 – 1.100 mio.) pr. år i 2035 (2020).

De væsentligste barrierer omfatter:

- en utilstrækkeligt defineret lovgivningsmæssig ramme samt utilsigtede konsekvenser af nuværende lovgivning.

Mulige politiske virkemidler omfatter:

- tydeliggørelse af den nuværende lovgivning
- tilvejebringelse af økonomiske incitamenter eller støtte til nye forretningsmodeller samt etablering af portaler over kapacitetsadgang til offentlige bygninger.



MASKININDUSTRIEN

Genfremstilling og nye forretningsmodeller baseret på performance-kontrakter/ servicekontrakter og returlogistik kan medføre en nettoværdi på DKK 1,1 – 1,9 mia. (400 – 800 mio.) pr. år i 2035 (2020). Ved ekstrapolering af disse aktiviteter i tilsvarende sektorer kan lignende muligheder give DKK 0,8 – 3,0 mia. (400 – 800 mio.) pr. år.

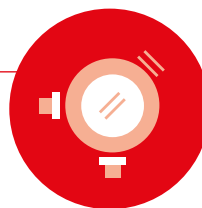
De væsentligste barrierer omfatter:

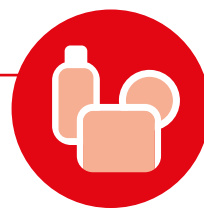
- mangel på kapacitet og færdigheder
- utilstrækkelig information om

nuværende muligheder samt utilsigtede konsekvenser af nuværende regulering.

Mulige politiske virkemidler omfatter:

- støtte til pilotforsøg med genfremstilling samt gennemførelse af informationskampagner og ændring af de eksisterende regelsæt samt vedtagelse af en overordnet regeringsstrategi for genfremstilling. strategy on remanufacturing.





EMBALLAGE

Øget genanvendelse af plastemballage ved bedre emballagedesign, højere indsamlingsprocenter og forbedret sorteringsteknologi kan medføre en reduktion i behovet for nyt plastmateriale på 70-100 000 tons pr. år i 2035.

De væsentligste barrierer omfatter:

- lav indtjeningssevne i værdikæden for genanvendelse (pga. af ikke medregnede eksternaliteter samt svingende priser)
- indsamlings- og sorteringsteknologi samt forskellige incitamenter for aktører i værdikæden.

Mulige politiske virkemidler omfatter:

- en forbedring af indsamlingsinfrastrukturen
- øgede nationale genanvendelsesmål
- standardiserede indsamlings- og sorteringssystemer samt øgede afgifter på affaldsforbrænding.

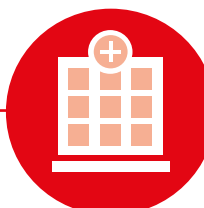
Biobaseret emballage, hvor det er fordelagtigt, medfører et innovationsdrevet omstilling fra fossilbaseret plast til biobaserede alternativer for udvalgte emballageanvendelser.

De væsentligste barrierer omfatter:

- teknologiens modenhed
- indtjeningssevne (pga. af ikke medregnede eksternaliteter) samt et utilstrækkeligt defineret regelsæt.

Mulige politiske virkemidler omfatter:

- finansiering af innovation og B2B-samarbejde
- investering i forbedrede slutbrugsveje for biobaseret emballage samt arbejde med klarheden af EU's regelsæt.



HOSPITALER

Servicebaseret indkøb fra indkøb af produkter til serviceaftaler for hospitalsudstyr, såsom avanceret diagnostisk udstyr, IT eller laboratorieudstyr, kan medføre en nettoværdi på DKK 0,5 – 0,7 mia. (80 - 110 mio.) pr. år i 2035 (2020).

De væsentligste barrierer omfatter:

- utilstrækkelig kapacitet og færdigheder pga. manglende erfaring
- ufuldkommen information i værdikæden samt vaner og adfærd.

Mulige politiske virkemidler omfatter:

- udarbejdelse af retningslinjer
- fastsættelse af mål
- opbygning af kapacitet samt definering af regler for indkøb.

Affaldsreduktion og genanvendelse på hospitaler gennem systematiske og centralt styrede initiativer.

De væsentligste barrierer omfatter:

- utilstrækkelige evner og færdigheder grundet mangel på erfaring
- samt vaner og adfærd og ufuldkommen information i værdikæden

Mulige politiske midler omfatter:

- pilotforsøg med affaldsreduktion og genanvendelse som en integreret del af personalets uddannelse
- fastsættelse af mål for affaldsminimering og genanvendelse samt øgede økonomiske incitamenter til at undgå generering af affald.

INTRODUCTION

The Denmark case study focused on five sectors: food & beverage, construction & real estate, machinery, plastic packaging and hospitals. This report covers the core findings for these sectors, as well as an integrated national perspective.

The findings for Denmark resulted from an intense analytical phase, going through all steps of the methodology as laid out in the toolkit report. While these findings cannot be directly transposed to other countries, they might serve as a source of inspiration for the identification of opportunities, barriers and policy options. It was evident early on that key stakeholder involvement is crucial for the success of a study such as this one. It has included consultations with more than 25 businesses, a group of senior policymakers, industry associations and other society stakeholders, and a series of international experts. It was especially crucial to involve businesses throughout the project in order to:

- (i) get insights and knowledge to identify the most relevant circular economy opportunities and barriers in each focus sector;
- (ii) create early alignment on common direction for the country and the focus sectors;
- (iii) further demonstrate circular economy benefits to businesses and build capabilities for implementation.

As the circular economy is a new notion to both policymakers and (certain) companies, business involvement is even more important than in other policy areas.

Thanks to the support and engagement of these stakeholders, the findings in this report give a good directional view on circular economy opportunities for Denmark. However, being the result of a pilot phase covering five major sectors in just a few months, the findings below do not aim to be as detailed as a typical impact assessment for one opportunity or policy. Similarly, the set of identified barriers would likely need to be analysed further. The set of opportunities is not exhaustive – significant opportunities may exist in addition to those identified here.

Each of the deep dives in chapters 2–6 covers the current state of the circular economy, the key circular economy opportunities and related barriers, and potential policy options to overcome these barriers.

1 NATIONAL PERSPECTIVE

Even in a country with a starting position as advanced as Denmark, there are significant opportunities to further transition towards the circular economy. Ten circular economy opportunities in five focus sectors were identified as most promising for Denmark. Modelling conducted in this study suggests that, by 2035, these could unlock, relative to a 'business as usual' scenario:

- **an increase in GDP by 0.8–1.4%;**
- **between 7,000 and 13,000 additional job equivalents;¹**
- **a reduction of the country's carbon footprint by 3–7%;²**
- **a reduction of consumption of selected resources³ by 5–50%;**
- **an increase in net exports by 3–6%.**

Each of these opportunities is limited, to varying degrees, by a number of barriers. Potential policy options to overcome these barriers have been identified. To enable a systemic transition towards the circular economy, Danish policymakers might also consider setting economy-wide direction for the circular economy, broader changes to the fiscal system, and a wider knowledge-building and education effort. These potential policy options should not be considered as recommendations; Danish policymakers would need to assess in the necessary detail their expected costs, benefits and feasibility.

DENMARK TODAY

Leading Danish companies, including large multinationals as well as SMEs, are pioneering circular economy solutions. The following are just three out of many inspiring examples.

- Shipping company Maersk has introduced product passports for their container ships, actively working with the Korean shipyard DSME and approximately 75 suppliers of parts. The passport, which will be updated throughout the life of the ship, is a database listing the material composition of the main parts of the ship, and documents approximately 95% (by weight) of the materials used to build the ships. It will enable better recovery of parts and materials used in the construction and maintenance of the vessels.⁴
- Brewing company Carlsberg is using the Cradle-to-Cradle® (C2C) design framework⁵ to develop C2C-certified packaging, and has set up the Carlsberg Circular Community, aiming to rethink the design and production of traditional packaging material and develop materials which can be recycled and reused indefinitely while keeping quality and value.⁶
- Baby clothing company Vigga offers a circular subscription model for baby clothes. The baby clothes, made from organic fabrics, are returned to Vigga once outgrown, where they are dry cleaned in an environmentally friendly way and

1 Employment impact modelled through conversion of labour bill to job equivalents via a wage curve approach (elasticity = 0.2). Percentage change is computed vs. 2013 total full-time employment.

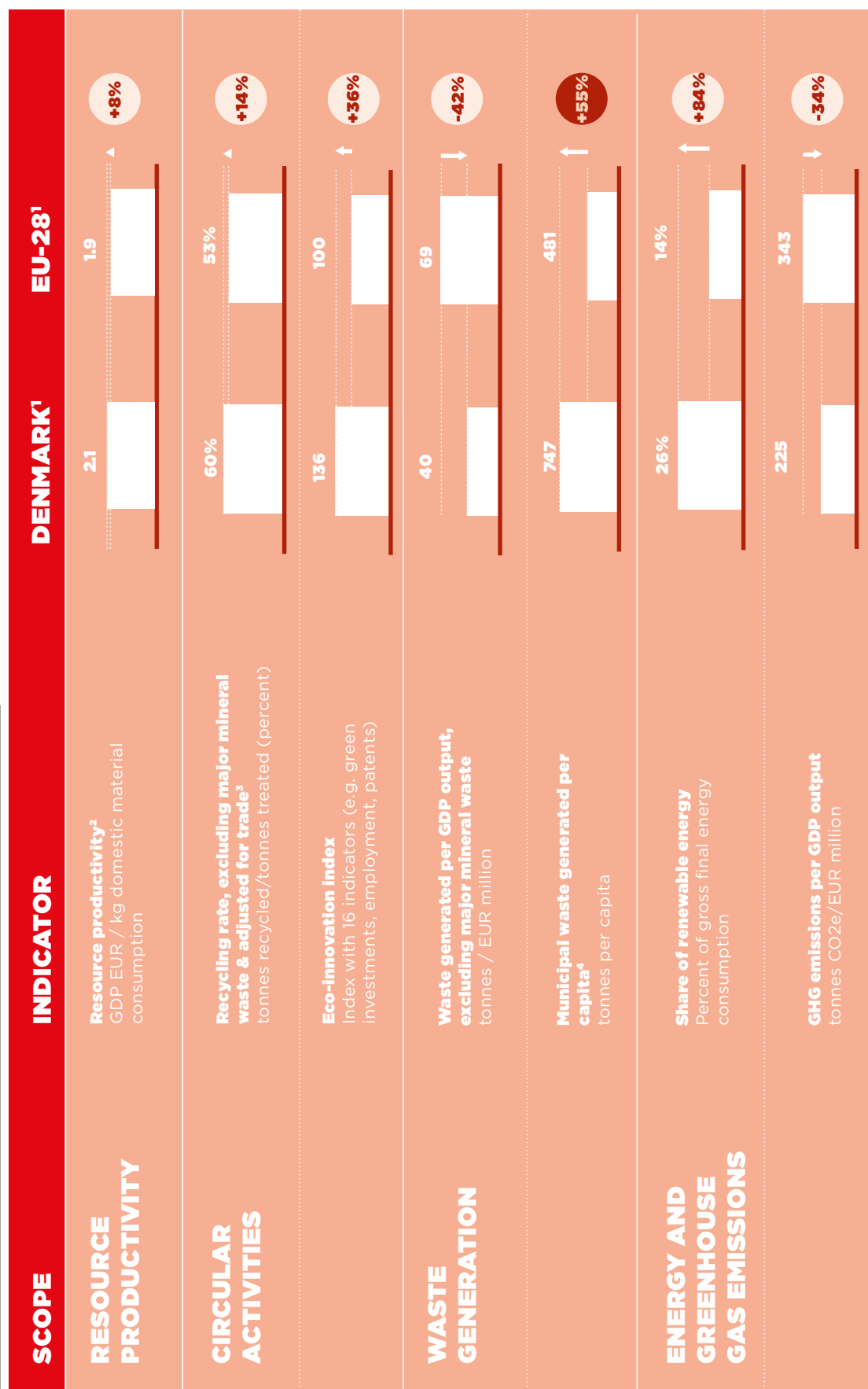
2 Measured as change in global carbon emissions divided by 'business as usual' Denmark carbon emissions.

3 For steel and plastic, in selected sectors in Denmark. Includes resources embedded in imported products/components.

4 Maersk. www.maersk.com/en/hardware/triple-e/the-hard-facts/cradle-to-cradle

5 Created by William McDonough and Professor Michael Braungart. www.c2ccertified.org

6 Carlsberg. www.carlsberggroup.com/csr/ReportingonProgress/SustainablePackaging/Pages/default.aspx

Figure 1: Circularity baselining in the Denmark pilot

¹ 2012 values if not stated otherwise

² Comparability of this indicator is dependent on sector structure.

³ Recycling of domestically generated waste (incl. exported waste, excl. imported waste)

⁴ 2013 data

SOURCE: Resource Efficiency Scoreboard 2014 Highlights, European commission (2014); Eurostat; Statistics Denmark, Danish EPA

made ready for another baby to optimise the use during the lifetime of the baby clothes.⁷

A circularity and policy baselining exercise conducted in the pilot reveals that Denmark has an advanced starting position compared to other European countries (Figure 1⁸). This is thanks to a long and rich tradition of innovating policies that stimulate resource efficiency and the circular economy. It introduced the very first deposit-refund scheme for beverage containers in the 1980s. It has incrementally increased landfill taxes since they were introduced in 1987.⁹ In 2011, it set the target to be fully independent from fossil fuels by 2050. More recently, Denmark has laid out a comprehensive waste management strategy in 'Denmark Without Waste I/II', focused on moving from incineration to recycling and waste prevention, respectively. It has established the Task Force for Resource Efficiency, the National Bioeconomy Panel, the Green Industrial Symbiosis programme, and the Rethink Resources innovation centre. Denmark participates in international initiatives such as the Ellen MacArthur Foundation's CE100 programme. A high-level description of the policy landscape in Denmark is given in Figure 2.

Denmark is internationally recognised as a front runner in the circular economy. A case in point is the Danish Business Authority winning the 2015 'Ecolab Award for Circular Economy Cities/Regions' at the World Economic Forum in Davos.¹⁰

In terms of opportunity identification, Figure 3 highlights that Denmark is already one of the world leaders in the domains of energy efficiency and the adoption of renewable energy, and has even more ambitious targets in place. Therefore, these areas were deprioritised when assessing circular economy opportunities.

Yet even Denmark has significant opportunities to further transition towards the circular economy. Across the economy, significant material value is left on the table as most waste streams and by-products are used for relatively low-value applications. Of the 93% waste diverted from landfill, only two thirds is recycled – the rest is incinerated.¹¹

In the construction sector, 87% of materials is recycled, but mainly for low-quality applications,¹² and there is only an estimated <1% reuse of building components and materials. In the machinery sector, >95% of its most important material (steel) is recycled, yet there is an estimated <1% remanufacturing.¹³ Nearly 100% of industrial organic waste is being valorised, but mainly in low-value applications such as incineration, direct fertilisation, or animal feed, while only ~3% of waste is used in biogas production and there is <1% cascading bio-refining.¹⁴

In addition, the headline figures quoted above hide pockets of opportunities. Municipal waste per capita is the highest in the EU (~750 kg/capita vs. ~480 kg/capita EU28 average).¹⁵ There is an estimated 80-90 kg annual avoidable food waste per household.¹⁶ Only ~15% plastic packaging is collected for recycling from households, of which only half actually gets recycled in new resin.¹⁷

7 www.vigga.us

8 See section 2.1.1 in the toolkit report for more details.

9 Danish Environmental Protection Agency, *From land filling to recovery – Danish waste management from the 1970s until today* (2013).

10 <https://thecirculars.org>

11 Eurostat.

12 Statistics Denmark; interviews with the Danish Environmental Protection Agency and sector experts.

13 Statistics Denmark; interviews with sector experts.







14 L. Lange, A. Remmen, *Bioeconomy scoping analysis* (Aalborg University, 2014); interviews with sector experts; Danish Government, *Denmark Without Waste I. Recycle more – incinerate less* (2013); Danish Energy Agency, *Biogas i Danmark – status, barrierer og perspektiver* (2014).

15 Eurostat. There are some discrepancies in how this metric is calculated in different member states.

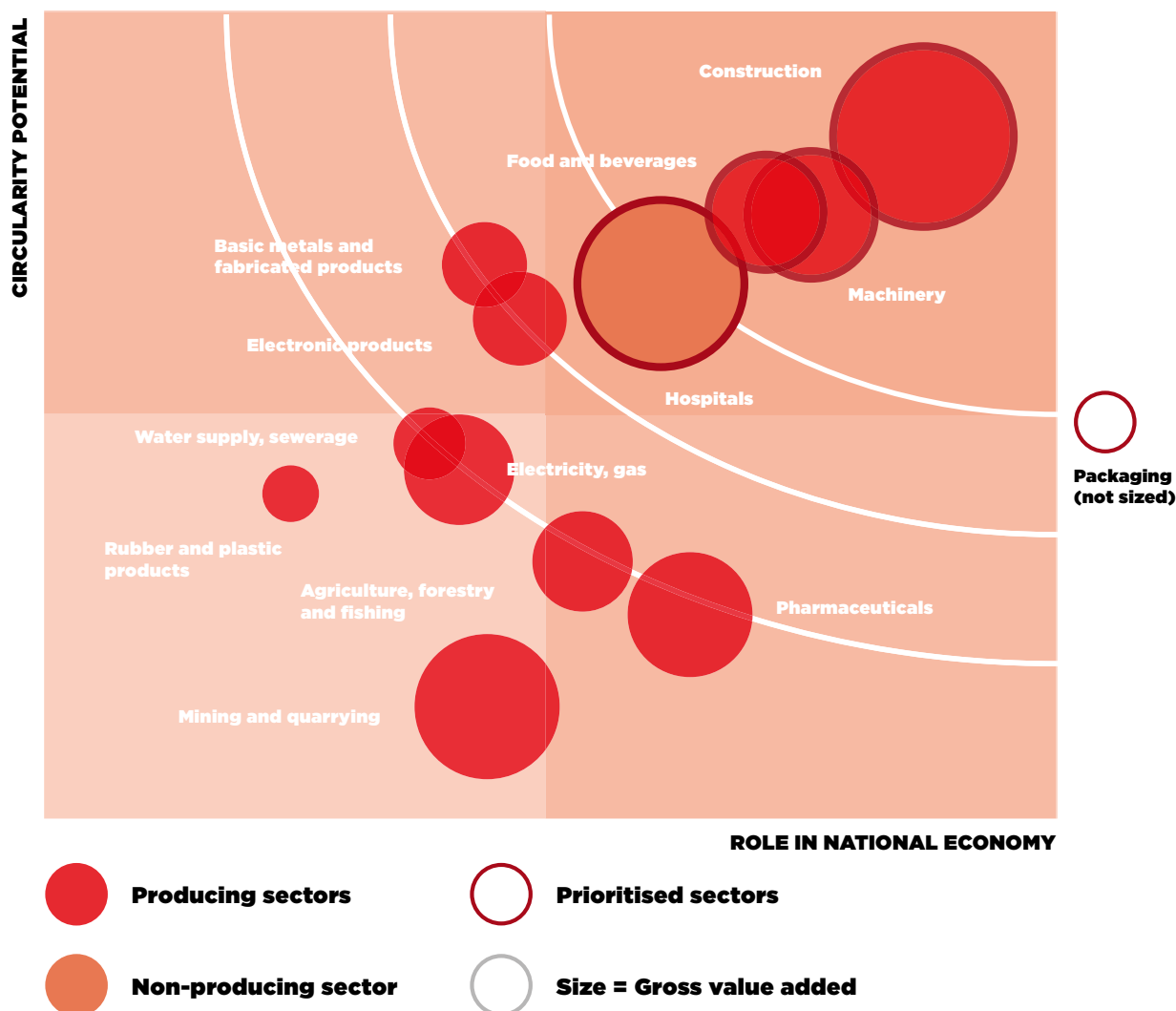
16 Danish Environmental Protection Agency, *Kortlægning af dagsrenovation i Danmark – Med fokus på etageboliger og madspild* (2014).

17 Danish EPA; Statistics Denmark.

Figure 2: Policy landscape in the Denmark pilot

POLICY INTERVENTION TYPES	EXAMPLES OF EXISTING INTERVENTIONS	EXAMPLES OF POSSIBLE ADDITIONAL INTERVENTIONS (AS OBSERVED AT START OF THE PROJECT IN WINTER 2014-15 AND NOT TAKING INTO ACCOUNT SUBSEQUENT ANALYSIS)
 EDUCATION, INFORMATION & AWARENESS	<ul style="list-style-type: none"> Consumer information campaigns, e.g. 'Use more, waste less' and 'Stop Wasting Food' 	<ul style="list-style-type: none"> Systems thinking integrated in curricula Further pilot projects to demonstrate circular economy potential to businesses
 COLLABORATION PLATFORMS	<ul style="list-style-type: none"> Green Industrial Symbiosis programme Four new partnerships (food, textile, construction and packaging) as part of the Danish Waste Prevention Strategy Rethink Resources, an innovation centre to support resource efficiency in companies 'Genbyg Skive' pilot project to re-use building materials to create business opportunities and reduce waste 	<ul style="list-style-type: none">
 BUSINESS SUPPORT SCHEMES	<ul style="list-style-type: none"> Fund for Green Business Development (EUR 27m 2013-2018) to support innovation and new business models Maabjerg Energy Concept (MEC) bio-refinery part funded by Innovation Fund Denmark (EUR 40m) 	<ul style="list-style-type: none"> Dutch 'Green Deal' inspired programme to provide on-demand support to companies in implementing circular economy opportunities
 PUBLIC PROCUREMENT & INFRASTRUCTURE	<ul style="list-style-type: none"> Government Strategy on Intelligent Public Procurement contains initiatives to support circular procurement practices Strategy on waste prevention also contains an initiative to develop guidelines for circular public procurement 	<ul style="list-style-type: none"> Guidelines on the circularity of materials and products integrated into public procurement policy
 REGULATORY FRAMEWORKS	<ul style="list-style-type: none"> Ambitious energy efficiency and GHG emissions targets, e.g. 40% GHG reduction by 2020 vs. 20% at EU level, Ambitious targets for recycling/incineration/landfill, updated every 6 years, e.g. recycle 50% of household waste by 2022 Taskforce for increased resource efficiency to review existing regulations affecting circular economy practices 	<ul style="list-style-type: none"> New metrics introduced to measure economic performance, e.g. complements to GDP such as natural capital Engagement at EU level to adapt existing or introduce new regulations relevant to the circular economy, e.g. product policy
 FISCAL FRAMEWORKS	<ul style="list-style-type: none"> Taxes on extraction and import of raw materials, vehicle registration and water supply High and incrementally increased taxes on incineration / landfill to promote recycling and waste prevention Highest energy taxes in Europe (70% above EU27) and CO2 taxes Tax cuts designed to promote use of low-carbon energy 	<ul style="list-style-type: none"> Investigation into effects of tax shift from labour to resources

SOURCE: European Commission, Tax reforms in EU Member States 2013; IEA, Energy Policies of Denmark: 2011 review; Nordic Council of Ministers, The use of economic instruments in Nordic environmental policy 2010-2013; Danish legislative council, Waste management policy in Denmark, 2014; The ExTax project, New era. New plan. Fiscal reforms for an inclusive, circular economy, 2014.

Figure 3: Results of sector prioritisation in Denmark pilot

NOTE: Only producing sectors (24% of national GVA) and hospitals (3.5% of national GVA) considered
 SOURCE: Statistics Denmark (2011 data); Danish Business Authority; Danish Environmental Protection Agency; Ellen MacArthur Foundation

SECTOR SELECTION

To focus the analytical work to the areas in the Danish economy with the highest circular economy potential, a structured sector selection approach was developed to select five sectors. Two dimensions were used to prioritise sectors based on both their role in the national economy and the circularity potential. The sectors were then assessed according to a 'score' for each dimension, which was computed by scoring a number of sub-dimensions:

- Role in the national economy: size (and growth) measured by share of GVA (gross value added), contribution to employment (and growth), international competitiveness.
- Circularity potential: material and energy intensity, volume of waste generated, share of waste landfilled/incinerated, high-level estimate of scope for improved circularity.

These sub-dimensions, and their relative weights in the scoring, are explained in further detail in Appendix A.

Subsequently, one to two product categories or sub-sectors were selected in each focus sector to drive the identification and quantification of circular economy opportunities.

They were selected based on their importance for sector value creation in Denmark, as well as the relevance for circular economy opportunities. The five selected focus sectors and their product categories are:

- Food & beverage, a producing sector. The analysis in this sector focused on the pork and dairy processing industry, but also included a deep dive on the consumer side.
- Construction & real estate, a producing sector. The analysis in this sector focused on the construction and renovation of buildings, but also included a deep dive on real estate utilisation (sharing).
- Machinery, a producing sector. The analysis in this sector focused on pumps and wind turbines.
- Packaging, a cross-cutting sector spanning consumer goods companies, wholesalers, retailers, and consumers. The analysis in this sector focused on plastic packaging.
- Hospitals, a public, consuming, service sector. The analysis in this sector focused on public procurement, and is important as a proxy to understand opportunities in the large public sector in Denmark.¹⁸
- The energy sector, while critical for the transition to the circular economy, has not been selected as a focus sector in this study, as Denmark is already working towards a target to base all energy consumption, including the transport sector, on renewables by 2050.¹⁹

The fact that some sectors were deprioritised in this study does not mean that there are no circular economy opportunities. But as in most projects, the scope of the Denmark case study prohibited deep-dive analysis into all aspects of the economy. It should also be noted that only producing sectors, as well as hospitals, were considered in the sector selection exercise. While most resource related circular economy opportunities are arguably concentrated in these sectors, other opportunities may also be interesting. Other public sectors (in total representing 26% of the national economy) or the transport sector (one of the top energy consumers in any country) could be interesting candidates for further analysis, despite being outside the scope of this study.

CIRCULAR ECONOMY OPPORTUNITIES AND THEIR POTENTIAL IMPACT

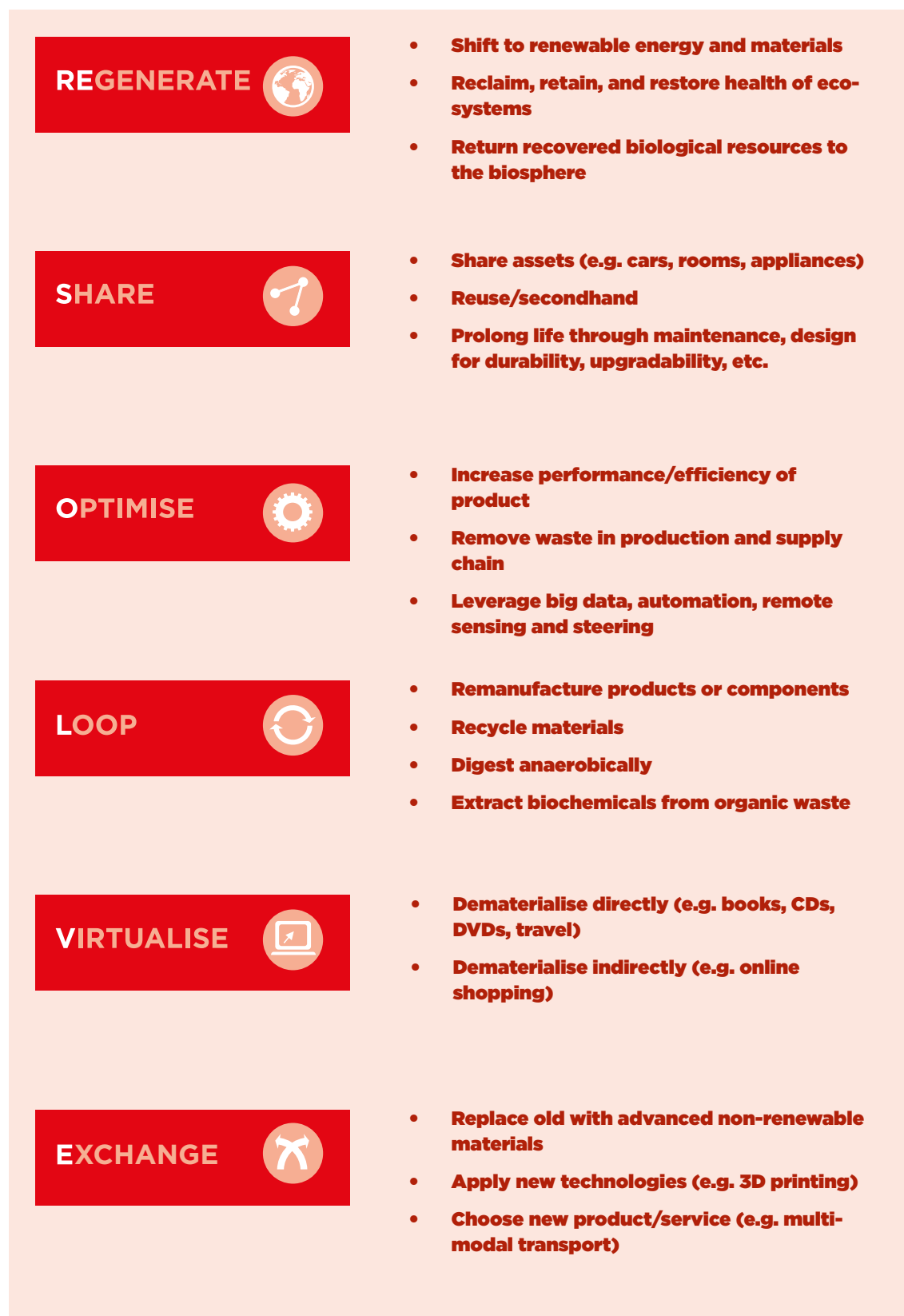
To identify and prioritise opportunities within the five selected focus sectors, the ReSOLVE framework²⁰ (shown in Figure 4 and described in detail in Appendix E) was employed. This exercise led to a qualitative mapping of which type of activities could have the largest impact in the respective sector (see Figure 5), and guided the prioritisation of ten circular economy opportunities in each sector. These opportunities are shown in Figure 6, and are detailed in Chapters 2–6, which each cover one sector.

¹⁸ The public sector represents 26% of the national economy. Data from Statistics Denmark.

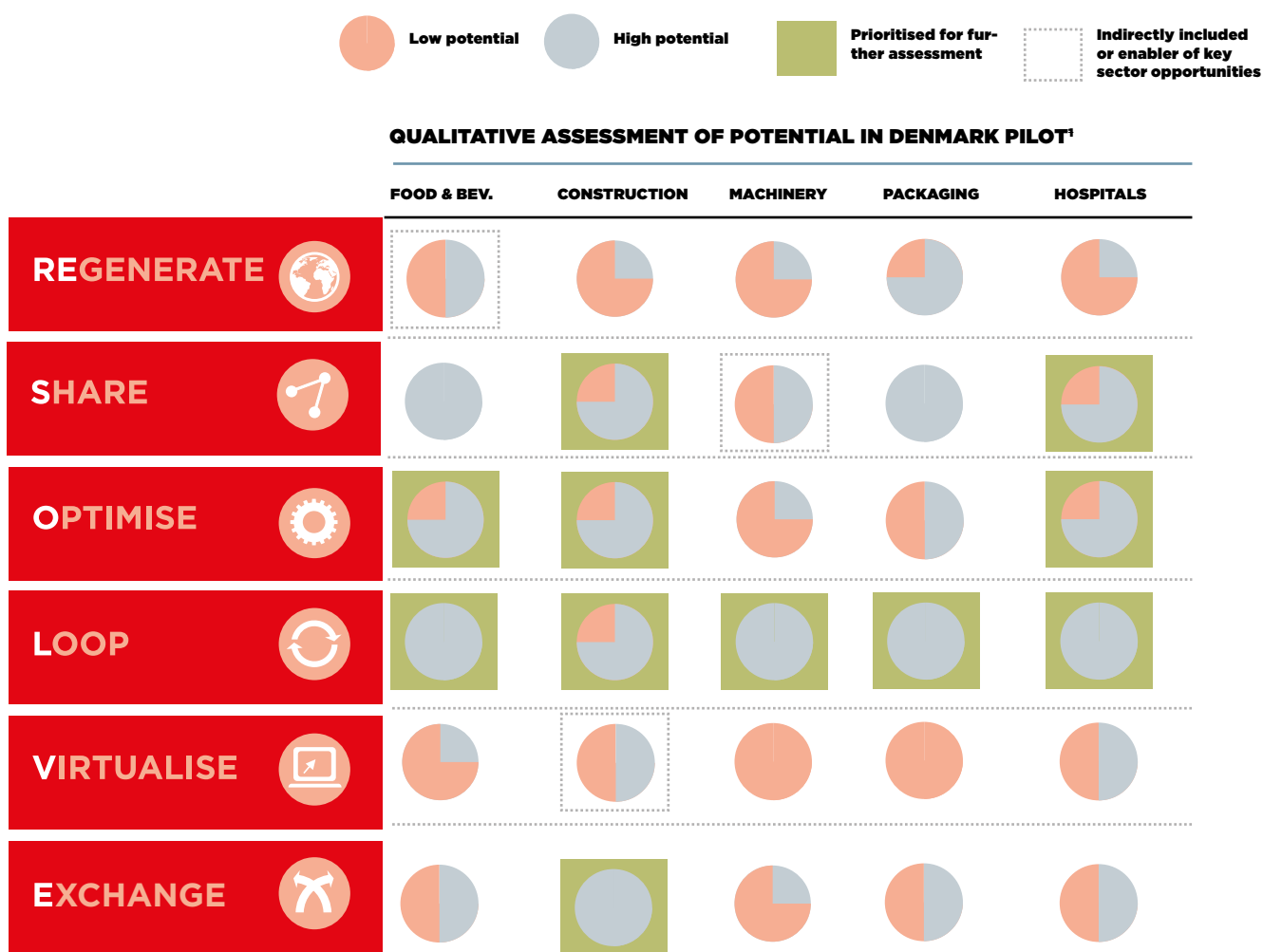
¹⁹ The Danish Government, *The Danish Climate Policy Plan* (2013).

²⁰ Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, *Growth Within: A Circular Economy Vision for a Competitive Europe* (2015).

Figure 4: The ReSOLVE framework: six action areas for businesses and countries wanting to move towards the circular economy



SOURCE: Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, *Growth Within: A Circular Economy Vision for a Competitive Europe* (2015). Based on S. Heck, M. Rogers, P. Carroll, *Resource Revolution* (2015).

Figure 5: Qualitative opportunity prioritisation of focus sectors in the Denmark pilot

¹ Assessment based on focus subsector, product category or material stream in each sector. Food & beverage: Waste/by-products from pork / dairy processing, residual biomass from agriculture, organic waste from households, retail & hospitality. Construction: New buildings. Machinery: Manufacturing of pumps and wind turbines. Packaging: Plastic packaging. Hospitals: Purchasing of goods.
SOURCE: Ellen MacArthur Foundation

These ten identified opportunities are already being pursued to some extent today, inside or outside Denmark. There is however significant potential to scale up. Doing so could bring Denmark from the – dependent on the sector – early or advanced transitioning economy it is today to an advanced transitioning and in some areas almost fully circular economy by 2035 (see Figure 7 on page 36-37).

Figure 6: Ten circular economy opportunities in five focus sectors

SOURCE: Ellen MacArthur Foundation

The impact quantification of the identified opportunities was conducted by estimating three key factors:

- (i) The adoption rate of the opportunity relative to ‘business as usual’
- (ii) The addressable value pool for the deep-dive sub-sector, e.g., ‘number of units produced’ or ‘volume of waste’
- (iii) The net value created per unit in the deep-dive sub-sector, considering impact on both revenues and cost.

To ensure a consistent ambition level when detailing these opportunities and assessing their impact, a short-term scenario of five years (2020) and a long-term scenario of 20 years (2035) were defined, each for which an adoption rate and the net value creation were estimated, see Figure 8. The year 2035 was selected to illustrate as much of the ‘full’ potential as possible, without going so far into the future that businesses and other stakeholders would find it hard to assess concrete opportunities. The scenario description served as a common backdrop to define and assess the different identified opportunities, by articulating how the business environment and consumer behaviour, as well as technology, could evolve going forward.

Furthermore, a ‘conservative’ and an ‘ambitious’ version of these scenarios were defined to illustrate the range of impact the circular economy development could have. These two levels differentiate assumptions on the scalability of impact from the deep dives into sector subcategories to the rest of the sector, and of the five focus sectors to adjacent producing sectors. The impact estimated for pumps and windmills, for example, is scaled up to the full machinery sector. The impact for the machinery sector is then, in turn, scaled up to the adjacent sectors electronics, other manufacturing, basic metals and fabricated metal products, and mining. In the conservative scenario, such scale-up is significantly discounted – for example, when scaling up the results from the construction of buildings to infrastructure construction, these results are reduced by 80%. In the ambitious scenario, higher scale-up rates are used. A detailed description of the approach of quantifying deep-dive sub-sectors and scaling up to the full sector is all its elements is given in Appendix B. A driver tree representation of the methodology can be found in Figure B2.

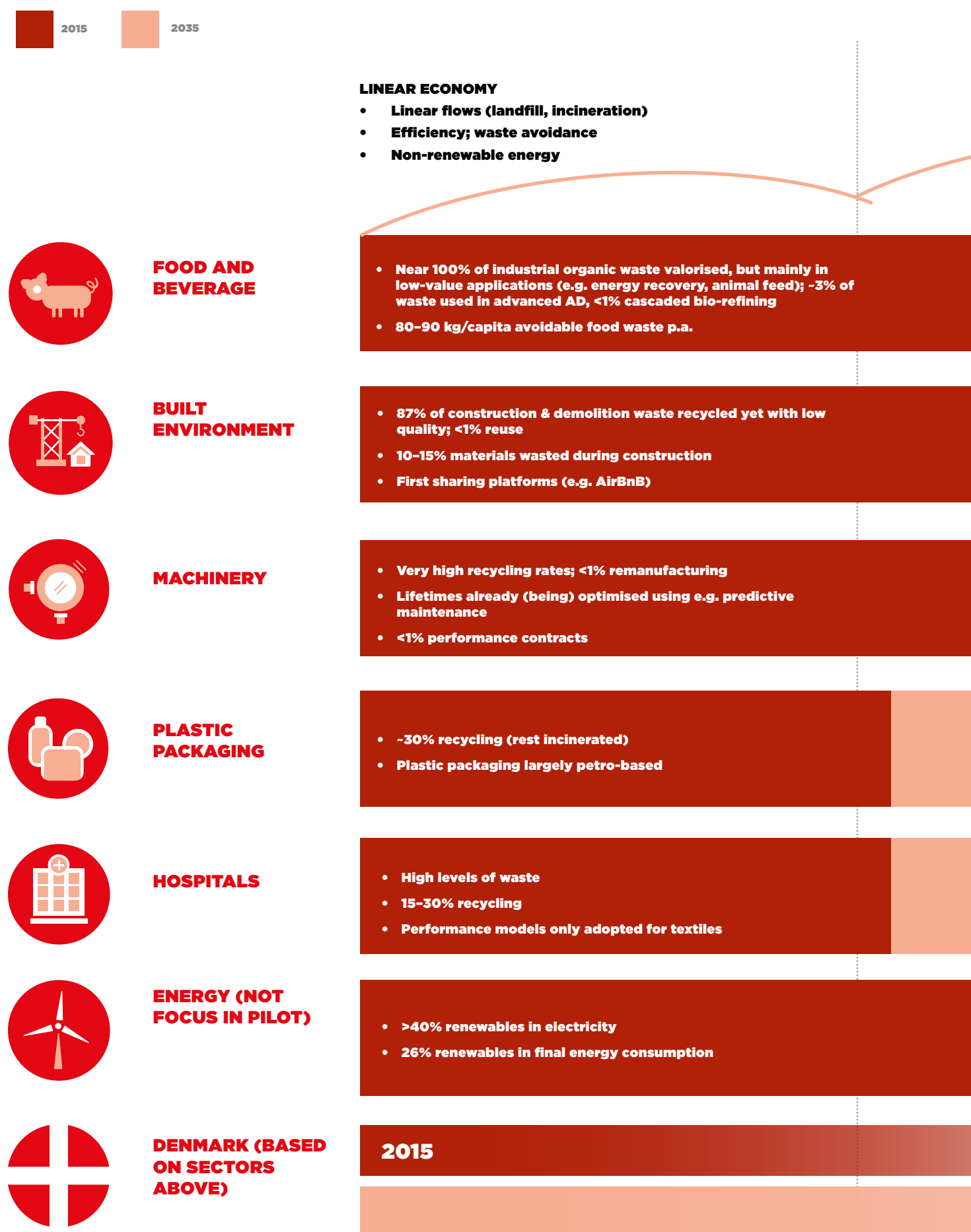
Figure 8: Short-term and long-term scenarios used in the Denmark pilot

	Short-term (2020)	Long-term (2035)
BUSINESS & CONSUMER BEHAVIOUR	<ul style="list-style-type: none"> Increased acceptance of performance based business models in businesses and the public sector, but still for niche product categories (e.g. ~10% of imaging / radiation equipment in hospitals, ~10% of machinery products) Households are comfortable using new separation systems introduced by municipalities as part of the “Denmark Without Waste” strategy (e.g. increase in collection rate of household plastic packaging waste by 15 percentage points) Significant remaining margins for improvement in waste reduction Rapidly increasing interest in sharing business models (e.g. shared residential and office space) 	<ul style="list-style-type: none"> Broad acceptance of access over ownership business models in businesses and public sector (e.g. ~30% of a broad range of products in hospitals, ~30-70% of machinery products) Fully optimised waste collection and separation infrastructure provided by municipalities and waste managers (collection of 70-80% of plastics for recycling) Avoidable food waste reduction approaching theoretical limits due to improved knowledge and use of best practices among consumers, businesses and public institutions (e.g. hospitals) Sharing has become the new norm for traditionally underutilised assets (buildings, cars, and durables)
TECHNOLOGY	<ul style="list-style-type: none"> Key circular economy technologies (e.g. cascading bio-refineries, bio-based alternatives to plastics, 3D printing and design for disassembly in construction, remanufacturing techniques), existing today at late R&D or early commercial stage, have been successfully piloted 	<ul style="list-style-type: none"> Key circular economy technologies existing today at R&D or early commercial stage have reached maturity due to accelerated innovation Increasing remanufacturing of machinery components for use in “as new” products enabled by increasing importance of software for performance

Source: Expert interviews; DBA; Danish EPA; Ellen MacArthur Foundation.

Overall, the underlying assumptions for both scenarios can be considered relatively conservative. The scenarios rely, for example, only on technologies currently at commercial stage or late R&D. In addition, the analysis focused on the producing sectors and hospitals only, representing, in total, 25% of the Danish economy²¹. No direct circularity effects have been modelled for the service sector (except hospitals), which represents (excluding hospitals) over 70% of the Danish economy. The Danish

21 Based on 2011 gross value added provided by Statistics Denmark.

Figure 7: Illustrative status of circular economy in Denmark today and potential by 2035

TRANSITION ECONOMY

- **Low-value circular flows (e.g. recycling, AD)**
- **Mix of renewable and non-renewable energy**

CIRCULAR ECONOMY

- **High-value circular flows (e.g. reuse, reman, cascaded value extraction for organics)**
- **Circular business models (e.g. sharing, leasing)**
- **Renewable energy**

- **-90% of organic waste in advanced AD and cascaded bio-refining**
- **40–50 kg/capita avoidable food waste p.a.**

- **15% of building materials and components reused; recycling with higher quality**
- **<1% waste in construction process**
- **Widespread building sharing**

- **15–35% remanufacturing**
- **10–15% performance contracts**

- **-75% recycling**
- **Bio-based materials replacing petro-based plastics in selected products**

- **Avoidable waste designed out**
- **>80% recycling (of non-toxic waste)**
- **40% performance models adoption for addressable equipment**

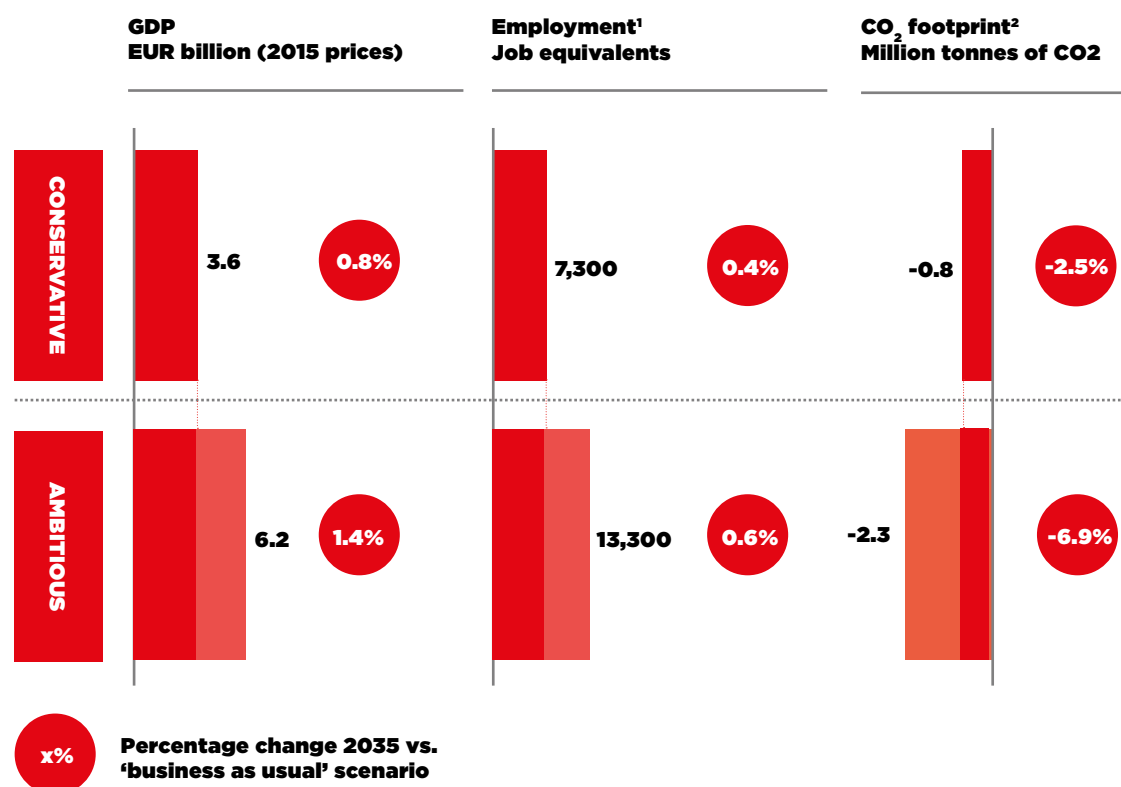
- **100% renewables in electricity and heating**
- **Oil for heating and coal phased out**
- **Fossil fuels remain in e.g. transport**

energy mix was assumed to be the same in the ‘business as usual’ and circular economy scenarios – which limits the size of the potential CO₂ reduction. More details on key macroeconomic model assumptions and data sources can be found in Appendix C.

In order to analyse the economy-wide impact, including potential knock-on effects on other sectors of the Danish economy, the quantified impact of the sector-specific circular economy opportunities was used as input to a computable general equilibrium model (see Section 2.3.1 and Appendix C in the toolkit report for further details). As seen in Figure 9, this analysis shows that relative to a ‘business as usual’ scenario, these opportunities could produce significant positive economic and environmental results by 2035. While such estimates by necessity rely on a number of assumptions and recognising that the methodology used to estimate them will continue to be developed, these findings support conclusions from a growing body of research (see Figure E3) that the impact of a circular economy transition on economic growth, job creation and carbon emissions is likely positive. For a detailed description of the impact assessment methodology, see Appendix B.

Figure 9: Estimated potential impact of further transitioning to the circular economy in Denmark

Economy-wide impact by 2035. Absolute and percentage change relative to the ‘business as usual’ scenario.



¹ Employment impact modelled through conversion of labour bill to job equivalents via a wage curve approach (elasticity = 0.2). Percentage change is vs. 2013 total full-time employment (Source: Statistics Denmark)

² Change in Global CO₂ emissions vs. Denmark baseline 2035 emissions; other GHG emissions are not included. SOURCE: Ellen MacArthur Foundation; NERA Economic Consulting

While such estimates by necessity rely on a number of assumptions and recognising that the methodology used to estimate them will continue to be developed, these findings support conclusions from a growing body of research (see Figure 4 in Chapter 1.1 of the main report) that the impact of a circular economy transition on economic growth, job creation and carbon emissions is likely positive.

Positive changes relative to the ‘business as usual’ scenario were identified in five key areas:

Economic growth (measured as change in Gross Domestic Product): Economic modelling suggests that the identified circular economy opportunities could expand Denmark’s GDP by between +0.8% (in the conservative scenario) and +1.4% (in the ambitious scenario) by 2035. This increase in national economic growth would be achieved mainly through a combination of increased revenues from emerging circular activities and lower cost of production through more productive utilisation of inputs. These changes in input and output of economic production activities affect economy-wide supply, demand and prices, rippling through the other sectors of the Danish economy and resulting in a series of indirect effects that add to the overall growth. Such effects include changed activity levels in the supply chains, and greater consumption and savings resulting from an increase in household income, in turn resulting from greater remuneration to labour. Together, these effects add up to a positive change in GDP (and contribute to other macro impacts described below).

Employment (measured as job equivalents estimated via a wage curve approach): Total remuneration to labour increases both as a result of general expansion of economic activity, and as a result of the increased labour intensity resulting from certain circular economy opportunities (e.g. remanufacturing). Although the impact assessment model used in the Denmark pilot does not explicitly calculate how this higher remuneration is distributed between wage increases and new jobs, it is possible to estimate this distribution using a ‘wage curve’ approach and an assumption on long-run labour supply elasticity (elasticity = 0.2). Through such a calculation, it is estimated that the direct and indirect effects of circularity could bring positive impacts to employment by adding between 7,000 (in the conservative scenario) and 13,000 (in the ambitious scenario) full-time job equivalents to the economy by 2035.²²

Carbon footprint (measured as change in global emissions as a result of Denmark’s more circular economy): Increased circularity and the associated reduction in resource consumption would lower the carbon intensity of Denmark’s own producing sectors, reduce Denmark’s imports of high-carbon-embodied goods, and increase Denmark’s exports of lower-carbon-embodied goods. These changes would directly affect the carbon emissions of Denmark and its trading partners, and indirectly also those of its non-trading partners. This could reduce global carbon emissions in a magnitude equal to between 3% (in the conservative scenario) and 7% (in the ambitious scenario) of Denmark’s ‘business as usual’ carbon emissions by 2035. This reduction excludes the effects resulting from a shift to renewable energy.

Resource use: By 2035, increased remanufacturing in the machinery sector could reduce demand for 60,000–90,000 tons of iron/steel annually (6–10% of total consumption in that sector).²³ In plastic packaging, demand for virgin plastic could be reduced by 80,000–100,000 tons annually due to increased recycling (40–50% of total in that sector²⁴).

International trade balance: In a circular economy, Denmark’s use of goods and services would be more productive than it would be otherwise. That is, Denmark would be able to produce goods and services, primarily those in the focus sectors, at a lower cost. This cost advantage from greater circularity would improve cost-competitiveness internationally, which would result in higher exports and erode the attractiveness of imports, reducing their volume. Such trade effects could ripple across to other countries, resulting in a shift in Denmark’s trading patterns with the rest of the world. By 2035,

22 Employment impacts are computed assuming a wage curve and a long-run labour supply elasticity of 0.2. This methodology is similar to the approach adopted by the Danish Economic Council (DØRS) when interpreting employment impacts within a CGE with full employment assumption. The chosen elasticity value is an average for European countries.

23 Total steel demand provided by Statistics Denmark. Steel savings estimated based on the adoption rate of component remanufacturing in the machinery sector (Chapter 3.4), informed by material composition provided by industry reports and sector experts.

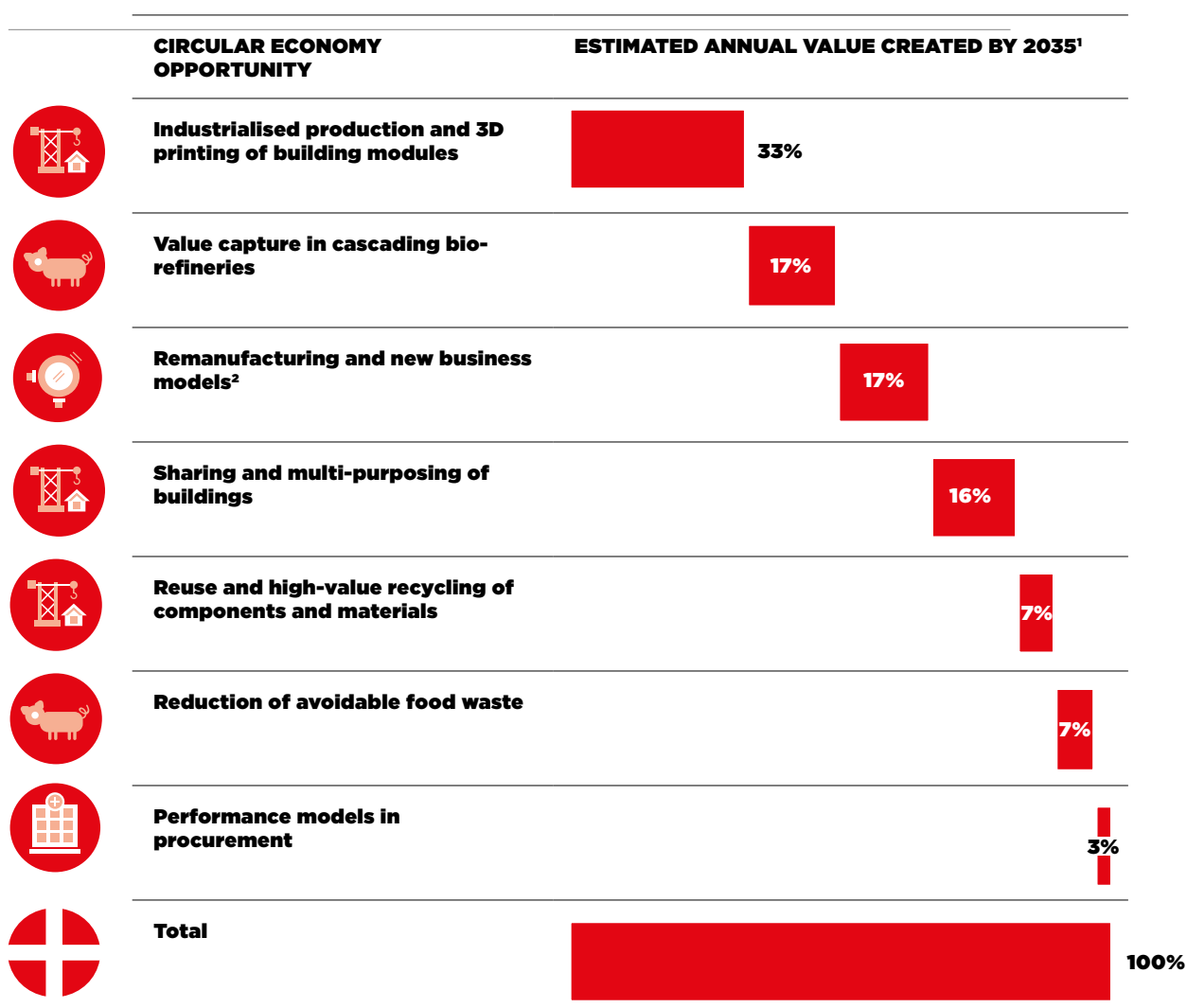
24 Measured by annual plastic packaging waste generated. Danish Environmental Protection Agency, *Statistik for emballageforsyning og indsamling af emballageaffald 2012* (2015 rev.).

net exports (i.e. exports minus imports) could expand, relative to the ‘business as usual’ scenario, by 3% (in the conservative scenario) and 6% (in the ambitious scenario).

Even though most of the identified circular economy opportunities by nature take time to realise, there are benefits in the short term. By 2020, adoption of the identified circular economy opportunities could increase GDP by EUR 400 million (0.1%), and create 1,300–1,400 new jobs. The model estimates a slight rebound effect in CO₂ emissions, with a 1.0%–2.0% increase by 2020. However, this should be understood in relation to a baseline scenario that factors in a significant decline in the use of fossil energy in Denmark, following the national target to reduce GHG emissions 40% by 2020 vs. 1990 levels

Figure 10 shows a breakdown of these results along the seven quantified circular economy opportunities. Three circular economy opportunities have not been quantified. The economic impacts of the two packaging opportunities and the opportunity related to waste reduction and recycling in hospitals have not been quantified as it is expected that their magnitude would be limited when compared to the full Danish economy.

Figure 10: Breakdown of potential economic impact by quantified opportunity



¹ Average between conservative and ambitious scenario. This sector-specific impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling.

² Including scaling from machinery sector (including pumps, wind turbines and other machinery products) to adjacent manufacturing sectors (electronic products, basic metals and fabricated products, other manufacturing, mining and quarrying)

SOURCE: Ellen MacArthur Foundation

BARRIERS AND POTENTIAL POLICY OPTIONS

While most circular economy opportunities identified in Denmark have sound underlying profitability, there are often non-financial barriers limiting further scale-up or reducing their pace. An overview of the barriers to each of the opportunities in the Denmark pilot is provided in Figure 11.

The social factor barriers of capabilities and skills and custom and habit are widespread, as the behavioural changes needed to realise many of the opportunities go against ingrained patterns of behaviour and skill-sets on the part both of consumers and businesses. Imperfect information was also often found to be a barrier: businesses can be unaware of potentially profitable new opportunities, or the information necessary to realise them is unevenly distributed.

Technology can be a critical barrier as well, especially for the more technology-dependent opportunities such as cascading bio-refineries, 3D printing of building components, and bio-based packaging.



Externalities feature as a barrier to many opportunities, though they do not threaten the fundamental profitability of most, with the exception of packaging. In this sector, without the additional factoring in of externalities, the profitability of both recycling and bio-based packaging is highly dependent on the price of the alternative – petro-based plastic, which is in turn determined by global oil prices. A similar reasoning applies to bio-refineries, although cascading bio-refineries could alleviate this concern by diversifying revenue streams beyond alternatives to petro-based fuels, chemicals and plastics.

The barrier of unintended consequences from existing legislation limiting circular economy opportunities is present for example in bio-refining where food safety regulations prevent the use of certain animal products as feedstock. Such barriers can be in the complexity and cost of adhering to regulations as well as in actual prohibition of certain activities. The devil is in the detail here, and more detailed analysis of unintended consequences would be required to determine the exact magnitude of this barrier for the different opportunities in Denmark.

Potential policy options that could overcome the barriers for each of these opportunities have been identified. These options cover a broad range of policy intervention types, and are detailed in the sector deep dive chapters below. They should not be considered as recommendations, rather as an input to Danish policymakers' discussions about if and how to shift to a circular economy. Policymakers would need to assess in detail their expected costs, benefits and feasibility.

To enable a systemic transition towards the circular economy, Danish policymakers could also reflect on setting an economy-wide direction for the circular economy, broader changes to the fiscal system, and a wider knowledge-building and education effort. While many circular economy opportunities already have a sound underlying profitability, a number of international organisations, such as the European Commission, the OECD, the IMF, and the International Labour Organization, have suggested further opportunities could be unlocked by shifting fiscal incentives towards labour from resources. However, the effects of such a shift would need to be carefully analysed, especially considering Denmark is a small and export-oriented country. Complementing today's flow-based metrics such as GDP as a measure of economic success with measures of a country's stock of assets could be an instrument for policymakers to account for the restoration and regeneration of natural capital.

Figure 11: Barrier matrix for the ten prioritised opportunities in Denmark

		CIRCULAR ECONOMY OPPORTUNITIES		
				
		Value capture in cascading bio-refineries	Reduction of avoidable food waste	Industrialised production and 3D printing of building modules
BARRIERS				
ECONOMICS	Not profitable for businesses' even if other barriers are overcome			
	Capital intensive and/or uncertain payback times			
	Technology not yet fully available at scale			
MARKET FAILURES	Externalities (true costs) not fully reflected in market prices			
	Insufficient public goods / infrastructure ² provided by the market or the state			
	Insufficient competition / markets leading to lower quantity and higher prices than is socially desirable			
	Imperfect information that negatively affects market decisions, such as asymmetric information			
	Split incentives (agency problem) when two parties to a transaction have different goals			
	Transaction costs such as the costs of finding and bargaining with customers or suppliers			
	Inadequately defined legal frameworks that govern areas such as the use of new technologies			
REGULATORY FAILURES	Poorly defined targets and objectives which provide either insufficient or skewed direction to industry			
	Implementation and enforcement failures leading to the effects of regulations being diluted or altered			
	Unintended consequences of existing regulations that hamper circular practices			
	Capabilities and skills lacking either in-house or in the market at reasonable cost			
SOCIAL FACTORS	Custom and habit: ingrained patterns of behaviour by consumers and businesses			

1 At market prices excluding the full pricing of externalities such as greenhouse gas emissions, ecosystem degradation and resource depletion

2 Infrastructure defined as fundamental physical and organisational structures and facilities, such as transportation, communication, water and energy supplies and waste treatment

2 FOOD & BEVERAGE

The Danish food and beverage industry has developed a track record of minimising processing waste and finding productive use for its by-products and remaining waste streams – but mostly in relatively low-value applications. It therefore has a significant opportunity to increase the value extraction from its by-products and waste streams by using cascading bio-refineries. While anaerobic digestion and other basic bio-refining technologies exist today, the technology to derive – in cascaded applications – high-value compounds is still an estimated five years away. If technological development continues and plant capacity is built up, modelling suggest that these cascading bio-refineries could yield, by 2035, a potential net value of EUR 300–500 million annually. In parallel, reducing the levels of avoidable food waste from 80–90 kg/capita to 40–50 kg/capita, enabled through building awareness and capabilities among households and businesses and improving technologies across the value chain, could save Danish households and businesses an estimated EUR 150–250 million annually by 2035.

Operating in a highly competitive international context, the Danish food and beverage industry has developed a track record of minimising processing waste and finding productive use for its by-products and remaining waste streams. However, most of these applications are relatively low-value, such as the production of animal feed or energy extraction. The Danish food and beverage processing industry therefore has a significant opportunity to increase the value extraction from its by-products and waste streams in cascading bio-refineries.

The retail and hospitality sectors and households, on the other hand, generate large quantities of avoidable food waste. Considering that Danish households spent over EUR 23 billion on food and beverages in 2013, or 20% of their total consumption,²⁵ significant value could be captured by reducing avoidable food waste.

2.1 Value capture in cascading bio-refineries

Opportunity:	Develop cascading bio-refineries that capture the full value of by-product and waste streams by extracting several different products.
2035 (2020) economic potential:	EUR 300–500 (50–80) million p.a.
Key barriers:	Capital to build and scale up capacity; technology; unintended consequences of existing regulation.
Sample policy options:	Long-term strategic targets for bio-refineries; support capacity for current technologies and create markets; support technological development.

Home to international players such as Carlsberg, Danish Crown, and Arla, the Danish food and beverage sector is a cornerstone of Danish industry, representing 25% of the total product exports, and 7.7% of the gross value added by the Danish producing sectors.²⁶

The Danish food-processing industry is already a leader in resource productivity, both in terms of minimising waste and valorising by-products:

²⁵ Eurostat, *Final consumption expenditure of households by consumption purpose* (2013).

²⁶ Based on gross value added in 2011, reported by Statistics Denmark. Producing sectors include agriculture, forestry and fishing; mining and quarrying; construction; electricity and gas; manufacturing.

- At Carlsberg, ~95% of brewery by-products are sold as fodder supplements, and the company is currently looking into biogas generation for additional value extraction.
- Danish Crown ‘does not think in terms of waste at all’ according to environmental manager Charlotte Thy. ‘It’s in our DNA to find applications for all our by-products’. Slaughterhouses today have a multitude of ways to valorise all parts of the animal. For example, bones, trotters and excess blood can be sold as animal feed, and even manure left in the intestines is collected and used for biogas generation.
- Arla has used whey, a by-product of cheese making, to produce high-protein products since the 1980s.

Other organic waste, such as wastewater from industries and households, and food waste, is used to extract energy using anaerobic digestion (biogas), combined heat and power, or direct district heating. Denmark had an estimated 1.2 GWh biogas capacity in 2012. The biogas plants treat 3% of Denmark’s organic waste as well as wastewater and manure. Most of the capacity was built before 2000, but in 2012 Denmark adopted a new support model and subsidy scheme for the production and use of biogas. The Danish Energy Agency now estimates that biogas capacity will increase to 2.8 GWh by 2020.²⁷

THE OPPORTUNITY FOR DENMARK

There is still a large opportunity to capture as most of the abovementioned applications extract only a fraction of the value residing in the various organic by-products and waste streams. According to an Aalborg University report, Denmark has a strong position in bioeconomy R&D, but it is insufficiently leveraged since new valorisation technologies have not yet been piloted to the extent required to accelerate them to commercial scale.²⁸

It has been argued for some years that advanced, cascading ‘bio-refineries’²⁹ could unlock this value by deriving valuable products from organic waste and by-products, in many ways emulating the conventional petroleum refinery.³⁰ The core principle is to cascade waste/by-product streams through a series of value-creating steps. The cascade could consecutively produce, for example, high-value biochemicals and nutraceuticals, followed by bulk biochemicals, and still be able to produce biofuels and/or biogas with the remaining biomass. The extraction of nitrogen, phosphorus and potassium (NPK)³¹ and the return of digestate to soils (restoration) ensures that the process also helps preserve natural capital.

To ensure viability of full value capture through a set of cascaded operations, development of the more advanced technologies that extract complementary products from the by-products or waste needs to accelerate. There are many promising examples of this group of technologies developed today. The following are selected examples; see also Notes 129 and 131):

- Use newly engineered enzymes to convert keratin-rich parts such as hairs, bristles or feathers to high-protein feed ingredients.
- Extract proteins and other food ingredients from under-utilised residues from plants (press cake from oil seed, potato peelings, brewers’ spent grain) or ani-

27 Danish Energy Agency, *Biogas i Danmark – status, barrierer og perspektiver* (2014).

28 Lange, L., Remmen, A., Aalborg University, *Bioeconomy scoping analysis* (2014).

29 A bio-refinery can be defined as a plant that is designed to convert an organic feedstock into several value streams by cascading the material through a series of extraction and/or conversion operations. This is not to be confused with pure-play biofuel or combined heat and power plants that also use an organic feedstock.

30 For more details, please see Ellen MacArthur Foundation, *Towards the Circular Economy I* (2012), p.52.

31 For example, the EU-led P-REX project seeks to demonstrate phosphorous recovery from municipal wastewater at scale. www.p-rex.eu

mals (by-catch and side streams from fisheries).

- Extract or synthesise nutraceuticals from pig blood and similar chemically rich by-products.
- Use microbes to synthesise bioplastics from sewage sludge or wastewater, such as in the Danish multi-stakeholder project at special ingredient manufacturer KMC's water treatment plant.³²

Aside from developing the technologies needed, it is challenging to make them all come together in an integrated way, and also make them work in concert with more basic technologies like anaerobic digestion. One of the few plants today operating in line with the definition of an advanced, cascading bio-refinery (see Note 130) is the Borregaard plant in Norway.³³ The plant, which used to make paper and cellulose, now produces a variety of fine chemicals for both food and chemical industries, cellulose-derived materials and biofuels, mostly based on feedstock from the forest industry. While Borregaard is not directly comparable to a bio-refinery based on organic waste, such developments are underway: for example, Veolia has launched a project in collaboration with UK-based Bakkavor Group to transform a wastewater treatment plant in Belgium to a fully cascading bio-refinery that produces pharma-grade chemicals, bioplastics, fertilisers, energy and clean water.³⁴

With the necessary investments in technology and capacity available, Denmark could become a leader in cascading bio-refining:

- By 2020, Danish businesses could have set up the first new bio-refineries to maximise the valorisation of existing waste streams using mature technologies (e.g. enzymatic protein extraction from animal by-products and chemical extraction from wastewater). Continuing extension of biogas and biofuel capacity could serve as platforms for emerging, more advanced technologies. Recognising that such technologies take time to develop at scale, it is estimated that 20% of the organic waste and by-products are available for additional value creation in the short term, and that 60% of the added value would come from extending and improving biofuel and biogas production with 40% provided by extracting bio(chemicals).
- By 2035, Danish businesses could become technology frontrunners in by-product (waste) valorisation in cascading bio-refineries, using by then mature advanced technologies for high-value extraction of biochemicals and nutraceuticals. By this time an estimated 90% of the waste streams could be processed in new applications, and 60% of the total value added could come from extracting bio(chemicals), with 40% coming from producing biofuel and biogas (either directly or by the cascading of material streams from higher-value applications).

By assuming a relatively conservative estimate of additional value extraction from existing waste and by-product streams, the impact assessment suggests that cascading bio-refineries could create an annual value of EUR 300–500 (50–80) million³⁵ in Denmark by 2035 (2020). This estimate builds on the work of The Netherlands Organisation for Applied Scientific Research (TNO), which has mapped the potential value increase of 34 organic waste and by-product streams that could be achieved by up-cycling to higher-

32 State of Green, *Producing more with less. Danish strongholds in bioeconomy & resource-efficient production* (2015).

33 www.borregaard.com

34 Veolia and Bakkavor presentation at The Water Event, 2013. www.thewaterevent.com/files/collaboration_and_partnership_delivering_sustainable_solutions_to_water.pdf

35 This *sector-specific* impact does not include indirect effects, e.g. on supply chains, captured in the economy-wide CGE modelling.

value applications, and estimated that up to 25–30% additional value.³⁶ These estimates have been applied to the Danish context with input from industry experts and Denmark-specific data. The findings give a directional view of the magnitude of this opportunity for Denmark. They rely by necessity on a number of assumptions, the most important of which are detailed in Appendix B.

DENMARK IS WELL POSITIONED TO CAPTURE THE OPPORTUNITY

Denmark would be well positioned to develop and expand to such next-generation cascading bio-refineries. With a large agriculture and food processing industry, it has significant access to feedstock. Denmark has a leading position in biotechnological research and innovation, both in academia and in companies such as Novozymes, Chr. Hansen and Daka. It was pointed out in interviews with academics and industry representatives that the biochemical technologies needed to unlock significantly larger value are only about five years from maturity, but investments are needed to take them from the lab to the market: numerous technologies are also already available, but due to a fragmented market nobody has yet connected the dots to create more integrated bio-refining systems.

There is already a focus on this new 'bioeconomy' in Denmark, and the government has appointed The National Bioeconomy Panel, which consists of experts from academia, industry and public bodies, to evaluate strategic options. In March 2015, the panel published a recommendation to support second-generation biofuel generation by introducing a 2.5% mixing requirement in petrol, and to support the use of yellow biomass³⁷ to produce biochemicals, biomaterials and biofuels through public procurement, increased research funding or other economic support.³⁸ The construction of a second-generation bioethanol plant in Maabjerg (The 'Maabjerg Energy Concept' or MEC plant), projected to come online in January 2016, further illustrates that there is a willingness to invest from both private and public stakeholders.³⁹

While the increased valorisation of existing waste and by-products is the focus of this analysis, there are several other ways to derive additional value in the bioeconomy. As highlighted during an interview by Mads Helleberg Dorff Christiansen from the Danish Agriculture & Food Council, there is large potential to continue the optimisation of input factors, such as crops with higher resilience and yield, improved livestock breeding, elimination of fertiliser leakage, and better feed. Another option is to deliberately modify plants to produce more auxiliary biomass to be used in bio-refineries. According to a study from the University of Copenhagen, it would be possible to produce an additional 10 million tonnes of biomass without significantly altering regular land use or output from agriculture and forestry sectors.⁴⁰ The report claims that products worth between EUR 1.9 and 3.5 billion could be generated from processing this biomass (mainly for fuel), while generating 12,000 to 21,000 new jobs.

BARRIERS AND POTENTIAL POLICY OPTIONS

The following paragraphs provide an initial perspective on the barriers limiting the 'value capture in cascading bio-refineries' opportunity (see Figure 11; also Section 2.2.4 of the toolkit report for the barriers framework). Although there were some variations in emphasis from the sector experts interviewed in the course of this study,

36 The Netherlands Organisation for Applied Research, *Opportunities for a circular economy in the Netherlands* (2013). It was estimated that new valorisation technologies could generate an additional EUR 1 billion annually in the Netherlands, compared to the current value of waste streams of EUR 3.5 billion.

37 Yellow biomass includes straw, haulm and dry crop residues.

38 The National Bioeconomy Panel, *Anbefalingen: Det gule guld – halmressources uudnyttede potentiale* (2015).

39 Adding to the existing 800,000–900,000 tonnes capacity to convert biomass into biogas, the new plant is expected to convert 300,000 tonnes of yellow biomass to 80 million litres of bioethanol. The total investment of -EUR 300 million comes from key industrial stakeholders such as DONG and Novozymes, but also from the EU (EUR 39 million) and Innovation Fund Denmark (EUR 40 million).

40 Gylling, M. et al., Department of Food and Resource Economics, University of Copenhagen, *The + 10 million tonnes study: increasing the sustainable production of biomass for biorefineries* (2013). The potential also includes better collection of biomass from farmland, road verges, waterweed and cover crops.

the central message was clear: the largest barriers preventing an acceleration of next-generation bio-refineries are technology and capital. The full value of organic waste and by-products cannot be extracted unless emerging technologies are supported to reach beyond R&D stage to commercial deployment. This study did not encounter any bio-refineries that use microbial or enzymatic processes to produce bio-based materials such as plastics at industrial scale, indicating that such technology is still at the development stage. Building an efficient bio-refinery operation is also capital intensive. The financing of the MEC plant at EUR 300 million would – if they were to take it on alone – represent 9–12% of the balance sheet of leading companies in the sector. Payback depends partially on the ability to use current technologies (such as bioethanol and biogas) as platforms, and then add to the biochemical cascade more advanced technologies when they become commercially viable. While the revenue streams from the high-value, low-volume products such as nutraceuticals combined with bulk biofuels or other chemicals could ensure profitability, the competitiveness of the products would be increased if the prices of alternatives derived from petro-based resources reflected their true costs (externalities).

Unintended consequences of existing regulations also stand in the way of the bio-refinery opportunity. It is important to keep in mind the complex and internationalised regulatory landscape for the food & beverage sector. Denmark, like other European member states, has only limited control over legislation governing raw material and product handling, as well as waste treatment, which is set at EU level. The most prominent example is the more extensive restrictions on animal by-products being rendered into animal feed, following the breakout of bovine spongiform encephalopathy (BSE) in the 1990s. This animal by-product legislation restricts some animal parts from being used in bio-refining. Several sector experts indicate that sometimes Denmark has chosen to implement this legislation more strictly than its peers.

While parts of the legislation governing food safety and waste treatment may have the unintended consequence of preventing advancement of new bio-refining operations, interviews indicate that in many cases it is more the complexity of the regulatory framework than the restrictions themselves that act as a barrier. The complexity creates uncertainty and imposes the significant administrative costs of understanding how to comply and going through the process of acquiring the required permits. It should therefore be noted that the regulatory situation in the case of each potential bio-refining value-generation opportunity needs to be investigated closely.

To address these barriers, the following policy options could be further investigated. They are the result of an initial assessment of how cost-effectively different policy options might overcome the identified barriers (see Section 2.3.4 in the main report and Appendix D):

- **As a starting point, including bio-refineries in the government's long term strategic plans.** This could guide and reassure investors—even more so if accompanied by a policy package to deliver the strategy.⁴¹
- **In the short term, providing capital to deploy commercial-scale versions of mature bio-refinery technologies.** Promising policies include providing low-cost loans or loan guarantees for the deployment of mature bio-refining technologies for example through existing Danish business support schemes, and financing at market rates that is better tailored to investors' needs (as provided for example by the UK Green Investment Bank in municipal energy efficiency). Public-private

⁴¹ In the G7 Germany, the USA and Japan have specific national bioeconomy strategies with targets. While France, the UK, Italy and Canada do not have a dedicated strategies they provide support for the biobased economy on the ground. Though some of these strategies and other programmes provide specific support to biorefineries, none places cascading bio-refining at their core. For more detail, see German Bioeconomy Council, Bioeconomy Policy: Synopsis and Analysis of Strategies in the G7 (2012).

partnerships to finance the deployment of mature bio-refining technologies also hold promise. An interesting example is the Closed Looped Fund NY that provides zero- or low-interest loans to municipalities or companies, albeit more active in developing recycling infrastructure.⁴²

- **In addition, creating markets** for bio-refinery output. Pricing externalities, setting targets (e.g. a minimum target for second-generation fuels within the EU's biofuels target) could contribute to such market development.
- **In the longer term, stimulating development of advanced, high-value bio-refining technologies.** The government could set up or fund cross-institutional R&D clusters to accelerate the move into high-value chemicals, nutraceuticals, pharmaceuticals etc. These could take on various forms, like the UK Catapults, a powerful example of public private partnerships in R&D, or the German Fraunhofer Institute, which plays an important role in European innovation with its long-term perspective and clearly defined mission to support application oriented research.⁴³
- **Complementing these measures with a business advice service.** The primary goal would be to help bio-refinery entrepreneurs navigate a relatively complex regulatory and policy environment, but it might also help the bio-refinery community shape this environment.
- **Identifying and communicating necessary changes to EU policy** (or its national implementation) to address the unintended consequences of some safety-focused regulations that unnecessarily restrict the trade in bio-refinery feedstock or products.

2.2 Reduction of avoidable food waste

Opportunity:	Reduce avoidable food waste by building awareness and knowledge for consumers, leveraging technology and best practices for businesses, and creating markets for second-tier (refused) food.
2035 (2020) economic potential:	EUR 150-250 (30-40) million p.a.
Key barriers:	Consumer custom and habit; business capabilities and skills; imperfect information; split incentives.
Sample policy options:	Consumer information and education; quantitative food waste targets; capability building; fiscal incentives.

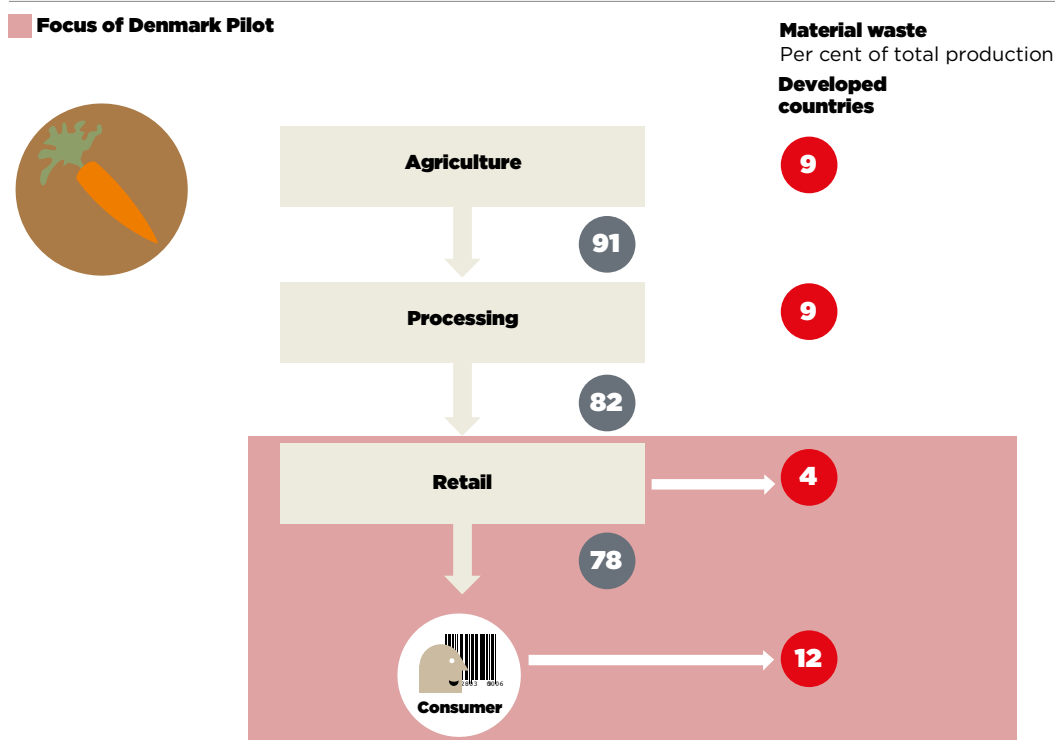
A significant opportunity lies in preventing the very generation of organic waste.⁴⁴ On average, 35% of food output is wasted along the value chain, and while developed economies like Denmark are comparatively good at reducing waste in food processing, there is a high waste volume generated by end consumers (see Figure 12). Denmark generates an estimated 80–90 kg/capita of avoidable food waste per year.⁴⁵

42 www.closedloopfund.com/about/

43 UK Catapults: See e.g. www.catapult.org.uk/; Fraunhofer Institute: See e.g. www.fraunhofer.de/en/publications/fraunhofer-annual-report.html

44 Known as the 'Lansink's ladder', the principle – to avoid waste over reuse, reuse over recycle, recycle over energy recovery, and energy recovery over disposal – has been part of the European Waste Framework Directive since 2008.

45 Danish Environmental Protection Agency, *Kortlægning af dagsrenovation i Danmark – Med fokus på etageboliger og madspild* (2014).

Figure 12: Main sources of food waste in global food value chain – production and consumption

SOURCE: FAO 'Global Food Losses and Food Waste – Extent, causes and prevention', Rome 2011; adapted from Ellen MacArthur Foundation, Towards the circular economy II (2013)

For this reason, the opportunity assessment for avoiding waste in the food and beverage sector focuses on the end-consumer-facing part of the value chain (including retail and hospitality).⁴⁶ The awareness of this issue has increased rapidly over the past five years, and waste minimisation is now an integral part of the government's 'Denmark Without Waste' strategy.⁴⁷ There have already been multiple information and awareness campaigns to reduce food waste among consumers, but much remains to be done.

The Danish EPA has estimated that 56% of the food waste generated by households, and 79% on average in the retail and hospitality sectors, is avoidable.⁴⁸ Danish households generate approximately 55% of the avoidable food waste,⁴⁹ and even if the value lost from discarded food is significant,⁵⁰ customers have a tendency to choose convenient solutions. While businesses have spent a long time minimising food waste, there is still large potential for improvement.

THE OPPORTUNITY FOR DENMARK

Consumers and businesses could save significant value by minimising avoidable food waste. A study by SITRA in Finland found that the savings from reducing food waste would be in the range of EUR 150–200 million annually.⁵¹ Translated to the size of the

46 While Danish food processing companies are generally regarded as proficient in preventing waste, the Danish Environmental Protection Agency notes that there are still losses from agriculture. Waste prevention in the agricultural sector was not however in the scope of the Denmark pilot.

47 Danish Government, *Danmark uden affald II. Strategi for affaldsforebyggelse* (2015).

48 Danish Environmental Protection Agency, *Kortlægning af dagsrenovation i Danmark – Med fokus på etageboliger og madspild* (2014); Danish Environmental Protection Agency, *Kortlægning af madaffald i service-sektoren: Detaljhandel, restauranter og storkøkkener* (2014).

49 Around 25% is generated by the retail sector and around 20% from the hospitality sector, based on data from Note 149.

50 A UK study estimated that the value of unconsumed food and drink amounted to USD 770 per household a year. WRAP, *Waste arising in the supply of food and drink to households* (2011).

51 SITRA, *Assessing the circular economy potential for Finland* (2015).

Danish economy, this corresponds to a prevention of roughly 30–50% (30–40 kg/capita) of total avoidable food waste,⁵² and an estimated saving of EUR 150–250 million annually by 2035.⁵³ These findings give a directional view of the magnitude of this opportunity for Denmark. They rely by necessity on a number of assumptions, the most important of which are detailed in Appendix B. The savings would be achieved by a number of activities, including:

- **Right-sizing the shopping basket.** Consumers could prevent waste by purchasing less unnecessary ‘big packs’ or ‘3 for 2’ deals, which would seem to save money upfront but could create more waste. A related issue is the practice of paying per unit for fresh produce (the current practice in Denmark, as opposed to paying by weight), which incentivises the consumer to buy the largest item – generating waste both on the consumer side (consumers buy a larger item than they need), and further back in the value chain, as smaller items could get deselected or even wasted without being sold⁵⁴. Restaurants could avoid excess purchases by relentless data tracking and planning, which would require investing in capability building but would not necessarily make procurement more time consuming.
- **Better knowledge about food preservation.** Despite not seeing themselves as ‘food wasters’⁵⁵, consumers often throw away useful food, either because they prepare too much for a meal, or because they believe the food is spoiled. Date labelling is required on packaged food to protect consumers, but many people throw away food that has passed the date even though it has been well refrigerated or appropriately stored and remains fresh, due to lack of knowledge of what the labelling actually means. This behaviour also affects food retailers, as they are forced to remove products approaching the ‘best before’ date. The EU has encouraged the discounted sale of such products since 2012 but market acceptance is low. Better knowledge about the preservation of food and when it can be safely used could lead to significant waste volumes being avoided.
- **Leveraging best practices.** A range of methods exists to reduce the significant volume of food waste occurring in the grocery store and along the value chain. Best practices include using data-driven optimisation of ordering and pricing,⁵⁶ and increasing shelf life by improving packaging techniques.⁵⁷ In the hospitality sector, preventing leftover waste could be achieved by using data to optimise the size of servings and avoiding unnecessary volumes on buffets.
- **Smart technology.** ‘Intelligent packaging’, able to transmit information about the food contained within, is a packaging improvement that has been anticipated for some time, and is now beginning to enter the market. In 2012 TetraPak launched a milk carton able to record the time spent at room temperature and change colour when too much exposure has been recorded. While indicators of time and temperature are only a proxy for real identification of changes in the content, packaging manufacturers are increasing by using chemical indicators for oxygen or carbon dioxide levels, as well as microbial activity.⁵⁸

52 In comparison, WRAP has estimated that directed efforts in the UK have reduced consumer food waste by 15–80%. WRAP, *Strategies to achieve economic and environmental gains by reducing food waste* (2015).

53 This sector-specific impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling. By 2020, the savings could amount to EUR 30–40 million annually.

54 Halloran, A. et al., Food Policy 49, *Addressing food waste reduction in Denmark* (2014).

55 Beck C. et al., FDB, Vallengsbæk, *Forbrugere: Vi smider ikke mad ud!* (2011).

56 International retailers like Tesco and CO-OP are already using big data to forecast local demand and adapt replenishment of fresh food. Planet Retail, *The Challenge of Food Waste: Retailers step up to the next level of inventory management* (September 2011).

57 For a more extensive analysis of waste prevention technologies in the food value chain, see Ellen MacArthur Foundation, *Towards the Circular Economy II* (2013). These activities have not been central to the circular economy opportunities assessed for Denmark as they are already advanced and assumed to continue developing even without policy interventions.

58 Swedish National Food Agency, www.livsmedelsverket.se

- **Create markets for second-tier food.** Grocers in developed economies such as Denmark are expected to present produce that is always fresh, plentiful and attractive, when in reality the size and appearance of produce always varies within a production batch. Although it is only a second-tier solution, supporting a market for this food, rather than discarding it, could significantly reduce waste produced along the value chain. In addition, products going off the shelf when they approach their ‘best before’ date could be sold at a discount, donated, or used to produce cheap, ready-made meals.

BARRIERS AND POTENTIAL POLICY OPTIONS

The following paragraphs provide an initial perspective on the barriers limiting the ‘reduction in avoidable food waste’ opportunity (see Figure 8; also see Section 2.2.4 of the toolkit report for the barriers framework). Custom and habit is the largest barrier limiting the reduction of avoidable food waste in Denmark. Interviews with retail store managers confirm that consumers often reject food in stores with shorter use dates if longer dates are available, often reject ‘odd-looking’ produce, and are usually unaware of the level and impact/consequences of the food waste they generate. Food waste experts at the Danish Environmental Protection Agency indicate that a lack of capabilities and skills is also very important; there is insufficient knowledge and experience among the general public about how to buy, store, evaluate the freshness of, and prepare food in such a way that minimise waste and left-overs.

There are also market failures: consumers face imperfect information on the true freshness of food since they are often unaware of the difference between ‘best before’ and ‘use by’ dates and also underestimate the tolerances that producers/retailers put around these dates. There are also split incentives: retailers have an incentive to sell more food and use, for example, ‘3 for 2’ offers on fresh produce. Producers have an incentive to shorten ‘best before’ dates to reduce liability and encourage the consumption or disposal of their product as early as possible to increase turnover. The final market failure is of externalities: if the full environmental cost of agriculture and food production was reflected in food prices, the incentive to reduce waste would increase.⁵⁹ Any potential solution to this barrier would of course need to take into account distributional effects. There is finally the regulatory failure of poorly defined targets and objectives; for example, the ‘Denmark Without Waste’ strategy covers avoidable food waste, but does not contain quantified targets to reduce it.⁶⁰

To address these barriers, the following policy options could be further investigated. These options are the result of an initial assessment of how cost-effectively different policy options might overcome the identified barriers (see Section 2.3.4 of the main report and Appendix D):

- **Informing and educating consumers** using information campaigns on the importance of avoiding food waste; a communication campaign to educate consumers about best-before and use-by labelling; and augmenting the national school curriculum with knowledge about nutrition, food preservation, judging the freshness of food, seasonality, and appropriate ingredient and portion sizing.
- **Creating the right framing conditions to avoid food waste in retail.** This could include adjusting regulations so as not to discourage the donation of food due to liability concerns; encouraging such donations, as was recently voted into law in France or by setting up brokering platforms to facilitate matching donors and beneficiaries, and clarifying the information on best before dates for food and beverages to further facilitate such donations (as has happened in Belgium⁶¹)

59 See for example, Nordic Council, *Initiatives on prevention of food waste in the retail and wholesale trades* (2011).

60 Danish Government, *Denmark Without Waste I. Recycle more – incinerate less* (2013), p.12.

61 Agence fédérale pour la Sécurité de la Chaîne alimentaire, *Circulaire relative aux dispositions applicables aux banques alimentaires et associations caritatives* (2013).

- **Stimulating the capability building through training programmes** to ensure that procurement, retail and kitchen staff possesses the necessary skills and tools to minimize food waste.
- **Introducing fiscal incentives** such as variable charging schemes for household waste. A small number of small- and mid-size Danish municipalities have implemented weight-based charging. Experiences in other countries show that fee-differentiated collection schemes are also feasible in larger cities with more multi-family buildings, and Switzerland has made such schemes mandatory in all municipalities.⁶²
- **Setting national or EU-level quantitative food waste targets.** This would provide overarching guidance to consumers and businesses on the government's objectives, and would likely be a very useful complement to some of the other policies.
- **Influencing other levels of policy-making, such as**
 - Informing and shaping EU marketing standards to avoid food waste arising as an unintended consequence of such regulations.
 - Motivating supermarkets to reduce waste (e.g. shifting more fresh produce sales to weight-based models). League tables at local authority level have proven their value in shifting practices regarding other environmental/social challenges and could work here as long as it does not require sharing confidential data.

3 CONSTRUCTION & REAL ESTATE

Identified as one of the sectors with the highest potential for circular economy at an early stage of the Denmark pilot, there are three main opportunities for the construction and real estate sector to become more circular. Industrialised production processes, modularisation and 3D printing could reduce both building times and structural waste if technology development continues and traditional industry habits are overcome. Reuse and high-quality recycling of building components and materials could reduce the need for new materials and decrease construction and demolition waste, if the split incentives created by a fragmented market are addressed. Sharing, multi-purposing and repurposing of buildings furthermore could reduce the demand for new buildings through better utilisation of existing floor space. Modelling suggests that the annual potential value unlocked by 2035 if these three opportunities are realised could amount to EUR 450–600 million, 100–150 million, and 300–450 million, respectively.

The European construction sector is fragmented, with many small firms, low labour productivity, and limited vertical integration along the value chain – especially in Denmark. There are different incentive structures for different players, and no systematic application of operational best practices, significant material waste and limited reuse of building components and materials.⁶³ In addition, utilisation of existing floor space is low; only 35–40% of office space is utilised during working hours in Europe.⁶⁴ The Danish

62 Ecotec, *Financing and Incentive Schemes for Municipal Waste Management Case Studies – Final Report to Directorate General Environment, European Commission* (2002).

63 Josephson, P.-E. & Saukkoriipi, L., Chalmers University of Technology, *Waste in construction projects: call for a new approach* (2007)

64 Norm Miller, *Workplace Trends in Office Space: Implications for Future Office Demand*, University of San Diego, 2014; GSA Office of Governmentwide Policy, *Workspace Utilization and Allocation Benchmark* (2011); Flexibility.co.uk, *Shrinking the office*.

construction sector has experienced slower productivity growth than leading peers (1% p.a. vs. 2% p.a. for e.g. Belgium and Austria between 1993 and 2007), and is also very fragmented.⁶⁵ The Danish Productivity Commission has pointed out that there is a need to increase productivity, especially in the construction sector, in order to maintain competitiveness.⁶⁶ The Danish government highlighted similar points in their building policy strategy, announced in November 2014.⁶⁷

While none of these issues can be fixed with one silver bullet, the Danish construction and real estate industries could apply a few different approaches that together could transform the built environment:⁶⁸

- Applying **industrial production** processes to reduce waste during construction and renovation, including **modular** construction of building components or, going even one step further, **3D printing** building modules.
- Expanding the **reuse and high-quality recycling of building components and materials** by applying design for disassembly techniques, material passports, innovative business models, and setting up a reverse logistics ecosystem.
- Increasing the utility of existing assets by unleashing the **sharing economy** (peer-to-peer renting, better urban planning), **multi-purposing** buildings such as schools, and **repurposing** buildings through the modular design of interior building components.

There are several other circular economy opportunities that could both unlock value and save resources in the construction sector. They were deprioritised in the present study primarily because in Denmark they are already the way to being realised (as for energy

65 According to Statistics Denmark, there were more than 2,000 enterprises with <50 employees in the construction sector in 2012, and fewer than 200 enterprises with 50+ employees.

66 Danish Productivity Commission, *Slutrapport: Det handler om velstand og velfærd* (2014).

67 Danish Ministry of Climate, Energy and Building, *Towards a stronger construction sector in Denmark* (2014).

68 The opportunity assessment builds on the 'built environment' deep dive in Ellen MacArthur Foundation, Stiftungsfonds für Umweltökonomie und Nachhaltigkeit (SUN) and McKinsey Center for Business and Environment, *Growth Within: A Circular Economy Vision for a Competitive Europe* (2015).

use optimisation), or because the level of detail required for a meaningful analysis was beyond the scope of this study (as for substitution of materials⁶⁹). Below follows a (non-exhaustive) overview:

- **Energy use optimisation.** New buildings could be designed and constructed as low-energy houses that consume up to 90% less energy than existing building stock.⁷⁰ Retrofitting old buildings could reduce their energy consumption by 20–30%.⁷¹ This opportunity has gained high priority in the EU: the European Energy Performance of Buildings Directive (EPBD) requires new buildings to be ‘nearly zero-energy’ by 2020. In Denmark this requirement is implemented through the building class 2020 in the building regulation. The class will be mandatory by 2020 at the latest.⁷² The Danish Energy Agency recently released a tool to calculate the total cost of buildings including their energy use, creating transparency and a clearer incentive for construction companies to build for optimisation of total cost of ownership (TCO) across the whole life cycle, not only construction costs.⁷³
- **Substituting materials,** or facilitated separation of hazardous components. Substituting materials that are difficult to reuse and recycle, or make it difficult to reuse or recycle other materials, with non-toxic, renewable alternatives is an important part of making buildings more circular. Buildings traditionally contain a complex mixture of compounds that are often difficult to separate, making material reuse and recycling difficult. Working to reduce hazardous materials or additives, for example toxic additives in PVC⁷⁴ – or at least making them easier to separate – is therefore crucial to enable better material recovery at a building’s end of use. Furthermore it would improve indoor air quality with improved productivity and health benefits for the users of the building.

3.1 Industrialised production and 3D printing of building modules

Opportunity:	Use industrial manufacturing methods, modularisation and 3D printing to reduce time and cost of construction and renovation.
2035 (2020) economic potential:	EUR 450-600 (40-60) million p.a.
Key barriers:	Inadequately defined legal frameworks; immature technology; custom and habit and capabilities and skills in the industry.
Sample policy options:	Augmented building codes; support for module production facilities; legal framework for 3D printing materials.

69 Countries with high-performing material science or engineering programs may of course choose to draw upon relevant insights around material substitution into its visioning or assessment work.

70 The houses are low energy consumers because they use, for example, natural air circulation, better exposition, and reinforced insulation to reduce energy requirements for space heating or cooling. Note that, from an LCA perspective, so called ‘passive houses’ could be more energy intense than conventional low-energy houses, and that the total embedded energy should be taken into account when optimising the energy use during construction and usage. See for example www.passivehouseacademy.com/index.php/news-blogs/what-is-passive-house; www.ecobuildingpulse.com/awards/ehda-grand-award-volkshouse_o

71 A case that has received much attention is the retrofit of the Empire State Building in New York. The project, guided by the Rocky Mountain Institute, saved the Empire State Building USD 17.3 million and reduced energy consumption by 38%. See www.rmi.org/retrofit_depot_get_connected_true_retrofit_stories##empire

72 Danish Government, *Strategy for energy renovation of buildings: The route to energy-efficient buildings in tomorrow’s Denmark* (2014).

73 Ulrik Andersen, Ingeniøren, *Ny vejledning kan dræbe den faste anlægspris* (14 April 2015).

74 See for example www.vinylplus.eu/; www.naturalstep.org/en/pvc#PVC:_An_Evaluation_using_The_Natural_Step_Framework

THE OPPORTUNITY FOR DENMARK

Almost 75% of the average cost of a new house comes from the construction process.⁷⁵ Importantly from a circular economy perspective, fragmented construction, maintenance and renovation processes – with multiple stakeholders, lack of full project oversight, and use of traditional on-site techniques – also lead to two sizable types of resource inefficiency:

- Large reliance on virgin, finite materials that are assembled manually on-site.
- 10–15% of materials are wasted on-site⁷⁶ (through e.g. over-ordering, inadequate storage, theft and poor coordination between stakeholders).

There is an increasing number of cases to show that industrial, off-site production of modules for on-site assembly, coupled with increased coordination of all stakeholders in the construction value chain, might greatly reduce today's construction waste and speed up the construction process considerably. As an example of this new approach, the Chinese builder Broad Group took only 6.5 months to build a 30-story hotel, of which only 15 days were spent actually erecting the building on-site. This was enabled by building each floor in 16x4 m modules, which were then assembled by ~200 workers. Total savings amounted to 10–30% vs. conventional construction.⁷⁷ Building interiors could also be modularised at high net savings, as shown by Canadian manufacturer DIRTT ('Doing It Right This Time'). DIRTT provides customisable, modular architectural interiors with standardised dimensions, which can be fitted in new buildings or within the envelopes of old buildings.⁷⁸ Players with similar offerings in Europe are Alho, Huf Haus, Baühu, and Caledonian Modular.

A more extreme, but according to many industry experts viable, approach to industrialising and modularising building component manufacturing is 3D printing. Given its exponential technological growth curve over the past years, it is likely that 3D printing of building components will be technically and economically feasible in the near future. Chinese construction company WinSun has demonstrated the revolution 3D printing could bring to the construction sector by building full-size houses made out of only 3D-printed components. WinSun has claimed 80% labour savings and 30–60% material savings.⁷⁹ Obviously, the material choice for 3D printing needs to be managed well to ensure positive environmental impact. WinSun has taken a promising approach by using a mixture of dry cement and construction waste, but it still needs to be verified that the long-term indoor quality of using this mixture can be secured, and that the construction waste does not contain hazardous materials that could leak into the environment. Before 3D printing of entire buildings is feasible at scale, the viability of producing smaller 3D construction modules for interior and exterior use is rapidly increasing. In a similar vein, Danish innovator Eentileen's automated process cuts sustainably sourced plywood based on a digital blueprint and significantly reduces waste and emissions.⁸⁰

By being an early adopter of these new building practices and techniques, Denmark could become a leader in making a step change in construction material productivity:

75 Josephson, P.-E. & Saukkoriipi, L., Chalmers University of Technology, *Waste in construction projects: call for a new approach* (2007).

76 Estimate, compiled from interviews with sector experts.

77 Ellen MacArthur Foundation, Stiftungsfonds für Umweltökonomie und Nachhaltigkeit (SUN) and McKinsey Center for Business and Environment, *Growth Within: A Circular Economy Vision for a Competitive Europe* (2015). See also www.archdaily.com/289496/

78 www.dirtt.net/

79 Ellen MacArthur Foundation, Stiftungsfonds für Umweltökonomie und Nachhaltigkeit (SUN) and McKinsey Center for Business and Environment, *Growth Within: A Circular Economy Vision for a Competitive Europe* (2015). See also www.yhbm.com/index.php?m=content&c=index&a=lists&catid=67

80 eentileen.dk/print

- **By 2020**, the construction sector could have adopted industrialised production processes for up to 5% of new buildings and major renovations, reducing waste and generating up to 10% net material savings. While 3D printing is likely to remain at a conceptual stage, it is reasonable to assume that approximately 2% of new building components could be 3D printed, for which around 25% material and 40% labour savings could be achieved.⁸¹
- **By 2035**, industrialised (non-3D printing) production of modular building components could have taken as much as 50% of the total market, leading to 15% material savings. 3D printing could grow to a sizable share of the market, addressing up to 25% of all building components.

If these opportunities are captured, modelling suggests that industrialised production and 3D printing of modules could create an estimated annual value of EUR 450–600 (40–60) million by 2035 (2020).⁸² These findings give a directional view of the magnitude of this opportunity for Denmark. They rely by necessity on a number of assumptions, the most important of which are detailed in Appendix B.

BARRIERS AND POTENTIAL POLICY OPTIONS

The following paragraphs provide an initial perspective on the barriers limiting the ‘industrialised production and 3D printing of building modules’ opportunity (see Figure 8; also see Section 2.2.4 in the main report for the barriers framework). The critical barriers to unlocking this opportunity lie in the technology and legal framework around 3D printing. As discussed above, while the application of 3D-printing technology in construction has progressed significantly in recent years, it is still at the early commercial stage and would need further development to be economic at large scale, able to compete with more standard methods. The WinSun 3D-printed houses referred to above were completed in spring 2014 (ten individual houses) and in early 2015 (a five-storey house and a villa).⁸³ Equally important is the lack of a strong legal framework to ensure that the technology has a positive impact, both in terms of environmental and technical performance and the health of occupants. According to industry and policy experts, it cannot become a widely trusted approach while it is still open to the use of any material, however non-circular or hazardous to the health of building occupants.

Experts in the industry were also of the opinion that important social barriers exist for both industrial production of modules and 3D printing. Many players in the construction industry are unwilling to change long-established operational practices, such as rigid business models and extensive subcontracting, resulting in fragmented (over-specialised) knowledge and capabilities. While this factor will to some extent be relevant in any industry, consultation with experts indicated that the construction industry is particularly bound by more traditional practices. On the consumer side homebuyers may also be unwilling to trust non-traditional building approaches. The capital intensity of the industrial facilities in which to produce modules would be a challenge for the industry in Denmark, as it is made up by a large number of SMEs.

To address these barriers, the following policy options could be further investigated. These options are the result of an initial assessment of how cost-effectively different policy options might overcome the identified barriers (see Section 2.3.4 of the toolkit report and Appendix D):

- **Complementing building codes with circularity ratings and targets:**
 - Ratings indicating the circularity potential of materials and construction techniques.

81 Estimated by taking half of WinSun’s reported savings, since there is still very little data to exemplify cost savings. Actual savings will vary on a case-by-case basis and be dependent on the size and complexity of components being 3D printed.

82 This *sector-specific* impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling.

83 Michelle Starr in CNET, *World’s first 3D-printed apartment building constructed in China* (20 January 2015).

- Circular economy targets that set minimum requirements using a scoring mechanism. Denmark and the UK have already introduced energy efficiency and carbon ratings. This could be deployed to stimulate circularity, for example with energy standards that incorporate carbon/kWh scores for both the energy embedded in the materials and that used during operations—with recycled materials scoring considerably better than virgin ones.
 - If targets are set, it is important that technology neutrality is maintained and the government is not prescribing the technologies, materials, or techniques to be used. In general, interventions along these lines would be expected to be most effective if introduced gradually, for example with gradually increasing standards as has been the case for energy efficiency within the Danish building regulations. In addition, these interventions would likely have impact across the three circular economy opportunities in the sector.
- **Supporting module production facilities.** The government might choose to play a role in motivating the financial industry to move into this area as such production facilities can yield good returns. If this is not an option or does not yield results at the desired scale or speed, low-cost government loans could also start addressing the access to capital barrier. If concessionary financing is undesirable, government agencies might provide loans at market rates that have been designed to meet the complex financing needs of nascent industries. For example, the UK Green Investment Bank has recently developed innovative loan products that are tailored to the specific needs of companies and local authorities wishing to make investment in energy efficiency improvements, which is a similarly immature market.
- **Creating legal framework for 3D printing materials.** Regulating input materials for 3D printing is necessary to realise the full potential of the technology. The timing is right to work on this, as the 3D printing industry is still young and supply chains are not yet mature and locked in. Given its complexity, developing this internationally—at the EU level or beyond—would make most sense. Along with material policies there is also a need for safety, quality, and environmental standards for the processes and technologies themselves.
- **Bringing together all stakeholders** in the construction value chain to work on systemic solutions to address the lack of skills and established norms that stand in the way of industrialising production. This could take the form of an industry-wide partnership focused on knowledge sharing and collaboration, a project with specific short-term objectives, or a private public partnership.
- **Supporting R&D.** Funding programmes to develop and bring to commercial scale new techniques in the 3D printing of building components and explore technological synergies between component printing and the on-going digitisation of construction. A technology challenge prize (as for example promoted by Nesta in the UK⁸⁴) could also be considered.
- **Launching public procurement pilots.** Such pilots could serve a triple purpose: demonstrate the viability and benefits of existing circular materials and construction techniques, stimulate the development of new materials and techniques (design competitions offer an alternative), and develop the necessary guidance and procedures for procurement teams to be able to accommodate such new or unfamiliar elements (e.g. adjustments to the typical pre-construction dialogues).
- **Funding for industry training programmes** tailored to the various actors along the construction value chain (architects, engineers, entrepreneurs, construction workers, etc.) covering off-site production and on-site assembly of components as well as 3D printing techniques.

3.2 Reuse and high-value recycling of components and materials

Opportunity:	Tighter ‘looping’ of building components through either reuse or high-quality recycling, enabled by, e.g. design for disassembly and new business models.
2035 (2020) economic potential:	EUR 100-150 (10-12) million p.a.
Key barriers:	Split incentives and lack of information across the construction value chain; custom and habit; capabilities and skills.
Sample policy options:	Augmented building codes; industry-wide training programmes; support for material inventory software.

THE OPPORTUNITY FOR DENMARK

As in other Danish industrial sectors, the construction industry has achieved very high industrial recycling rates, especially of valuable materials such as steel and other metals. The overall recycling rate is 87%, but like in most markets the reuse of building components (such as wall or floor segments) and lower-value materials (such as bricks) is very limited. Three characteristics of the construction sector could help explain this situation:

- Strong safety concerns and a tightly regulated sector, leading to uncertainties about both performance and health issues of reused or recycled materials and components.
- A fragmented value chain, with different incentives for initial investors, architects/engineers, (sub)contractors, owners and tenants, leading to limited uptake of circular design. The fragmentation also makes it hard for new practices to gain traction, such as deconstruction rather than demolition, which would salvage more useful components and materials for reuse and high-value recycling.
- Long-lived construction objects, meaning that those facing demolition or renovation today were not designed with reuse of materials or components in mind.

Fortunately, there are a number of innovative design and operations examples on how to enable increased looping of components:

- **Design for disassembly and reuse of components and materials.** The ‘tightest’ loop for building components would be to design for non-destructive disassembly and full reuse of building components in new projects.⁸⁵ Although not a new idea – the British Pavilion in the 1992 Seville Expo being one example⁸⁶ – there are still few buildings designed for disassembly (and reuse). Turntoo, the Dutch company founded by architect Thomas Rau, has led the work of retrofitting the Brummen Town Hall in the Netherlands, where the architects worked together with the material suppliers to establish performance contracts where the suppliers retained ownership of the materials.⁸⁷ The renovated town hall, completed in 2013, is designed for disassembly and has an attached materials passport to fully track the building’s material assets. In the same vein, the

85 Claire, Subr:im Bulletin 05, *Avoiding Future Brownfield Sites through Design for Deconstruction and the Reuse of Building Components* (November 2007).

86 www.steelconstruction.info/Recycling_and_reuse#What_is_recycling_and_reuse.3F

87 turntoo.com/en/projecten/town-hall-brummen/

C2C-designed Park 20/20 office complex, developed in the Netherlands by Delta Development, is being built for disassembly and incorporates asset tracking for future reuse.⁸⁸ Design for disassembly could also include design regular review and upgrade, which would enable the use of some materials with a lower environmental footprint, e.g. glulam beams as load-bearing construction elements.

- **Use of recycled materials.** Even though few buildings today have been constructed with deconstruction and reuse in mind, it is possible to recover significant quantities construction materials and use them for new buildings. The US EPA's buildings One and Two Potomac Yard in Arlington, VA, were built using 27% recycled content – including slag concrete aggregate, fly ash, and gypsum wallboard.⁸⁹ Examples of companies including recycled industrial materials in their products are insulation manufacturer Rockwool⁹⁰ as well as DIRT⁹¹ (see above). A relevant case example from Denmark is the 'Upcycle house', built using processed recycled materials and reducing the overall CO₂ emissions by 86% compared to the building of a benchmark house.⁹² As the reuse of components and recycling of materials proliferates and a new reverse cycle ecosystem emerges, a market will emerge for material 'brokers' connecting suppliers with buyers, as with the Scottish Material Brokeage Service.⁹³ There are two challenges to be overcome when reusing/recycling materials from existing buildings: the challenge of hazardous chemicals (including those no longer permitted in building materials today); and the technical performance of components/materials not designed for reuse/recycling.⁹⁴
- **New business models.** The examples above introduce the concept of performance contracts in the real estate sector: the property owner does not necessarily own all materials and systems in the building and might instead buy utility (e.g. lux-hours instead of light fixtures).
- **Deconstruction.** In Japan, Taisei Corporation has demonstrated that deconstruction is possible even for tall buildings such as The Grand Prince Hotel Akasaka. A Taisei-developed approach deconstructed the 141-meter building from the top down, reducing carbon emissions of the deconstruction process by 85%.⁹⁵

Employing these best practices in the construction and real estate sector, Denmark could increasingly use recovered building components and materials in more valuable cycles than downgrading recycling. Examples of value retention already exist; Skive municipality runs a project to improve the reuse of old construction components by incorporating new targets in the municipality's 2015–24 waste management strategy and creating an environment for new business models centred on material looping,⁹⁶ and The Fund for Green Business Development has funded a partnership where innovative public procurement is used to increase the reuse of building components and materials

88 See www.park2020.com/; urbanland.uli.org/sustainability/park-2020-amsterdam-born-recycled/. The office park is expected to be completed by 2017.

89 US Environmental Protection Agency, *Using Recycled Industrial Materials in Buildings* (2008).

90 sustainability.rockwool.com/environment/recycling/

91 www.dirtt.net/leed/_docs/DIRTT-MaterialsAndProduction_v1-2.pdf. DIRT⁹¹ pledges to add more recycled content into their materials every year.

92 The Upcycle House was built in collaboration between Realdania Byg and Lendager Architects. www.archdaily.com/458245/upcycle-house-lendager-arkitekter/

93 The Scottish Material Brokerage Service began operating in January 2015. Its aims are twofold: (i) to deliver collaborative contracts for waste and recyclable materials from Scottish local authorities and other public bodies of sufficient scale to help them achieve better value for money, and reduce risk from price volatility; (ii) to create the business conditions for investment in domestic reprocessing by providing certainty in the volume and duration of supply of valuable materials. See www.zerowastescotland.org.uk/brokerage

94 These challenges are currently investigated under the Danish Government's strategy for construction. Danish Ministry of Climate, Energy and Building, *Towards a stronger construction sector in Denmark* (2014).

95 See for example www.wired.co.uk/news/archive/2013-01/15/japan-eco-demolition; www.taisei.co.jp/english/csr/hinsitu/jirei_hinsitu.html. No information was found on the potential for reuse of the deconstructed building components.

96 Skive municipality, *Afslutningsrapport Projekt Genbyg Skive* (2015).

in new public building projects.⁹⁷ In addition, the Danish Eco-Innovation Program funds a number of projects around, among others, using more reusable and recyclable materials in buildings.⁹⁸

Designing for disassembly could be enabled by better coordination and alignment of incentives across the value chain. Digital material passports (already introduced in Denmark by Maersk as described in Chapter 1) and leasing could become the new norm, driven by a change in business models and emergence of material brokers who link material supply and demand in the reverse supply chain. By 2035 (2020), looping of materials could be increased to 15% (5%) by weight, resulting in 30% material cost savings (adding 5% additional labour cost). At this adoption rate, modelling suggests the construction sector could save EUR 100–150 (10–12) million annually.⁹⁹ These findings give a directional view of the magnitude of this opportunity for Denmark. They rely by necessity on a number of assumptions, the most important of which are detailed in Appendix B.

BARRIERS AND POTENTIAL POLICY OPTIONS

The following paragraphs provide an initial perspective on the barriers limiting the ‘re-use and high-value recycling of components and materials’ opportunity (see Figure 8; also see Section 2.2.4 in the toolkit report for the barriers framework). A wide range of barriers prevent increasing rates of component and material reuse in the construction sector. Chief among them is the structure of the industry itself, which leads to split incentives along the value chain. There is limited vertical integration and each player – including the investor, architect, developer, engineer, (sub)contractor, owner and tenant – naturally maximizes their own profits at the expense of the others. Since designing for circularity requires some alignment of incentives to close the loop in the value chain, not having such incentives makes the economic case for reuse difficult to make. The fragmentation of the industry also leads to the barriers of transaction costs and imperfect information: the flow of information and resources necessary to provide a system of design for disassembly and reverse logistics is difficult to achieve. Digital information on the materials used in component production that would be very helpful at the point of refurbishment or demolition is lacking or unevenly distributed: while Building Information Modelling approaches are developing, they are not yet in widespread use.¹⁰⁰

While buildings can already be designed for disassembly, additional technological progress in the production of circular, separable materials and components could accelerate the concept’s applicability. Acceptance of such technological advances in the industry could be aided by demonstration that new materials/components meet required technical specifications and are as practical to work with as those that they replace. It would also be helpful if the true environmental costs of using virgin, finite materials were reflected in their market prices. Finally there are inertia factors – pointed out by a range of industry experts – in the construction industry in the form of customs and habits and a lack of the requisite capabilities and skills that make reuse difficult to implement.

To address these barriers, the following policy options could be further investigated. These options are the result of an initial assessment of how cost-effectively different policy options might overcome the identified barriers (see Section 2.3.4 in the toolkit report and Appendix D):

- **Complementing building codes with ratings and targets** as laid out in Section 3.1.

97 groenomstilling.erhvervsstyrelsen.dk/cases/962460

98 ecoinnovation.dk/mudp-indsats-og-tilskud/miljoetemaer-udfordringer-og-teknologiske-muligheder/%C3%B8kologisk-og-baeredygtigt-byggeri/tilskudsprojekter/

99 This *sector-specific* impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling.

100 UK Government, Building Information Modelling (2012).

- **Funding industry-wide training programmes** how to develop loops in construction, such as minimising and sorting construction waste targeting actors along the entire value chain (i.e. everybody from architects to sub-contractors working on the ground).
- **Supporting the creation of material inventory software** to keep track of the materials used in construction, maintenance, and renovation projects from start to finish and provide information on their lifetime impacts and opportunities for looping. Such support could come in the form of a publicly funded design competition.
- **Creating a ‘positive materials list’.** A comprehensive database of construction materials that are favourable for circular design could help inform, educate, and inspire developers, architects, and clients alike. The initiative could define the criteria a material has to meet to get on the list and create an initial set of materials. It could also be expanded with commercially available branded products – it would require the initiative to define a simple application process through which companies can submit their products, and set up a review board. Such a list could then be taken over at the EU level, so as to inform other member states and create more consistency for companies in the industry.
- **Adjusting public procurement practices.** This would allow for more public construction projects with higher resource efficiency by encouraging technological standards that facilitate later repair, remanufacturing, or reuse (e.g. in lighting or heating, ventilation and air conditioning); use of recycled or reused materials and components; procurement of decommissioning services that focus on value preservation; or mandating the inclusion of performance models or Total Cost of Ownership (TCO) metrics. As a first step, an advisory mechanism on circular public procurement practices could be set up. This could be complemented with training programmes for public procurement teams. At a later stage the actual procurement rules themselves might be adjusted.

3.3 Sharing and multi-purposing of buildings

Opportunity:	Increase utility of existing buildings through sharing, multi-purposing and repurposing.
2035 (2020) economic potential:	EUR 300-450 (100-140) million p.a.
Key barriers:	Inadequately defined legal frameworks; unintended consequences of existing regulations.
Sample policy options:	Clarifying the legislation; financial incentives or support; municipal access portals.

THE OPPORTUNITY FOR DENMARK

There is an increasing awareness that most buildings are under-utilised – 60–65% of European office space is under-utilised even during working hours. Similarly, roughly half of owner-occupied homes are ‘under-occupied’, with at least two bedrooms more than needed.¹⁰¹ These figures suggest a massive structural waste that could be reduced by increasing the ‘utility’ of the floor space.

Airbnb has done just that. Launching its peer-to-peer platform for housing space in 2008, Airbnb’s booking rates has grown by 80–90% in the last few years and is

¹⁰¹ No data available for Denmark; UK survey taken as proxy. UK Department for Communities and Local Governments, *English Housing study. Headline report 2012–13* (2014).

expected to overtake worldwide hotel listings in four to five years.¹⁰² In May 2015, Airbnb had approximately 15,000 listings in Denmark. Meanwhile, a number of not-for-profit communities for sharing living space are growing rapidly, such as Hoffice¹⁰³ and Couchsurfing.¹⁰⁴

In a time of rapid digitisation, it is not difficult to imagine a more virtualised and shared office environment. Since office spaces are already under-utilised, business could rethink the role of the office as central but temporary place for colleagues to meet while spending a significant share of their time working remotely. This would entail increased desk sharing and reduced need for floor space. Another option is to temporarily rent out unused space, an idea Liquidspace capitalises on by connecting people in need of desks or conference rooms with nearby suppliers, much like an Airbnb for office space.¹⁰⁵

Businesses are very aware of the potential cost savings from reducing office space. In a 2012 survey, over 70% of 500 corporate executives indicated that the gross square foot per person in their organisations would drop to a point that is more than 55% below the current industry average.¹⁰⁶ Two major technology companies, IBM and Cisco, have gradually increased the staff-to-desk ratio by encouraging teleworking, saving EUR 100–250 million a year.¹⁰⁷ A Scandinavian example is Microsoft Sweden, who reduced their office space by 27%, while still adding 1,500 additional seats.¹⁰⁸

Increased repurposing of existing floor space would make it possible to better utilise old buildings and change the use of freed-up office space to, e.g. residential housing, in a cost-efficient way and reduce the need for demolition and renovation. This is particularly relevant since ~80% of Europeans live in buildings that are at least 30 years old, which risk slipping into costly obsolescence as changing lifestyles and shifting demographics and age distribution drive construction of new buildings.¹⁰⁹ The repurposing concept of companies like DIRT – with interior building components that are modular and standardised – allows for maximum efficiency in changing the use of a building.

Complementary to repurposing, which changes the *sequential* use of a building, public buildings could be multi-purposed for *parallel* use of the floor space, meaning that different activities can take place during a short and repetitive time cycle. Making better use of schools or libraries for evening activities (e.g. classes and cultural events) is probably the most accessible example – such multi-purposing is indeed extensively implemented in Denmark. A more advanced practice would be to design more multi-purposed buildings. This is already common practice for sports, cultural and conference venues, but could in principle be implemented for smaller buildings as well. Public spaces could be designed for both multi-purpose use *and* gradual repurposing to optimise their economic value; an interesting example is the Boston Convention & Exhibition Center whose parking structure has been designed to be gradually transformed into retail and residential space.¹¹⁰ So could office spaces; an example is the Park 20/20 mentioned in Section 3.3.2, designed with shared and multi-purposed spaces for meetings, videoconference and other functions.

By 2035, Danish companies could be expected to reduce their need for office space due to shared desk policies and increased teleworking, which together with multi-purposing

102 www.airbnb.com; www.venturebeat.com

103 www.bloomberg.com/news/articles/2015-02-19/hoffice-co-working-puts-freelancers-in-each-other-s-homes; hoffice.nu/en/. The concept can be seen as a hybrid in floor-space sharing, where higher utilisation of living space leads to a reduced demand for office space.

104 www.couchsurfing.com/.

105 liquidspace.com/. Liquidspace has also partnered with Marriott to provide conference rooms and other functions, thereby increasing traffic to the hotels.

106 Cushman & Wakefield, *Office space across the world* (2013).

107 GSA Office of Government-wide Policy, *Workspace utilisation and allocation benchmark* (2011).

108 vasakronan.se/artikel/det-digitala-arbetslivet-ar-har

109 architecturemps.com/seville

110 Franconi, E. & Bridgeland, B. Rocky Mountain Institute, presentation at Re:Thinking progress conference, *Circular Business Opportunities for the Built Environment* (14 April 2015).

of public buildings, repurposing of old buildings and freed-up office space, and the accelerating sharing of residential floor space could increase the overall utilisation of buildings by 60% (20%) by 2035 (2020). This could lead to a reduced demand for new buildings by 9–10% (3–4%) by 2035 (2020), saving the Danish economy an estimated EUR 300–400 (100–140) million.¹¹¹ These findings give a directional view of the magnitude of this opportunity for Denmark. They rely by necessity on a number of assumptions, the most important of which are detailed in Appendix B.

BARRIERS AND POTENTIAL POLICY OPTIONS

The following paragraphs provide an initial perspective on the barriers limiting the ‘sharing and multi-purposing of buildings’ opportunity (see Figure 8; see also Section 2.2.4 of the toolkit report for the barriers framework). The principal barriers to increasing the sharing and multi-purposing of buildings are regulatory. There are the inadequately defined legal frameworks, as well as unintended consequences of existing regulations, for example:

- Contractual restrictions on tenants/owners to their sub-letting of houses or flats for short periods; for example in New York State it is illegal to rent out an apartment for a period shorter than 30 days if a permanent resident of the apartment is not present.¹¹²
- Uncertain compliance with other regulations; for example in Chicago, Airbnb has begun to collect city hotel taxes from its hosts, but hotel associations still claim they are not paying all taxes that hotels are obliged to pay.¹¹³
- When sharing is allowed it might be under-regulated; there is for example concern in Los Angeles that Airbnb is starting to turn residential areas into ‘hotel areas’, potentially competing with local residents for accommodation.¹¹⁴

Denmark has partially addressed the lack of clear legal frameworks – it is currently possible to sub-let apartments on Airbnb or similar sites for six weeks per year before asking the local municipality for a permit. There are however several uncertainties to address; a sector expert notes that the housing and office rental sector is highly regulated, but that this existing legislation has not yet been fully adapted to account for the concepts of sharing.

When it comes to market failures it is often not cost effective for building owners and tenants to spend the time finding other individuals or organisations with which to share their buildings. Factors exacerbating these transaction costs are the efforts and costs involved in changing building insurance, handling security issues and the need for changes to the building (e.g. locks). Furthermore, while some sharing platforms have been successful, there might still be an inherent resistance in the public to changing habits around the sharing of their own homes, and some businesses have deeply rooted norms and traditions around the use of offices. Recent research¹¹⁵ has confirmed the results of a study made by The Industrial Society’s research from 2002¹¹⁶: that there are limits to the attractiveness of shared office space to employees and that individual space such as a desk or a workstation is still highly valued.

To address these barriers, the following policy options could be further investigated. These options are the result of an initial assessment of how cost-effectively different

111 This *sector-specific* impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling.

112 James Surowiecki in *The New Yorker*, *Airbnb’s New York Problem* (8 October 2013).

113 Crain’s Chicago Business, *Hotels to Airbnb hosts: Pay up* (14 February 2015).

114 LA Times, *Airbnb and other short-term rentals worsen housing shortage, critics say* (11 March 2015).

115 Naomi Shragai, Financial Times, *Why building psychological walls has become a key skill at work*, (29 April 2015).

116 The Industrial Society, *The state of the office: The politics and geography of working space* (2002).

policy options might overcome the identified barriers (see Section 2.3.4 in the toolkit report and Appendix D):

- **Clarifying the legislation** governing (participants in) sub-letting residential and office space, and sharing business platforms (like Airbnb and Liquidspace) by defining unambiguously who is entitled to practice it (private tenants, commercial players) and which regulation they need to follow. Doing so could lower the risks perceived by individuals and companies wanting to engage in such transactions.
- **Creating financial incentives or financial support** to local, regional and national public-sector entities such as schools and other public infrastructure could help overcome hesitance towards renting out their properties when not in use (without distorting competition), and possibly remove some practical barriers such as locks that need to be added or changed. This could also have demonstration effects for private owners, facility managers in industrial and commercial real estate, and landlords.
- **Setting up municipal access portals** that provide information on public building availability and matches users with providers. This could start out with public buildings; private spaces could be added later, for instance in case a territory is too small or not sufficiently densely populated to warrant a commercial intermediary.

4 MACHINERY

The potential for Danish businesses to engage in remanufacturing and refurbishment is significant. Since this opportunity requires the development of new capabilities, business models and technologies, capturing it could take time, but by 2035, modelling suggests these practices could create an estimated potential net value of EUR 150–250 million annually.

Opportunity:	Remanufacturing of components and new business models based on performance contracts and reverse logistics.
2035 (2020) economic potential:	EUR 150–200 (50–100) million p.a. (plus additional potential in adjacent sectors).
Key barriers:	Lack of capabilities and skills; imperfect information of existing opportunities; unintended consequences of existing regulations
Sample policy options:	Remanufacturing pilots and information campaigns; amendment of existing regulatory frameworks; adoption of an overarching government strategy.

The Danish machinery sector is characterised by the presence of several large manufacturers of long-lived industrial products, such as Grundfos (pumps), Vestas (wind turbines), and Danfoss (thermostats, heating and power solutions) and >1,000 parts manufacturers and service providers supporting these industries.¹¹⁷ Across the board, these companies have adopted the most common efficiency measures, such as waste reduction in production processes, light-weighting components and products, and waste reduction and energy efficiency in production processes.

Danish machine manufacturers are also proficient in recycling and are increasingly looking into designing for recyclability. Grundfos, for example, notes that around 90% of the components inside pumps are recyclable. In the wind turbine industry, almost all parts are recycled. The last remaining challenge is the rotor blades, which consist of epoxy-covered composites. A number of possible uses for old blades are currently being pursued, guided for example by the Genvind project.¹¹⁸

By contrast, discussions with sector experts revealed that there is only a limited number of remanufacturing or refurbishment activities. Remanufacturing and refurbishment (Box 1) leads to higher value retention than materials recycling since a large part of the added value of a product or component is maintained, and more steps along the value chain are bypassed (c.f. Figure E1). Danish companies could thus exploit the largely untapped potential in remanufacturing and refurbishment. In parallel, recycling and efficiency optimisation is likely to continue to improve in the sector, as part of the trajectory Denmark is already on.

¹¹⁷ According to Statistics Denmark, there were 26 companies with 250-plus employees in the machinery sector in 2012, and just over 1,000 with fewer than 250 employees, of which half had 0–9 employees.

¹¹⁸ www.genvind.net

Box 1: Remanufacturing and refurbishment¹¹⁹

Component remanufacturing is defined as a process of disassembly and recovery at the subassembly or component level. Functioning, reusable parts are taken out of a used product and rebuilt into another. This process includes quality assurance and potential enhancements or changes to the components. By definition, the performance of the remanufactured component is equal to or better than ‘as new’.¹²⁰

Product refurbishment involves returning a product to good working condition by replacing or repairing major components that are faulty or close to failure – and making ‘cosmetic changes’ to update the appearance of a product. The replacement components could themselves be remanufactured. Any subsequent warranty is generally less than issued for a new or remanufactured product, but the warranty is likely to cover the whole product. Accordingly, the performance may be less than ‘as new’.

REMANUFACTURING IS ALREADY A VIABLE BUSINESS CASE

There are numerous examples to show that there is a strong business case for remanufacturing. The consultancy Lavery-Pennell has calculated that for a case with remanufactured items selling for 20% less than new items, and increased labour costs for the remanufacturing process, the gross profit could still be up to 50% higher due to the large reduction in input costs, and that the earnings could be even higher with a performance-based business model.¹²¹ Indeed, several large companies have already run successful remanufacturing operations for quite some time:

- Renault’s remanufacturing plant in Choisy-le-Roi, France, re-engineers different mechanical sub-assemblies, from water pumps to engines, to be sold at 50% to 70% of their original price with a one-year warranty. The remanufacturing operation generates revenues of USD 270 million annually. Renault also redesigns components (such as gearboxes) to increase the reuse ratio and make sorting easier by standardising components. While more labour is required for remanufacturing than making new parts, there is still a net profit because no capital expenses are required for machinery, and much less cutting and machining to remanufacture the components, resulting in waste minimisation and a better materials yield. Renault has achieved reductions of 80% for energy, 88% for water and 77% for waste from remanufacturing rather than making new components.¹²²
- Caterpillar founded its CatReman business line in 1973. It now has global operations with over 4,200 employees, and fully remanufactures a large range of heavy-duty equipment to as-new state, including long-term warranties. Caterpillar has reported that remanufactured components reduce resource consumption by 60–85%.¹²³
- Ricoh’s ‘comet circle’ is a well-known and established business model, including remanufacturing and refurbishment of components, and recycling of materials.¹²⁴

119 For more details, see for example Ellen MacArthur Foundation, *Towards the circular economy I* (2012).

120 Nasr, N., Rochester Institute of Technology, presentation at Re:Thinking progress conference, *Circular Economy and Remanufacturing* (14 April 2015).

121 Lavery, G., Pennell, N., Brown, S., Evans, S., *The Next Manufacturing Revolution: Non-Labour Resource Productivity and its Potential for UK Manufacturing* (2013).

122 Ellen MacArthur Foundation, *The Circular Economy Applied to the Automotive Industry* (2013); group.renault.com/en/commitments/environment/competitive-circular-economy/

123 Caterpillar Sustainability Report (2006).

124 <https://www.ricoh.com/environment/management/concept.html>

As ~70% of components in a printer or copier can be remanufactured,¹²⁵ these products are well placed to be provided on an access-based contract. Ricoh already sells 60% of their products through service contracts, and remanufacturing is an important lever to reach its ambitious target of reducing resource consumption by 2050 to 12.5% of the 2000 levels.

Remanufacturing and refurbishment have been predicted to have a net positive effect on GDP and employment, as well as boosting innovation.¹²⁶ The UK All-Party Parliamentary Sustainable Resource Group has reported that remanufacturing could contribute GBP 2.4 billion to the UK economy and create thousands of skilled jobs.¹²⁷ Zero Waste Scotland estimates that increased remanufacturing alone could add 0.1–0.4% to Scotland's GDP and provide up to 5,700 new jobs by 2020.¹²⁸ However, remanufacturing does pose a significant challenge to product design and is especially difficult for manufacturers of long-lived products and/or in industries where the largest efficiency gains are still driven by hardware improvements. Manufacturers often design for optimised in-use efficiency rather than designing for remanufacturing.¹²⁹ Products from companies like Grundfos and Vestas have anticipated lifetimes of 20 years or more, during which time hardware technology can improve significantly. Few would want to remanufacture equipment put on the market 20 years ago, as performance of the hardware has increased manifold since then, and in the case of wind turbines the size has increased significantly. Another consideration is that the content of hazardous substances that have been phased out in new products could make a component or product unwanted for remanufacturing.

But even when the hardware development is still significant, remanufactured or refurbished equipment could be sold to secondary markets. There is already a growing market for used and refurbished wind turbines,¹³⁰ and pump manufacturer KSB is looking at selling refurbished products to secondary markets. As hardware technology matures and efficiency improvements become increasingly driven by software it will become increasingly viable to integrate remanufactured components into the next generation of products. An industry expert notes that efforts to increase pump efficiency are likely to shift gradually towards software upgrades over the next five years.

THE OPPORTUNITY FOR DENMARK

In brief, this analysis suggests a large potential for Danish businesses. Even if not all machinery components are addressable for remanufacturing or refurbishment today, applying these practices to a selection of durable components becomes increasingly feasible but requires adaptations in the business model, product design, and the reverse supply chain. Done right, remanufacturing or refurbishment could unlock significant value.

As described in Section 2.2.1 in the toolkit report there are four principal building blocks that a business can adopt to pursue a circular economy opportunity: product design (and technology), business models, reverse cycle skills, and cross-sectoral collaborations.¹³¹ Figure 13 summarises the main transitions in the first three dimensions to enable remanufacturing for liquid pumps, a hallmark product in the Danish machinery

125 N. Nasr, Rochester Institute of Technology, *Circular Economy and Remanufacturing*, presentation at Re:Thinking progress conference (14 April 2015).

126 See Ellen MacArthur Foundation, *Towards the Circular Economy I–III*.

127 All-Party Parliamentary Sustainable Resource Group, *Remanufacturing. Towards a resource efficient economy* (2015).

128 Zero Waste Scotland, *Circular Economy Evidence Building Programme: Remanufacturing study* (2015).




129 It could indeed be more rational to design primarily to increase in-use energy efficiency. At the same time, a life cycle assessment report by PE International on a Vestas V112 3.0 MW turbine showed that the major life-cycle impact comes from the manufacturing stage, indicating significant potential to capture value through remanufacturing. PE International, *Life Cycle Assessment of Electricity Production from a V112 Turbine Wind Plant* (2011).

130 See for example hitwind.com/; www.windforprosperity.com/

131 Ellen MacArthur Foundation *Towards a Circular Economy I* (2012); p.61. Note that the need for cross-sectoral collaborations, such as a focus on the circular economy in education and R&D, and wider acceptance for alternative ownership models, is also highly relevant to capture the remanufacturing opportunity.

sector. In the same vein as reverse logistics for remanufacturing, Grundfos is currently piloting a take-back program for circulator pumps in Denmark, in order to support the recyclability of components and materials. For wind turbines, it was pointed out by a sector expert that there are typically over 2,000 parts that are already fairly standardised, not subject to steep performance improvements and need replacement before the end-of-use of the turbine itself; there are thus interesting opportunities to shape both business model and product for gradually replacing and remanufacturing such components.

Figure 13: Examples of what remanufacturing and new business models could look like for pumps in Denmark

	FROM		TO
PRODUCT DESIGN (AND TECHNOLOGY)	<ul style="list-style-type: none"> • Design focused on performance in one lifecycle • Most product improvements through hardware upgrades 		<ul style="list-style-type: none"> • Standardised and modular design to simplify disassembly, remanufacturing and lifetime extension • Most product improvements through software upgrades
BUSINESS MODEL	<ul style="list-style-type: none"> • Traditional product sales with service warranties 		<ul style="list-style-type: none"> • More focus on complete solutions including system optimisation¹ • Sales of ‘pumping as a service’ with repair and product upgrade scheme included • Manufacturer ownership retention drive increased efficiency improvement during lifecycle
REVERSE CYCLE SKILLS	<ul style="list-style-type: none"> • Difficulty to return dispersed products • Lack of remanufacturing skills and facilities 		<ul style="list-style-type: none"> • Third-party installers incentivised to return old products for commission • Large-scale remanufacturing facilities with high degree of automation

¹ As for example in Grundfos collaboration with Heerlev University Hospital water-cleaning facility, <http://www.theguardian.com/sustainable-business/grundfos-partner-zone/2014/nov/11/new-water-treatment-technology-reduces-risks-from-hospital-wastewater>

SOURCE: Industry expert interviews; Ellen MacArthur Foundation

There are two categories of remanufacturing opportunities for Danish companies.


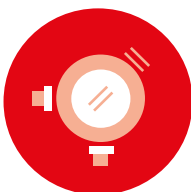
- **Remanufacture or refurbish components or whole products and sell to secondary markets.** This could be a developing market but might also be a local secondary market. Remanufactured equipment could become new product line, as in the case of CatReman.
- **Remanufacture components and use them in new products.** Since remanufacturing by definition restores a component to an ‘as new’ condition, it would be viable to use components again in new products, provided the dimensionality

and design is consistent over product generations. This would save significant costs as both the raw material value and most value added from manufacturing the components are retained. This opportunity resembles Ricoh's business model for office printers.

By leveraging the circular economy building blocks and utilising both these opportunities, the Danish machinery sector could gradually adopt remanufacturing and refurbishment. A conservative estimate is that half of all product components could be addressed for remanufacturing. Until 2020, they would likely focus on sales to secondary markets, while by 2035, 15–50% of remanufactured components could be used in new products rather than sold to a secondary market. Figure 14 gives an overview of the estimated potential adoption rates and value creation estimated on a component level for two machinery products, wind turbines and pumps. Overall, this would contribute to net value creations of 1–3% as share of overall product costs by 2020, increasing to 4–9% by 2035. These findings give a directional view of the magnitude of this opportunity for Denmark. They rely by necessity on a number of assumptions, the most important of which are detailed in Appendix B. It should be emphasised that the estimates take into account the significant challenges of remanufacturing and refurbishment of long-lived equipment, such as liquid pumps and wind turbines.

Figure 14: Estimated potential adoption rates and value creation in wind turbines and pumps in the Denmark pilot

Ranges, adoption rates and value estimated on a per component basis

		2020	2035
 <p>64% of components addressable for remanufacturing (by value)</p>	Adoption rate per addressable component¹	2-15% (0%)	10-70% (2-15%)
	Additional value created per component	20-50%	25-50%
	Net value created per component	1-7%	2-25%
 <p>65% of components addressable for remanufacturing (by value)</p>	Adoption rate per addressable component¹	5-10% (0%)	30-50% (10-15%)
	Additional value created per component	15-35%	25-40%
	Net value created per component	1-4%	5-15%

¹ Adoption rates in brackets indicate 'business as usual' scenario

SOURCE: Expert interviews; Ellen MacArthur Foundation

Scaling up this value creation to the full machinery sector including pumps, wind turbine and other machinery, it is estimated that businesses could create a net value of EUR 150–250 million annually¹³² by increased adoption of remanufacturing and/or refurbishment and new business models. But they need to be prepared to challenge their perception

¹³² This sector-specific impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling.

of both their business models and design to capture the opportunity. For example, the product design requires taking into account resource use and costs over several life cycles, and identifying sub-components that could be more standardised and modularised. There are also large logistical challenges to bring widely dispersed, large products back to a remanufacturing facility, and to bring heavily worn parts back to an ‘as new’ state.

Finding solutions to overcome all these challenges will require further investigation, but it can be noted that there are a number of methods to restore worn metal components to ‘as new’ condition, for example cold spraying and other additive processes.¹³³ The US defence industry performs significant remanufacturing of aircraft, ships and ground systems, of which many have been over 20 years in operation. It is also widely anticipated that increased digitisation is an important enabler, both to drive the continued efficiency improvement and to automate the remanufacturing process, for example through fault detection software.

BARRIERS AND POTENTIAL POLICY OPTIONS

The following paragraphs provide an initial perspective on the barriers limiting the ‘remanufacturing and new business models’ opportunity (see Figure 8; also see Section 2.2.4 in the toolkit report for the barriers framework). The critical barrier limiting the industry from taking the remanufacturing opportunity is a lack of capabilities and skills: industrial designers and engineers in the machinery sector often lack the knowledge and experience necessary to run successful remanufacturing operations, which require the ability to design for disassembly and set up reverse logistics systems. An industry player highlighted the challenge to establish efficient and effective partnerships along the value chain in order to ensure a reversed flow of products and components. While getting the products into the market is a capability that has been developed for decades, the capabilities for getting the products back are still in an immature state and also highly dependent on the national market conditions.

The most important market failures are the transaction costs related to finding and negotiating with new suppliers, since remanufacturing could significantly disrupt material flows across the value chain; and the uneven distribution of knowledge among manufacturers about the economic potential of remanufacturing and new business models.

There is a steep technological development of hardware in many machinery categories, which makes remanufacturing unfeasible in the short term, e.g. the size of wind turbines is increasing rapidly, making the remanufacture of old parts for use in new products unfeasible.

Even when they are fundamentally economic, some international remanufacturing operations face a high administrative burden to comply with the regulations relevant to being able to move remanufactured components across borders. The exact impact in Denmark of such regulatory barriers would need to be further investigated for each product type.

To address these barriers, the following policy options could be further investigated. These options are the result of an initial assessment of how cost-effectively different policy options might overcome the identified barriers (see Section 2.3.4 in the main report and Appendix D):

- **Stimulating remanufacturing pilots** that allow businesses (in particular SMEs) to gain experience with remanufacturing and make the benefits more tangible to them. In this context, it is worth investigating the scope for funding such pilots through the Danish Fund for Green Business Development.
- **Using these pilots in industry information campaigns** that highlight best

¹³³ For example, the Golisano Institute for Sustainability at the Rochester Institute of Technology develops methods such as cold spraying and collaborates with companies to improve these technologies.

practices in remanufacturing and refurbishing and also draw on international case studies (such as Caterpillar’s CatReman business unit). The aim would be to build business awareness of the benefits of remanufacturing (especially among SMEs) and to accelerate the transition to performance models.

- **Encouraging the establishment of a training programme** to ensure that manufacturing and procurement staff in key industries possesses the necessary skills for businesses to fully benefit from the potential of remanufacturing.
- **Create a level playing field** between remanufactured and new products by identifying unintended consequences of national, European and international regulation that put remanufactured products at a disadvantage.¹³⁴ Potential examples are health and safety regulations and regulation prohibiting the sale of remanufactured products as ‘new’.
- In addition to reviewing existing regulation, **informing the development of new tools at the EU level** that help to provide detailed information on the composition of products and how to dismantle them. Examples include guidance on how to develop product passports and bills of material, product standards (e.g. expansion of existing eco-design rules), or quality-standards and labels on the reliability of remanufactured products.
- **Adopting an overarching government strategy for remanufacturing** and by giving it a clear space in the overall industry/manufacturing strategy (and hence with associated targets and milestones), to galvanise the industry and give it clarity on the direction of future policy development.
- **Supporting the development of remanufacturing technology and design** through strategic funding and investigate the scope for further leveraging the Eco-Innovation Program administered by the Danish Ministry of the Environment for this purpose. The new Scottish Institute of Remanufacture is an example, which is funded by the Scottish Funding Council, Zero Waste Scotland and a range of business interests. Its focus is on delivering industry led research and development projects in collaboration with academia.

¹³⁴ In May 2015, the Basel convention adopted new technical guidelines on an interim basis to amend its regulation on transboundary shipment of hazardous waste. While the main focus is on EEE, formulations such as exempting materials ‘destined for failure analysis, and for repair and refurbishment’ from being classified as waste signals an ambition to address unintended consequences.

5 PACKAGING

Plastic packaging is a central challenge to the circular economy. Although some of the potential solutions require multi-stakeholder alignment at international level, two opportunities stand out in Denmark at the national level: increased recycling and introduction of bio-based materials. By addressing the need for improved collection systems and working together with stakeholders on ways to increase standardisation, Denmark could increase the recycling of packaging to 75% by 2035, saving both embedded energy and carbon. In addition, Danish companies could develop a competitive advantage in bio-based materials, if the need for accelerated technological development and creating functional end-of-use pathways is addressed.

In terms of value, consumer packaging is forecasted to have an annual growth of ~3–5% globally for the next few years.¹³⁵ The use of plastics for packaging applications is forecasted to continue to grow at the expense of other materials.¹³⁶ Because of their short period of use, packaging materials become waste relatively quickly after they have entered the market. Recirculating plastic packaging is particularly challenging since it is not only very dispersed and therefore relatively hard to collect – which is generally the case for consumer packaging – but it also has a diverse make-up in comparison to, for instance, board-based packaging; plastics also have low material value compared with aluminium or tin-plated steel.

The plastic packaging value chain comprises firstly the design and production of plastic material and packaging, and secondly the after-use phase of collection, waste segregation, and reprocessing. The challenge with influencing the production elements is that they are typically international, so potential regulations or standardisations concerning materials or additives must be decided on an international level. The after-use phase is more localised, and so is an easier area of direct influence for an individual national policymaker. But after-use measures cannot be optimised in isolation; they need to be made in concert with design and production standards. While the outcome of applying this toolkit provides a set of options for national or regional policymakers, another project – the Global Plastic Packaging Roadmap (GPPR, see Box 2) addresses the systemic issues of the current linear plastics economy at a global level, by bringing together international stakeholders involved in plastics and packaging design as well as national stakeholders responsible for collection and recovery systems.

Thus, the Denmark pilot takes a national perspective on opportunities to increase recycling by focusing on improving the after-use treatment (Section 5.1). The opportunity to develop bio-based packaging (Section 5.2) should meanwhile be seen in the context of driving technology and innovation rather than setting national regulations for bio-based materials.

¹³⁵ Annual growth over the 2013–2018 period, with constant 2012 prices and exchange rates. Forecast compiled from Freedonia, Euromonitor, and Smithers PIRA.

¹³⁶ Smithers PIRA (2014).

Box 2: The Global Plastic Packaging Roadmap

Mobilized in 2014, as part of the MainStream Project, the Global Plastic Packaging Roadmap (GPPR) initiative leverages the convening power of the World Economic Forum, the analytical capabilities of McKinsey & Company, and the circular economy innovation capabilities of the Ellen MacArthur Foundation. The vision of the Global Plastic Packaging Roadmap (GPPR) is of an economy where plastic packaging never becomes waste but re-enters the economy as defined, valuable, biological or technical nutrients – a 'new plastics economy'.

The GPPR provides an action plan towards this new plastics economy as an economically and environmentally attractive alternative to the linear model. The project is driven by a steering committee composed of nine global leading company CEOs and more than 30 participant organizations across the entire plastics value chain ranging from plastics manufacturers to brand owners and retailers in FMCG to municipal waste collection and after-use treatment systems. This integrative project setup allows for accelerating systemic change through innovation and collaboration. The GPPR works collaboratively with a number of existing initiatives focused on ocean plastics waste including the Global Oceans Commission, Ocean Conservancy, the Prince's Trust International Sustainability Unit, governmental institutions and policymakers. The project's unique focus on systemic change will complement and inform these other initiatives.

Besides fostering innovation and collaboration across the value chain, the GPPR project will also inform and influence policy on a corporate and governmental level, by highlighting interventions that either hinder or accelerate the transition towards the new plastics economy. First results from the GPPR will be published in January 2016 at the World Economic Forum in Davos.

5.1 Increased recycling of plastic packaging

Opportunity:	Increased recycling of plastic packaging driven by better packaging design, higher collection rates, and improved separation technology.
2035 (2020) economic potential:	Not quantified.
Key barriers:	Profitability, driven by unpriced externalities and price volatility; collection and separation technology; split incentives.
Sample policy options:	Mandated improvement of collection infrastructure; increased national recycling targets; standardised collection / separation systems; increased incineration taxes.

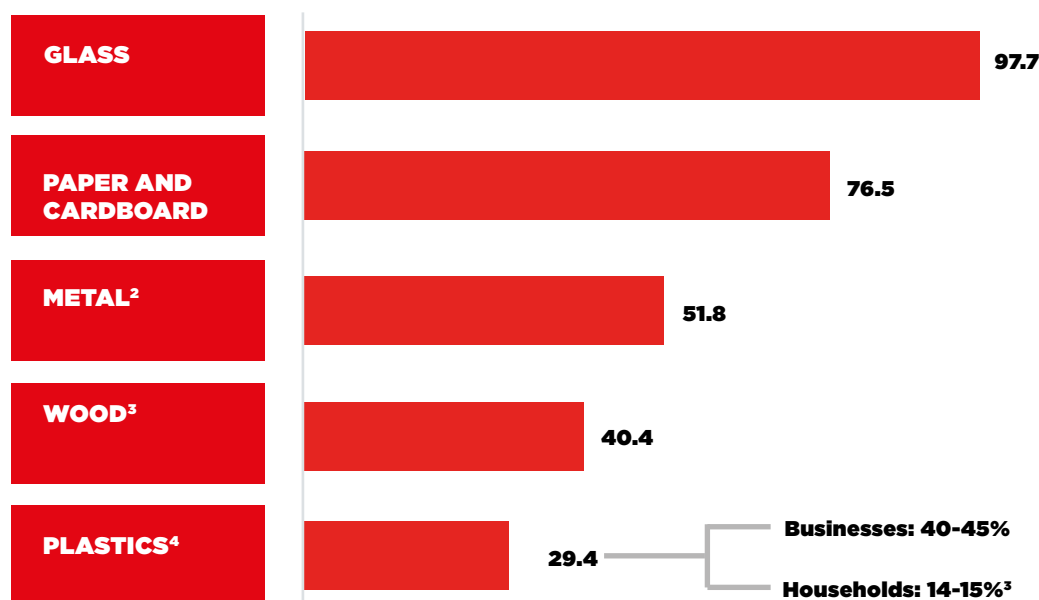
In Denmark, the volume of plastic packaging waste grew 2% p.a. over 10 years, to 184,000 tonnes in 2012, while the volume of other packaging waste, such as glass and paper, declined at a rate of 1.3% p.a. over the same period.¹³⁷ While Denmark has spearheaded many recycling initiatives, such as one of the first successful deposit-refund systems for bottles, recycling rates are still low for plastic packaging (Figure 15). One root cause may be the large waste incineration capacity in Denmark, using combined heat and power plants to generate electricity and provide district heating. Since low utilisation undermines incinerator economics, the incentive to switch packaging volumes over to recycling has been limited. In the 'Denmark Without Waste' resource strategy,

137 By tonne. Danish Environmental Protection Agency, *Statistik for emballageforsyning og indsamling af emballageaffald 2012* (2015 rev.).

the Danish government expresses a goal to gradually move from incinerating valuable materials – such as plastics – to recycling. Consequently, the estimated projected incinerator capacity is flat.¹³⁸

Figure 15: Share of plastic packaging collected for recycling in Denmark

Percent, 2012¹



¹ Indicates share of waste collected for recycling – actual recycling rates vary depending on material quality.

² Danish EPA estimates that this is on the low side. Volumes are based on sales of beer and soft drinks, and main uncertainty comes from extensive border trade with Germany. Main leakage point from households is mixed garbage, which gets incinerated. Metal salvaged from incineration ashes is not included in this number.

³ Large share of wood incinerated in incinerators and some parts in household stoves.

⁴ Including PET bottle recycling in deposit-refund scheme.

SOURCE: Danish EPA; Statistics Denmark; Ellen MacArthur Foundation

THE OPPORTUNITY FOR DENMARK

Given this starting point, there is significant potential for Denmark to increase recycling of plastic packaging.

- By **2020**, Denmark could increase the amount of plastic packaging collected for recycling to up to 40% (20% for households and 60% for businesses). This means an overall improvement with 10 percentage points compared to current recycling rate (5 percentage points for households and 20 percentage points for businesses).
- By **2035**, a ~75% recycling rate (65% for households and 85% for businesses) and improved valorisation of the collected plastic waste could become feasible.

A transition towards increased recycling would centre on three key levers – design, collection and sorting – each with a few different enabling mechanisms:

- **Higher collection rates for recycling.** This could mean more convenient collection schemes such as the kerbside collection of plastics or mixed recycling instead of requiring drop-off at recycling centres, or finding better ways to collect plastics that have been in contact with food.¹³⁹ Much could be achieved through

¹³⁸ Danish Government, *Denmark Without Waste I. Recycle more – incinerate less* (2013); Danish Environmental Protection Agency, *Danmark uden affald. Vejledning fra Miljøstyrelsen nr. 4* (2014).

¹³⁹ One waste management expert notes that consumers typically dispose of plastic packaging that is 'sticky' from contact with food since there is no convenient, hygienic way of storing it with recyclables, and that collecting this 'sticky' packaging is essential to increase collection rates significantly above current levels.

better incentives for households to sort recyclables from mixed waste. Deposit schemes could be applied for a larger number of container types – if made cost-efficient and associated with carefully implemented reverse vending supply chains. On a regional level, higher collection rates could be achieved through standardised collection systems that provide scale effects.

- **Improved sorting technology.** Better combinations of existing technologies (mid- and near-range IR, colour, x-rays, electrostatic, and visual spectrometry) lead to larger resin volumes extracted from the mixed waste or mixed recyclables stream, at higher qualities.¹⁴⁰ In the absence of such equipment the burden rests fully on households and businesses to deliver such volume and quality through their own choices and actions (for example, carefully separating resins).
- **Design for recycling.** Plastics and packaging manufacturers could use purer materials, for example without unnecessary coloration, to enable production of recycled plastics with qualities comparable to those of virgin sources.¹⁴¹ Well-considered chemical compositions may also facilitate the sorting of materials. For example, black-coloured trays, popular for ready-made meals and other food applications, have been difficult to sort: the carbon black typically used to provide the black colour cannot be detected by commonly used near-range IR sensors.¹⁴² A multi-stakeholder effort led by WRAP and including Danish Faerch Plast has now identified alternative, detectable colorants for PET and polypropylene food trays. In a wider perspective, standardisation is instrumental for being able to create broad alignment on elimination of structural plastic waste (such as too many compounds or contamination of additives; also see Note 242).

By 2020, increased recycling could reduce demand of virgin plastic material by 20,000–25,000 tonnes; by 2035 this could be 70,000–100,000 tonnes.¹⁴³ Compared to using the same amount of virgin plastic material, recycled plastics require approximately 70% less energy to produce: One tonne of recycled plastics saves roughly 10,000–12,000 kWh of energy. By 2035, Denmark could therefore also save as much as 700–1,200 GWh of energy p.a.¹⁴⁴ These findings give a directional view of the magnitude of this opportunity for Denmark. They rely by necessity on a number of assumptions, of the most important of which are detailed in Appendix B. In addition to energy savings, Denmark's carbon footprint would be reduced – but by how much would depend on what source of energy is used to replace the heat and electricity generated from incineration.

BARRIERS AND POTENTIAL POLICY OPTIONS

The following paragraphs provide an initial perspective on the barriers limiting the 'increased recycling of plastics packaging' opportunity (see Figure 8; also see Section 2.2.4 of the toolkit report for the barriers framework). The main barrier to increased plastic packaging recycling is the price pressure the relatively small plastics recycling industry faces from producers of virgin or primary plastics whose large market share grants them bargaining power. While the barrier at its core is one of unpriced negative externalities of petro-based packaging, this market failure manifests itself in a lack of profitability and capital. Plastics recyclers face volatile profit margins due to a largely fixed cost structure and revenues that are highly dependent on oil prices. This makes raising capital more difficult due to uncertain payback periods. A recent example of this economic pressure is Closed Loop Recycling, Britain's biggest recycler of plastic milk

140 See for example the pilot study conducted by the Plastic ZERO project. *Plastic ZERO. Public private collaborations for avoiding plastic as a waste* (2014). [www.plastic-zero.com/publications/publications-of-plastic-zero-\(1\).aspx](http://www.plastic-zero.com/publications/publications-of-plastic-zero-(1).aspx)

141 As noted above, this enabler is difficult to drive solely on a national level, and is best addressed through an integrative approach engaging stakeholders at a multi-national level and across the entire value chain, such as in the GPPR project.

142 WRAP, *Development of NIR Detectable Black Plastic Packaging* (2011).

143 Acknowledging that the recycling business is international, this assumes that the corresponding volume of recycled plastic material replaces virgin plastic material in Denmark.

144 www.factsonpet.com/

bottles with 80% market share, which in March 2015 warned of potential bankruptcy citing the slump in global oil prices as a major reason. Since the price of recycled plastics shadows that of petro-based plastics, the slump has caused prices for recycled plastics to fall nearly 40% in the second half of 2014 and first quarter of 2015 (another contributing factor is that milk is one of the main battlegrounds in the price war currently being fought between major supermarkets, leaving no margin to pay slightly more for recycled plastics).¹⁴⁵

Compounding these economic challenges is the lack of rollout in Denmark of two types of technology: packaging designs that reduce the cost of recycling, and plastics separation technologies at the recycling plant. Improving design (such as the detectable colorant mentioned above) and deploying more advanced separation technology would allow recyclers to separate plastics fractions more cost efficiently. Split incentives are also present: producers of plastics lack the incentive to design for recycling since third parties capture the value; and there is a well-documented overcapacity of municipal incinerators in Denmark that reduces municipalities' incentive to recycle plastics.

To address these barriers, the following policy options could be further investigated. These options are the result of an initial assessment of how cost-effectively different policy options might overcome the identified barriers (see Section 2.3.4 in the toolkit report and Appendix D):

- **Mandating the improvement of the collection infrastructure for household plastic waste in municipalities.** Nordic country experience suggests that kerb-side collection generates less contamination than the 'bring' approach.
- **Increasing the national target for the plastics recycling rate from 22.5% to up to 60%.** This would move Denmark from the minimum level under current EU law to the levels envisaged in the 2014 EC review of waste policy and legislation presented as part of the EC's circular economy proposals. This could also help insure targets and objectives are well defined.
- **Standardising collection and separation systems across municipalities** to pave the way for economies of scale and stronger sorting and treatment capabilities at the national level. This could lead to a higher profitability of domestic recycling operations.
- **Reviewing fiscal incentives around incineration of plastics.** This could both tackle the externality barrier and accelerate the shift towards the complete recycling of plastic waste. In Denmark the taxation rate is already high in comparison with other European countries,¹⁴⁶ so policymakers might consider differentiating the tax rate based on whether or not plastics are separated out before incineration. Catalonia has such a differentiated incineration tax rate for organics collection programmes.¹⁴⁷
- **Bringing together all stakeholders** in the plastics supply chain to work on systemic solutions to address split incentives that affect plastic recycling. This could take the form of a project with specific short term objectives, or a network, or a private public partnership.
- **Working towards EU-wide rules and standards**
 - on the plastics used in retail packaging solutions to better ensure

145 The Guardian, *UK's biggest plastic milk bottle recycler on brink of collapse*, (26 March 2015).

146 D. Hogg, DG Environment, European Commission, *Incineration taxes : Green certificates—Seminar on use of economic instruments and waste management* (2011).

147 Ibid.

recyclability. Ultimately this could result in a EU-wide positive list of material/format combinations for which recycling performance is superior.

- for waste recovery and management procedures so as to create more standardized outputs and allow better trade opportunities for the waste processors.
 - on minimum shares of recycled material in plastic products (as in California) in order to increase and stabilise market revenues for plastic recycling.
- **Setting up league tables ranking neighbourhoods based on their recycling performance.** In the UK for example the Department for Environment, Food and Rural Affairs maintains such a league table and provides information to households on how their communities' recycling rates compare to others. A study made by the University of Guildford concluded that this type of feedback encouraged households to recycle more.¹⁴⁸

5.2 Bio-based packaging where beneficial

Opportunity:	Innovation-driven shift to bio-based alternatives for selected plastic packaging applications.
2035 (2020) economic potential:	Not quantified.
Key barriers:	Technology; profitability driven by unpriced externalities; inadequately defined legal frameworks.
Sample policy options:	Funding of innovation and B2B collaboration; investment in improved end-of-use pathways; working to clarify the EU regulatory framework.

Bioplastics could potentially replace many applications of petroleum-based plastics. Broadly they may meet one or both of the following definitions: (i) bio-based¹⁴⁹ materials, which have a biological source (in a renewable and sustainable form) and (ii) biodegradable¹⁵⁰ materials, which have a biological fate, returning to the biosphere as nutrients. In the context of the Denmark pilot, discussion centres mainly on bio-based materials that could replace petro-based plastics. If they are used in applications most likely to end up as uncontrolled waste in the environment – such as films, bags, or closures – these materials should preferably be biodegradable.

The prevalence of bio-based plastics is still limited,¹⁵¹ but growing. Nova-Institute determined the tonnage-based share of bio-based structural polymers at 2% in 2013, up from 1.5% a year earlier.¹⁵² European Bioplastics, a trade association, even expects global capacity to quadruple by 2018, mainly driven by rigid packaging applications.¹⁵³

148 See, for example www.letsrecycle.com/news/latest-news/localised-feedback-boosts-recycling-participation/

149 'Bio-based' is defined here as any fibre or polymeric material derived from organic feedstock, e.g. paper or polymers from cellulose, plastics such as PHBV, polyesters or PLA.

150 According to the EU packaging directive it is only allowed to market/state that a packaging is biodegradable if it complies with the CEN-standard EN 13432. For the purposes of this report, it is assumed that the material can be readily decomposed under composting or anaerobic digester conditions in a short, defined period of time.

151 According to analysis based on SRI, FO Licht, Frost and Sullivan, and press clippings (2011), in 2010-11 less than 2% of the chemical industry's sales worldwide consisted of biopolymers and other bulk biomaterials such as natural rubber and bio-based polyols.

152 Nova-Institute, *Bio-based Building Blocks and Polymers in the World* (2015).

153 European Bioplastics, *Bioplastics – facts and figures* (2013).

There are two principal pathways for companies and regions to shift from a petro-based plastic to a bio-based material, both facing a set of critical challenges.

- Using a bio-based feedstock to make ‘drop-in’ monomers to produce the same polymers as from a petroleum source, using the existing plastic value chain – this is the market segment that is globally seeing the strongest growth, spearheaded by partly bio-based PET which is forecasted to grow from ~600 000 tonnes in 2013 to ~7 million tonnes in 2020.¹⁵⁴ Drop-in bio-based resins or resin-precursors (for example ethylene glycol monomers for PET) are functionally indistinguishable from their petro-based counterpart, but are difficult to produce cost-competitively compared to petro-based counterparts at current prices (similar to the challenges for biofuels).
- Replacing the material altogether, either with a new plastic or an alternative material with the same or similar properties. These materials face difficulties matching the performance of petro-based plastics and have been largely limited to very specific applications where new characteristics are desired, such as with Ecovative’s mycelium-based and compostable packaging materials,¹⁵⁵ or disposable tableware (which can both be composted or anaerobically digested).

Another challenge for bio-based alternatives is the considerable apparatus that is already in place to produce and use petroleum-based plastic packaging. Accelerating a switchover beyond the conventional investment cycle is therefore expensive and complex. Consider, for example, one large fast-moving consumer goods (FMCG) company that noted that it might take five to eight years to get a new product from concept to shelf – a large share of which is packaging design.

There are nevertheless two strong arguments for making the shift towards bio-based materials.

- **Responding to increasing material demand and price volatility.** The anticipated addition of 1.8 billion more middle-class consumers worldwide between 2010 and 2025 would lead to a 47% increase in demand for packaging. As long as the plastic is sourced from a fossil feedstock, there will eventually be issues of supply and cost unless resource extraction increases at the same pace – leading to increasing risk from price volatility.¹⁵⁶ Bio-based materials would be less sensitive to price volatility and contribute to securing the rising demand from consumers.
- **Ensuring unavoidable leakage is bio-sourced.** The highly dispersed nature of plastic packaging means that leakage to the biosphere is always likely – even with excellent recycling – and leakage of petro-based plastic creates either a net addition of CO₂ to the atmosphere or slow degrading waste in the landfill or oceans. In Denmark, 10-11% of plastic bottles do not end up in the deposit-refund system, while this number is 0-2% for refillable glass bottles.¹⁵⁷ But even low leakage rates are problematic for a high turnover item like food and beverage packaging.¹⁵⁸ Another example is the large variety of plastic packaging that is disposed of as mixed garbage, thus having near 100% leakage. If there is (unavoidable) leakage, it is preferable that this material comes from a bio-based feedstock so that the net carbon addition to the atmosphere is minimised upon incineration, or is biodegradable if it is likely to leak into the biosphere without incineration.

154 Nova-Institute, *Bio-based Building Blocks and Polymers in the World* (2015).

155 www.ecovatedesign.com/mushroom-materials/. Also see Ellen MacArthur Foundation, *Towards the Circular Economy II* (2013), p.71.

156 World Bank; Ellen MacArthur Foundation, *Towards the Circular Economy III* (2014), p.25.

157 Danish Return System.

158 Take aluminium beverage cans for example, which have a 60-day life from can to (recycled) can. Even at a 70% recycling rate, all the original material would disappear from the economy after only one year.

THE OPPORTUNITY FOR DENMARK

Denmark businesses could leverage both the drop-in and replacement pathways described above to shift from petro-based plastics to bio-based materials. Some international companies have shown that there are business cases for both options:

- The Coca Cola Company launched its PlantBottle™ concept in 2012, where up to 30% of the plastic is made from drop-in, bio-based chemicals. Coca Cola now also collaborates with, among others, renewable chemicals producer Gevo, which intends to supply bio-based paraxylene for making PET. Going further, Coca Cola aims at producing bottles from 100% residual biomass.¹⁵⁹
- DSM has a number of bio-based plastics for non-packaging applications on the market, for example Arnitel®, partially made using rapeseed oil and used for making temperature-resistant pan liners; and EcoPaXX®, an engineering plastic made from 70% biological feedstock, used for engine covers in cars.¹⁶⁰
- In Denmark, ecoXpac is developing a cellulose fibre-based material that can be moulded like plastics and is biodegradable. In a partnership with Carlsberg, Innovation Fund Denmark and the Technical University of Denmark, they are using the Cradle-2-Cradle® design principles, in the development of the the first bio-based, biodegradablebeer bottle.¹⁶¹

Bio-based materials have been controversial because of their potential impact on land use and waste recovery systems, and indeed should be introduced where they are beneficial from a *system perspective*, and aligned with design criteria that include:

1. **Minimise overall waste:** New materials should not increase other waste streams (i.e. reduced gas/liquid barriers of bio-based materials may lead to higher food spillage, biodegradable materials may cause reduced recycling rates and be too slow to decompose).
2. **Do not increase land use:** bio-based packaging materials should, where possible, be derived from secondary organic material streams (e.g. fibre from residual biomass, microorganisms growing on organic waste) in order not to compete with food supply or further increase land use (although the biomass need for plastics substitution is small – currently at 0.01% of the area globally under agricultural cultivation;¹⁶² given the current share of biopolymer at ~2% of total polymer volume (see above), even a fully bio-sourced supply would occupy around 0.5%).
3. **Do not leak nutrients from the bio-cycle to the technical cycle.** Since bio-based materials are essentially taken from the bio-cycle to be used in the technical cycle, it is important to avoid leakage of essential biological nutrients. This is typically avoided by ensuring that produced materials are pure,¹⁶³ and that they are returned to the biosphere either directly through composting or digestion, or indirectly through incineration.
4. **Consider existing end-of-use infrastructure:** If a new bio-based material is introduced, it should not disrupt existing end-of-use treatment systems so that overall costs increase. If a biodegradable alternative is introduced, there should already be an end-of-use pathway for it, such as an operational collection system for organic waste.
5. **Avoid leakage of non-circular materials:** Product-by-product evaluation is necessary to assess best end-of-use option. There is a fundamental question around

159 www.coca-cola.com/content-store/en_US/SC/PlantBottle/; www.gevo.com/?post_type=casestudy

160 www.dsm.com/products/arnitel/en_US/home.html; www.dsm.com/products/ecopaxx/en_US/home.html

161 www.ecoxpac.com

162 Food and Agriculture Organization of the United Nations (FAO); Institute for Bioplastics and Biocomposites (IfBB), University of Applied Sciences and Arts, Hannover.

163 Polymers typically contain only carbon, hydrogen, oxygen and nitrogen.

whether the packaging material should be looped within the technical cycle or returned to the biological cycle (c.f. Figure E1).

- **Technical cycle.** Beverage containers that are relatively clean and easy to recognise and could participate in deposit refund schemes with high recycling rates may benefit from further focusing on recyclability, which could mean a petroleum feedstock is still preferable even if there is the option to use bio-based drop-in chemicals.
- **Biological cycle.** Packaging typically incinerated as mixed waste (such as film and sticky food containers) may benefit from being bio-based – or potentially also biodegradable such that it can be disposed of together with food waste in the organics bin (and be recovered in composters or anaerobic digesters).

Based on these design criteria, Denmark could start the shift to bio-based alternatives, first for selected disposable packaging with high tendency of being incinerated as mixed waste, and subsequently start introducing bio-based feedstock for plastic packaging applications with high degree of recycling. The materials could be sourced from non-food organic feedstock, for example residual wood fibre or plant biomass, or organic waste. Apart from making Denmark more resource resilient, this innovation-driven development could create a competitive advantage and opportunities to export new products and technologies.

- By **2020**, Denmark might seek to launch the first successful at-scale examples of replacing petro-based plastics by new, advanced bio-based materials (as already conceptualised by Carlsberg/ecoXpac). While little replacement of plastics protecting food is anticipated, Denmark could investigate pockets of opportunity where petro-based plastics properties are overspecified and replace these with a bio-based material with lower barriers. Due to the lead time required to build capacity for production of drop-in monomers, e.g. in bio-refineries (see Section 2.1), the estimated increase in bio-based feedstock for existing plastic materials is limited.
- By **2035**, Denmark might seek to introduce bio-based drop-in chemicals at scale for the production of recyclable plastic packaging (e.g. PET), leveraging an anticipated bio-refining capacity (see Section 2.1). At the same time, Denmark could introduce biodegradable alternatives to replace, in particular, petro-based food packaging with low recycling rates, as well as creating a differentiated packaging offering for exported FMCGs to prioritise biodegradable versions for developing markets with low recycling rates.

BARRIERS AND POTENTIAL POLICY OPTIONS

The following paragraphs provide an initial perspective on the barriers limiting the 'bio-based packaging where beneficial' opportunity (see Figure 8; see also Section 2.2.4 of the toolkit report for the barriers framework). To enable bio-based materials to successfully contribute to the new plastics economy (see Box 2), it is critical to ensure that working pathways exist for them to be produced, to fulfil their role, to be accurately separated, and to reach their intended fate at end-of-use. At this point there is still a large need for technological innovation in all segments of such pathways. For example, advanced bio-based materials with the right properties¹⁶⁴ to replace petro-based plastic packaging and with limited negative effects, e.g. without competition with food crops, are still mostly at the advanced R&D or early commercial stage.

The incentive to innovate further is lowered by the actual and potential low cost of petro-based plastics, which are determined by global oil prices. Low prices of petro-

164 For example, good gas and liquid barrier properties are crucial for food packaging.

based plastics neither reflect the true environmental costs of their production¹⁶⁵ nor the cost of recycling them. This suppresses the potential prices that competing bio-based alternatives can command, meaning that margins remain low except in cases of high-price, low-volume products for specific applications. It gives rise to challenges to the profitability of producing bio-based plastics, which is highly dependent on the oil price. In addition, several stakeholders in the packaging value chain point out that moving towards using bio-based materials could complicate the supply chain from the point of view of packaging users because it adds more suppliers and types of material, thereby increasing transaction costs.

Finally, many stakeholders suggest that legal frameworks need to be better defined. For instance, ecoXpac indicated the benefits of a more transparent and speedy approval process for innovative new materials for food packaging. In another example, the field of bio-based materials could benefit from a Danish Act on excise duties that distinguishes better between petro-based and bio-based materials, in line with its aim of promoting environmentally benign types of packaging.

To address these barriers, the following policy options could be further investigated. These options are the result of an initial assessment of how cost-effectively different policy options might overcome the identified barriers (see Section 2.3.4 in the toolkit report and Appendix D):

- **Fund collaboration in the R&D and design phases.** With sufficient budget available this could take the form of funding R&D platforms—the further development of bio-based materials in collaboration with large CPG companies could follow international best-practice models for public-private innovation (for example the Fraunhofer Institute in Germany and UK’s Catapults). More modest collaboration support could bring together designers and engineers in formats that draw inspiration from the packaging eco-design advisory services that Eco-Emballages offers in France.¹⁶⁶
- **Investing in improving end-of-use pathways** for bio-based and biodegradable materials (including plastics and food waste) in the collection/separation systems.
- **Working to clarify the EU regulatory framework for approving new materials** for food packaging so as to minimise unintended consequences that could hamper innovation and growth in the bioplastics industry.
- **Considering contributing to an EU-wide debate on taxation** of petroleum-derived materials.

¹⁶⁵ Whereas the emissions from producing ethylene from Brazilian sugarcane amount to 0.1 tonnes CO₂e/tonne of product (assuming no forest was cleared to cultivate the sugarcane), this rises to 2.1 tonnes for the same product derived from Chinese naphtha.

¹⁶⁶ See for example: www.ecoemballages.fr/; ec.europa.eu/environment/waste/prevention/pdf/Eco_Emballages_Factsheet.pdf

6 HOSPITALS

Hospitals constitute a large, public service in Denmark and as such procure and consume large amounts of resources. The two key circular economy opportunities identified are to adopt performance models in procurement, and to become leaders in recycling and waste reduction. Modelling suggests that performance models in procurement could save hospitals EUR 70-90 million by 2035. With a systematic effort Danish hospitals could become leaders in recycling and minimisation of avoidable waste. For these opportunities to be realised, it is important that necessary capabilities are developed and existing custom and habits are addressed, for example by supporting pilots and training programmes, and by creating national guidelines and/or targets.

The healthcare sector in developed economies face a tremendous challenge over the next decades. Healthcare costs are increasing, for example driven by an ageing population, technological development and increased expectations from patients. Although Denmark is the country with the lowest projected cost increase, its public spend on healthcare is expected to rise from ~7% of GDP in 2008 to ~10% GDP by 2050.¹⁶⁷ Such projections obviously motivate investigations for cost reductions and productivity improvement.

Hospitals are different from the ‘producing’ sectors discussed in Chapters 2–4 in that their output is a service. Hospitals do, however, procure, use, and discard vast quantities of goods and materials. For this sector this report therefore focuses on how hospitals could use their scale and centralised management to maximise resource efficiency through performance models, and minimise their waste through best practices in prevention and recycling.

In 2013, Danish hospitals spent EUR ~2.4 billion on physical goods.¹⁶⁸ Based on what types of products are already offered in the form of performance models, an estimated 38% of the total purchases could be addressable (Figure 16). This includes a range of advanced equipment (e.g. MRI scanners, radiation treatment equipment, and laboratory instruments) and also (semi-)durable goods (e.g. scalpels, cuffs, and surgical apparel). It does not include the long tail of smaller product categories in ‘other medical equipment’, so the estimate is likely on the conservative side.

There are also large quantities of structural waste in healthcare that could be addressed using circular principles. Though these were not explicitly analysed in the Denmark pilot, a few deserve mentioning:

- **Virtualisation.** Although the technology is not yet mature beyond the level of isolated trials, it is anticipated that the efficiency of part of the healthcare system could be significantly improved by leveraging connectivity and technology-driven cost reduction of diagnosis. Two existing examples are the blood glucose monitor for diabetic patients and the various ‘e-health’ applications; a plausible development is that patients take a variety of samples at home using a connected table-top device, send the diagnostic outcome electronically, and consult physicians remotely using a videoconference application.
- **Preventive healthcare.** Increasing healthcare costs have prompted the idea of governments reducing the need for costly healthcare interventions by increasing the overall health of the population. Shifting the focus to disease prevention could offer a tremendous opportunity, not only in terms of avoided investment in hospital beds (and the materials associated with construction and usage/management) but also in terms of reduced productivity loss in the society. The

¹⁶⁷ The King's Fund, *Spending on health and social care over the next 50 years. Why think long term?*, (2013).

¹⁶⁸ Expenses for Denmark's 5 major regions, data from Danish regions. Purchase of goods represents ~15% of total hospital budgets; hospitals purchase services for an additional EUR 2,400 million.

Alzira model from Valencia offers an early example: driven by the nature of the public-private partnerships in the model, healthcare providers are incentivised to focus on health promotion and in the long-term reduce the patients' need for healthcare.¹⁶⁹ It is also highly relevant to address the increasing caloric intake that has been growing steadily in Europe other developed economics, and could drive exceedingly high healthcare costs.¹⁷⁰

Figure 16: Share of purchased goods in Danish hospitals that could be covered by performance models

	COST BREAKDOWN OF PURCHASED GOODS		ADDRESSABLE FOR ACCESS OVER OWNERSHIP MODELS
	PERCENT		
Diagnostic imaging and radiation equipment	<div><div></div></div> 12	✓	
Surgical equipment	<div><div></div></div> 9	✓ ¹	
Patient care and wound treatment	<div><div></div></div> 9	—	
Medical apparel and textiles	<div><div></div></div> 4	✓ ²	
Other medical equipment	<div><div></div></div> 26	— ³	
Medical equipment and accessories	<div><div></div></div> 60	✓	
Laboratory, observation and test equipment	<div><div></div></div> 13	✓	
Food and beverage	<div><div></div></div> 7	—	
IT equipment	<div><div></div></div> 4	✓	
Other	<div><div></div></div> 15	— ³	
Total	<div><div></div></div> 100		
Addressable for access over ownership models	<div><div></div><div></div></div> 38 62	100	



Readily addressable / high potential



Addressable long-term/low-mid potential



Not addressable

¹ Semi-durable equipment (e.g. scalpels, cuffs, sterile drapes) addressable in the longer term

² Clothing and linen already widely addressed in Denmark

³ Not assessed; long tail of small product categories, although access over ownership models should be feasible in many cases

SOURCE: Statistics Denmark, Danish Regions

¹⁶⁹ NHS European Office, *The search for low-cost integrated healthcare. The Alzira model – from the region of Valencia* (2011).

¹⁷⁰ Today, the average caloric intake exceeds 3,500 kcal per day, 40% above the recommended daily intake. In addition, the diet has become more fatty, salty, and sweet over the past 40 years. EEA, 2008; Food Standards Agency; European Food Safety Authority; J. Schmidhuber, *The EU Diet – Evolution, Evaluation and Impacts of the CAP* (FAO, Rome, 2008).

6.1 Performance models in procurement

Opportunity:	Shift towards performance models in procurement of advanced and (semi)durable equipment.
2035 (2020) economic potential:	EUR 70–90 (10–15) million p.a.
Key barriers:	Insufficient capabilities and skills due to lack of experience; imperfect information; custom and habit.
Sample policy options:	Guidelines and targets; capability building; procurement rules.

The central idea in ‘performance’¹⁷¹ models is a contract in which the customer pays for the use, or the performance, of a product rather than the product itself. The rationale is that there is no inherent benefit in owning the product. On the contrary, ownership can entail additional costs (upfront investment), risk (unpredicted repair, maintenance or obsolescence), and end-of-use treatment costs.

THE OPPORTUNITY FOR DENMARK

Performance models are relevant for many of Danish hospitals’ purchasing categories, whether it is leasing clothing and bed linens or contracting the full management of scanning and radiation equipment. At the heart of each such model lies a mutual benefit for suppliers and customers to reduce the total cost of ownership. While the customer is able to reduce purchasing and maintenance costs, as well as maximise performance and uptime, the supplier is able to secure sustainable revenue streams, maximise resource utilisation, and drive efficiency during the use phase.¹⁷² Importantly, performance models also incentivise manufacturers to design more durable products that are easier to maintain, repair and refurbish or remanufacture (see Chapter 4).

There are already multiple examples of suppliers providing performance that are relevant to, or directed exclusively towards, hospitals. In the healthcare sector, suppliers like Siemens, Philips and GE are already rolling out performance models for their equipment, in addition to having existing refurbishment operations.¹⁷³ Some of the most well-known examples outside the healthcare sector include Ricoh’s and Xerox’ service contracts for high-volume printers, Desso’s carpet tile concept,¹⁷⁴ and Philips’ lighting services (selling ‘lux’ instead of lighting fixtures¹⁷⁵).

The partnership between Stockholm County Council and Philips Healthcare for the Nya Karolinska hospital has received a great deal of attention.¹⁷⁶ The 20-year comprehensive, function-based delivery and service agreement covers the delivery, installation, maintenance, updating and replacement of medical imaging equipment such as MRI and ultrasound equipment, where the cost risk is carried by Philips and the upside potential (e.g. future lowered prices) is shared. This coincides with Philips opening a new, dedicated refurbishment and remanufacturing facility in Best, the Netherlands in

171 Performance models used to collectively denote performance contracts, leasing, asset centralisation contracts and other models designed for supplier to help customer minimise total cost of ownership.

172 For a more in-depth discussion on performance-based business models, see Stahel, W. R., Palgrave MacMillan, *The Performance Economy* (2006).

173 www.healthcare.siemens.com/refurbished-systems-medical-imaging-and-therapy; www.healthcare.philips.com/main/products/refurbished_systems/; www.3gehealthcare.com/en/products/categories/goldseal_-_refurbished_systems/

174 www.desso-businesscarpets.com/corporate-responsibility/cradle-to-cradler/

175 By owning the energy bill, Philips is able to significantly reduce energy consumption and cost. www.ellen-macarthurfoundation.org/case_studies/philips-and-turntoo.

176 Katharine Earley in *The Guardian*, *Hospital innovation partnership set to deliver high quality, sustainable patient care* (13 November 2014).

2014, announced as ‘the next step in our circular economy journey’.¹⁷⁷ Allowing suppliers to retain control over their equipment and making full use of parts and components throughout their entire life cycle could generate substantial savings for the hospitals. Jens Ole Pedersen at Philips Healthcare Nordics notes that hospitals could save approximately 25% on TCO of the provided equipment.

Performance-based contractual models could cover more than technically advanced equipment or installations. Uniforms, bed and bathroom linens are commonly procured on a leasing contract. And even semi-durables, which are often used as one-way disposable equipment, are addressable for performance models. In Catalonia, which like Denmark focuses increasingly on the circular economy, Axioma Solucions provides sterilised surgical clothing as a service, while Matachana Group provides sterilisation solutions for equipment at hospitals’ facilities. Axioma Solucions notes that according to an independent study, their ‘Steripak’ can be cycled 75 times and consequently has a resource footprint one eighth that of corresponding one-way clothing, while being up to 15% more cost efficient.¹⁷⁸

Danish hospitals have not yet adopted performance models to a large extent. The only category where there is a large penetration is in textiles; laundry services and leasing are already widely adopted.¹⁷⁹ There is therefore a large opportunity to initiate such a shift, and the timing to do so appears very good. There are currently 16 large hospital projects in Denmark, seven greenfield projects and nine that are major renovations or expansions.¹⁸⁰ Similar to the Nya Karolinska example, they could take a holistic, performance-based approach to procurement of equipment. These new hospitals will open within the next five to ten years, sufficient time to build a new procurement organisation and culture, with less concern for legacy equipment or old habits.

Given the current starting point, Denmark could gradually shift purchasing of goods towards performance models for the addressable share of the purchasing budget (Figure 13):

- By **2020**, hospitals could seek to adopt performance contracts for up to 10% of selected product categories (diagnostic imaging and radiation equipment, IT equipment, and laboratory, observation and test equipment).
- By **2035**, overall adoption of performance models could have increased to as much as 40%. In addition to product categories already addressed in the short term, similar procurement models could also have begun to penetrate other durable and semi-durable goods, such as selected surgical tools and apparel, where the safety/hygiene issues with looping materials can be properly addressed.

With total estimated savings of 15–30%¹⁸¹ compared to traditional procurement, applied to an addressable cost base of 38% of total hospital procurement (see Figure 13), modelling suggests Danish hospitals and equipment suppliers could by 2035 (2020) save EUR 70–90 (10–15) million annually.¹⁸² These findings give a directional view of the magnitude of this opportunity for Denmark. They rely by necessity on a number of assumptions, the most important of which are detailed in Appendix B. The estimate has not included more ‘generic’ products, such as lighting, flooring or printers.

177 philips.exposure.co/behind-the-factory-doors

178 The resource efficiency study was conducted by the Autonomous University of Barcelona.

179 Interview with De Forenede Dampvaskerier. Global players like Berendsen plc are also active in this field; www.berendsen.dk/hospital

180 Information provided by Danish Regions.

181 Savings rate depends on product category. Based on expert interviews with healthcare equipment providers and case studies from performance contracts in other industries (e.g. white goods, automotive, printers).

182 Based on current procurement volumes. This *sector-specific* impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling. In addition, the distribution of savings between hospitals and suppliers has not been modelled. It could be argued that it is skewed towards hospitals in the short term since suppliers want to create incentives for hospitals to set up performance contracts, but could equilibrate at a more even split in the long-term as the model gets established and consolidated.

BARRIERS AND POTENTIAL POLICY OPTIONS

The following paragraphs provide an initial perspective on the barriers limiting the ‘performance models in hospital procurement’ opportunity (see Figure 8; see also Section 2.2.4 of the toolkit report for the barriers framework). Sector experts from both suppliers and hospitals have noted that the critical barrier to hospitals increasing their use of performance models is that hospital procurement staff are not trained and have limited experience of other forms of tenders such as performance contracts or assessing offerings based on total cost of ownership (TCO) – as well as limited time to change practices. Another social factor mentioned in interviews is the customary perception that leasing is often more expensive than buying and the uneasiness that performance contracts could allow increased private sector influence in public healthcare. Furthermore, hospital management and procurement departments in many cases lack information compared to equipment providers on the economic case for access over ownership. These barriers combine to provide a powerful force of inertia in procurement departments.

To address these barriers, the following policy options could be further investigated. These options are the result of an initial assessment of how cost-effectively different policy options might overcome the identified barriers (see Section 2.3.4 in the toolkit report and Appendix D):

- **Guidelines and targets.**
 - **Creating guidelines** for regions or hospitals for the procurement of solutions rather than products, and how to work with target setting on different levels. International examples may serve as ‘blueprints’, such as the Philips-Nya Karolinska contract in Sweden. Through an innovative contract structure, the hospital secures access to a pre-defined level of functionality rather than the availability of specific equipment. Target setting also occurs in regional procurement partnerships in Denmark, e.g. the partnership for green procurement.
 - **Stimulating shared/centralised procurement amongst hospitals** where appropriate, to reap economies of scale and leverage purchasing power. This could take the shape of a centrally negotiated performance-based contract across all regional hospitals, e.g. for lighting. The resulting additional cost savings could further accelerate a large-scale move towards such access-based contractual models.
 - **Supporting measures to optimise equipment utilisation** such as equipment loan programmes between hospitals could round out the benefits from reshaping procurement procedures and skillsets.
- **Capability building.**
 - **Developing skillsets for circular economy-oriented procurement, e.g.**
 - **Training staff** in optimal procurement design for access over ownership (e.g. the hospital could provide specialist training courses based on a nationally developed curriculum).
 - **Initiating a performance model pilot to develop and apply the total cost of ownership (TCO) concept** to allow a more holistic view of cost in hospital procurement – thereby creating a mindset as well as bidding rules that are more conducive towards performance contracts.
 - **Building a repository of case studies** from national and international examples to build confidence around issues such

as e.g. cost efficiency, long-term benefits, contractual flexibility, and dependence on fewer suppliers.

- **Establishing a government advisory body** with the explicit mission of promoting performance-based contractual models in hospital procurement. Hospitals could be given the option to seek such advice for all or specific procurement projects. This could take the form of a partnership, task force, or network to facilitate knowledge sharing.
- **Procurement rules**
 - **Adjusting budget rules** to enable joint budgets and closer working between procurement and technical teams (“breaking down siloes”). This could enable more performance-based contracts (with more procurement staff and fewer technical maintenance staff). Removing regulatory or governance barriers that impede interaction of hospital teams and supplier teams could also help.
 - **Adjusting procurement rules and procedures.**
 - **Augmenting the procedures for assessing the quality** of competing bids with tightly defined ‘circularity’ criteria or KPIs. Such criteria could be part of the (non-binding) guidelines for public procurement and could include promotion, piloting, and knowledge sharing of purchasing criteria). Examples include length of lifetime, reparability, presence of chemicals that hinder recycling, design for disassembling features.
 - **Incorporating accounting for externalities** (e.g. the life cycle carbon/water/virgin materials footprint) into the guidelines or rules for all public procurement to create full cost transparency.

6.2 Waste reduction and recycling in hospitals

Opportunity:	Centrally managed and systematic initiative to reduce waste and increase recycling.
2035 (2020) economic potential:	Not quantified.
Key barriers:	Insufficient capabilities and skills due to lack of experience; custom and habit; imperfect information.
Sample policy options:	Pilot of waste reduction and recycling management integrated into staff training; waste minimisation and recycling targets; increased fiscal incentives to avoid waste generation.

Large hospitals are like miniature cities, with many sizable and complex flows of materials and information. And, similar to cities, they produce large quantities of waste. Hospitals are run by a central management that coordinates staff and sets a strategic direction for the whole organisation, and thus might have the potential to holistically optimise their waste management. Therefore, as is the case for other centrally and tightly controlled systems such as airports, it is reasonable to envision hospitals as champions in both waste prevention and recycling.

THE OPPORTUNITY FOR DENMARK

The largest source of (non-hazardous) waste in hospitals is the purchasing and preparation of food and beverage. As explained by one sector expert, it is common for departments to order too many meals from the kitchen to add a safety margin, which risks being magnified by the kitchen’s safety margins. As a result hospital kitchens may

end up purchasing more food and ingredients than needed, which ultimately produces avoidable food waste.

The approach to prevent avoidable food waste for large institutions such as hospitals differs from the alternatives laid out for the consumer-facing market (Section 2.2) in that it is more centred on right-sizing procured volumes. One way of incentivising this planning challenge is to set standards on sustainable procurement of the food and catering services, such as introduced by the NHS in the UK.¹⁸³

Given its scale, hospitals could systemise and improve recycling beyond the already ambitious targets of the Danish society set by the 'Denmark Without Waste' strategy. Hospitals are part of the service sector where the target for recycling packaging waste in 2018 is 70% (paper, glass, metal and plastic) and 60% for recycling of organic waste in 2018.¹⁸⁴ In comparison, Danish hospitals today note recycling rates of 15–30%, with an average below 20%.¹⁸⁵

Danish hospitals therefore have an opportunity to make a systematic effort with strong management commitment to improve recycling, while at the same time reducing waste generation. While this effort needs to be driven primarily by a well-informed and committed staff, it could be guided by, for example, working with waste management suppliers that increasingly provide waste minimisation services apart from operating the logistics and treatment. While the potential has not been fully quantified in this case, it should be feasible to achieve overall recycling rates above of approximately 85% (70%) by 2035 (2020). This corresponds to being aligned with the 'Denmark Without Waste' target by 2020 and then gradually outpacing it.

BARRIERS AND POTENTIAL POLICY OPTIONS

The following paragraphs provide an initial perspective on the barriers limiting the 'waste reduction and recycling in hospitals' opportunity (see Figure 8; see also Section 2.2.4 of the toolkit report for the barriers framework). Hospitals face similar social factor and information barriers when aiming to reduce waste generation and increase recycling as when trying to increase the use of performance models in procurement. There is limited capacity within hospital administrations to consider waste prevention and waste handling and, while procurement departments are already highly professional, hospitals lack expertise in waste prevention and management. Furthermore, hospital targets are centred on quality of healthcare; expert interviews indicate that there is resistance to the idea of adding to or diluting such targets with targets relating to waste. Furthermore, there is limited information on the economic benefits of reducing waste and increasing recycling due to a lack of analysis of procured and disposed materials in hospitals. As in the food and packaging sectors, the incentive to reduce waste and increase recycling would rise if the market prices of packaging, food and other consumables reflected their true environmental costs.

As before, at the level of individual hospitals, the main short-term challenge is improving capabilities and skills as well as changing mindsets. Over a longer time horizon, policymakers might choose to play a role by creating supporting guidelines (non-binding) and rules (binding) as well as appropriate incentives. Central government might also take on the externalities barrier by internalising more externalities in the production of food, packaging and other products that may end up being disposed of by hospitals as waste. Doing so would likely increase hospitals' monetary incentive for waste avoidance and recycling.

To address these barriers, the following policy options could be further investigated. These options are the result of an initial assessment of how cost-effectively different policy options might overcome the identified barriers (see Section 2.3.4 in the toolkit report and Appendix D):

183 UK Department of Health, *The Hospital Food Standards Panel's report on standards for food and drink in NHS hospitals* (2014).

184 Danish Government, *Denmark Without Waste. Recycle more – incinerate less* (2013).

185 Excluding construction and garden waste. Based on interviews and correspondence with representatives from hospital environmental managers and Danish Regions.

- **Piloting the integration of waste reduction and recycling management into staff training** across all hospital functions in new or leading hospitals, and syndicating the results into case studies for wider knowledge building.
- **Setting waste minimisation and recycling targets** for hospitals in line with overall national targets but taking into account its different, challenging) character, and include associated circular economy metrics in the performance criteria for hospital management.
- **Investigate fiscal incentives to avoid non-hazardous waste streams to level the playing field for recycling initiatives** as part of a national initiative for all sectors. A complementary measure would be the publication of waste avoidance/management performance league tables for hospitals.
- **Creating or supporting a platform for Danish hospitals** to share information, exchange best practices and develop a joint strategy for reducing waste and increasing recycling rates with a view to establishing the country as a frontrunner.
- **Initiating a discussion on pricing in of externalities** (but balancing with distributional effects) so that the market prices of food, packaging and other consumables reflect the full social and environmental costs of their production, consumption and disposal—and ultimately inform better procurement and operational decisions.



APPENDIX

APPENDIX

A A detailed overview of sector selection in the Denmark pilot

This appendix summarises the details underlying the sector selection ‘matrix’ developed for the Denmark case study and shown in Figure 1: the selection of sub-dimensions, the data collection and the calculations. The list of sub-dimensions does not aim to be exhaustive and is not necessarily the optimal one for other regions, but could serve as an inspiration when conducting the sector selection elsewhere. See section 2.1.3 in the toolkit report for a more extensive discussion about the approach used.

Figure A1 provides an overview of the sub-dimensions used in the Denmark pilot for the dimensions ‘Role in national economy’ (A) and ‘Circularity potential’ (B). It displays the type of assessment (quantitative vs. qualitative), an indication of how the calculations were performed and the relative weight of quantities within each sub-dimension. When the assessment was qualitative, a scoring-based assessment was performed to yield a ‘semi-quantitative’ result. The sources behind the data and analyses are reported. Figures A2 and A3 provide an overview of the relative scoring of each sub-dimension in the Denmark pilot.

A brief description of the sub-dimensions follows below.

Dimension A. Role in national economy.

- A.1. **Contribution to the national economy in terms of gross value added.** Both the relative size of each sector’s gross value added and the relative growth rate were taken into account, in order to reflect shifting long-term trends as well as current contributions.
- A.2. **Contribution to national employment and job creation.** Employment is obviously a key priority for any policymaker and was thus included in dimension A. Both the relative importance of each sector in terms of full time equivalents and the relative growth rate were taken into account, in order to reflect shifting long-term trends as well as current contributions.
- A.3. **Competitiveness – trade openness and security of supply.** Export and import volumes were included to reflect each sector’s competitiveness on the international market.
- A.4. **Competitiveness – strategic dimensions.** This sub-dimension is the *sum* of four qualitatively or quantitatively evaluated quantities illustrating the strategic importance of each sector for Denmark’s competitiveness in terms of technology, productivity and sensitivity to global trends. The *sum* synthesis was selected to reflect that all quantities are important but not necessarily interdependent. The qualitative evaluation was done by assigning a score of ‘high’, ‘medium’ or ‘low’ to each quantity, associated with scores of 10, 5 and 1 respectively.
 - *Patent activity* – Danish patent activity in relation to other countries in the EU, by technology area mapped on Danish sectors.
 - *Export specialisation* – Classification based on whether each sector’s share of Danish exports is significantly above, similar to, or below the average share of exports within the OECD.
 - *Productivity advantage* – Reflects how productive Danish sectors are in comparison with the same sectors in international peers.
 - *Energy price sensitivity* – Energy expenditure as share of output value, included to reflect each sector’s sensitivity to changes in energy prices.

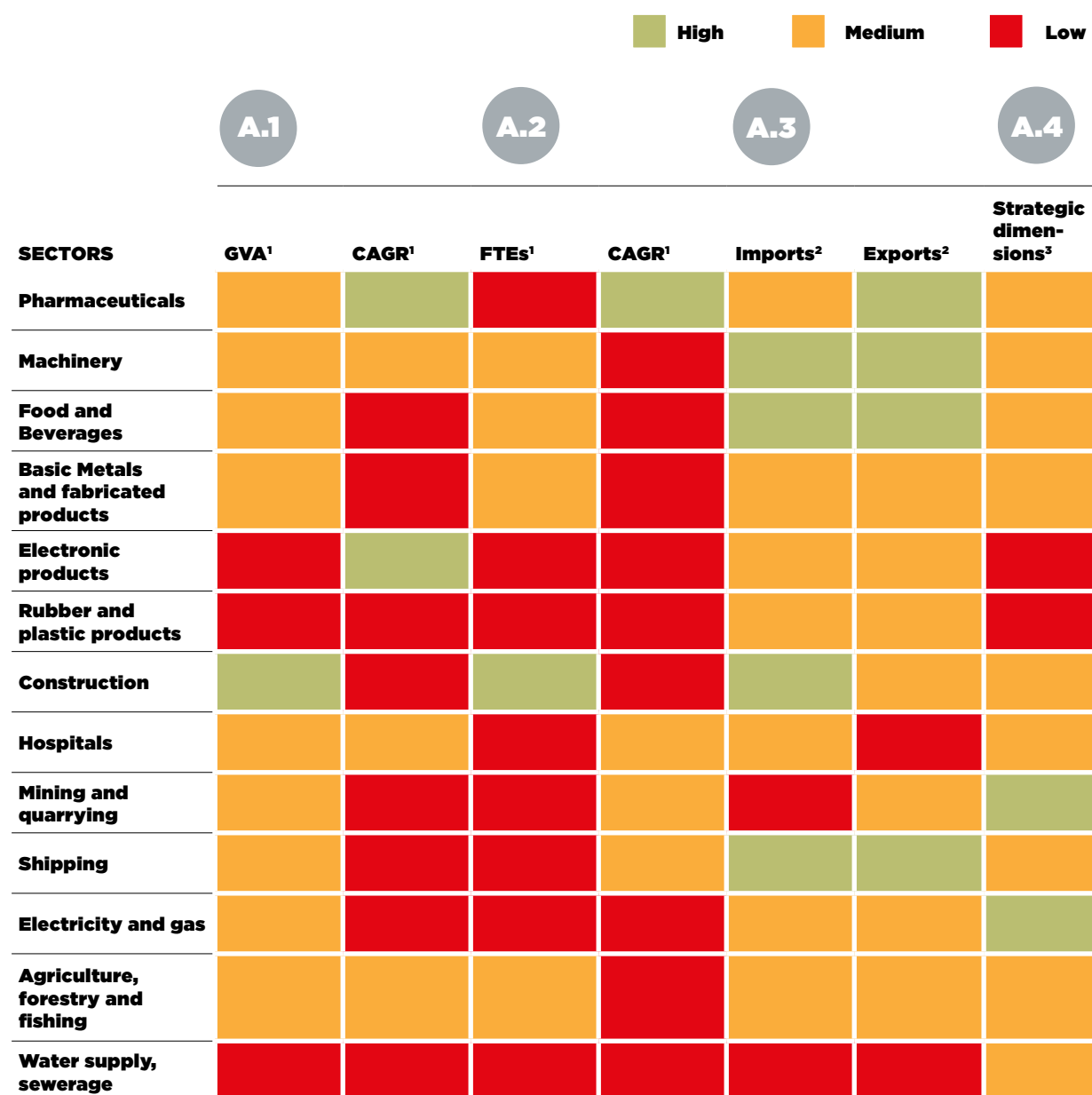
Dimension B. Circularity potential.

- B.1. **Material intensity** – *Purchase of commodities are shown as a share of the sector's turnover to reflect how dependent the sector is on physical resources.*
- B.2. **Environmental profile** – Includes weights of both total waste volumes and recycling, in order to reflect both the tendency to create a leakage of material, which could potentially be avoided, and the proficiency with which the material is recovered today, which could potentially be improved.
- B.3. **Scope for improved circularity** – The *product* of three qualitatively evaluations. A score of 'high', 'medium' or 'low' was assigned to each quantity, associated with scores of 10, 5 and 1 respectively. The *product* synthesis was selected due to the interdependence of the four quantities.
- *Intrinsic material value of output (and waste).* Qualitatively estimates the intrinsic value of the material handled in each sector. Both raw materials and value-added parts are taken into account. Implies both economic and environmental value.
 - *Potential for higher value-add from circular activities.* States how much more value could potentially be added through circular economy activities; e.g. the theoretical amount of intrinsic material value, value added services, and longer lifetime. Implies both economic and environmental value.
 - *Feasibility in terms of cost and complexity of implementation.* Sizes the estimated feasibility of improving circularity, accounting for e.g. whether products/materials cross borders or not, how materials are mixed, the cost of separation, and feasibility to engage customers.

Figure A1: Summary of methods and data used in the sector selection in the Denmark pilot

Sub-dimension	Quantity	Type of calculation	Calculation	Weight	Sources
A.1 Sector contribution to national economy in terms of gross value add	Total GVA	Quantitative	Normalised Index	2/3	Statistics Denmark.
	10-year CAGR	Quantitative	Normalised index, shifted so that lowest value = 0	1/3	
	Total Employment	Quantitative	Normalised Index	2/3	
	10-year CAGR	Quantitative	Normalised Index, shifted so that lowest value = 0	1/3	
A.2 Sector contribution to national employment and job creation	Export volume	Quantitative	Normalised Index	2/3	Statistics Denmark.
	Import volume	Quantitative	Normalised index	1/3	
A.3 Competitiveness – trade openness and security of supply	Patent activity	Qualitative	Normalised, semi-quantitative scoring where high=10, mid=5, low=1	1/4	Based on patent activity in relation to other countries distributed on technology areas 2006-2009. Danish Ministry of Business and Growth, <i>Competitiveness – strength and potential</i> (2012); European Patent Office.
	Export specialization	Qualitative		1/4	
	Productivity advantage	Quantitative	Normalised Index	1/4	Indexed sector productivity compared international peers, to Danish Ministry of Business and Growth, <i>Competitiveness – strength and potential</i> (2012); EU KLEMS.
	Energy price sensitivity	Quantitative	Normalised energy expenditure as share of output value	1/4	
	Sum of A subdimensions			A.1 + A.2 + A.4 + A.4	
B.1 Material intensity	Sector's purchase of commodities as share turnover	Quantitative	Normalised Index	1	Statistics Denmark; data only available for manufacturing sectors and mining & quarrying.
	Waste volumes	Quantitative		2/3	Danish Environmental Protection Agency, <i>Afaldsstatistikken 2012</i> (2014); Statistics Denmark.
B.2 Environmental profile	Share of waste not recovered	Quantitative		1/3	Average manufacturing taken as value for all manufacturing sectors. Danish Environmental Protection Agency, <i>Afaldsstatistikken 2012</i> (2014)
	Intrinsic material value of output and waste	Qualitative	Semi-quantitative scoring of each quantity, where high=10, mid=5, low=1; total score is the normalised product of all 4 scores		Ellen MacArthur circular economy team analysis; industry and environmental experts.
	Potential for higher value-add from circular activities	Qualitative			
	Feasibility in terms of cost and complexity of implementation	Qualitative			
Sum of B subdimensions			B.1 + B.2 + B.3		

NOTE: GVA = gross value added; CAGR = compound annual growth rate.

Figure A2: Overview of scoring of ‘Role in national economy’ in the Denmark pilot




























































1 Green: value add/employees >4% of total, CAGR >3%; Red: value add/employees <1% of total; CAGR <0%, Orange: value add/employees 1-4% of total, CAGR 0-3%.

2 Green: imports/exports >5% of total; Red: imports/exports <1% of total; Orange: Imports/exports 1-5% of total.

3 Semi-quantitative.

SOURCE: Ellen MacArthur Foundation.

Figure A3: Overview of scoring of ‘Circularity potential’ in the Denmark pilot

	 High	 Medium	 Low	 Information n/a
	 B.1	 B.2		 B.3
SECTORS	Material intensity¹	Waste generated²	Share not recovered³	Score for improved circularity
Pharmaceuticals				
Machinery				
Food and Beverages				
Basic Metals and fabricated products				
Electronic products				
Rubber and plastic products				
Construction				
Hospitals				
Mining and quarrying				
Shipping				
Electricity and gas				
Agriculture, forestry and fishing				
Water supply, sewerage				

1 Green: material value >40% of sales turnover; Red: material value 10% of sales turnover; Yellow: material value 10-40% of sales turnover.

2 Green: waste generated ≥10%; Red: waste generated <1%; Yellow: waste generated is 1%-10% of total waste in Denmark

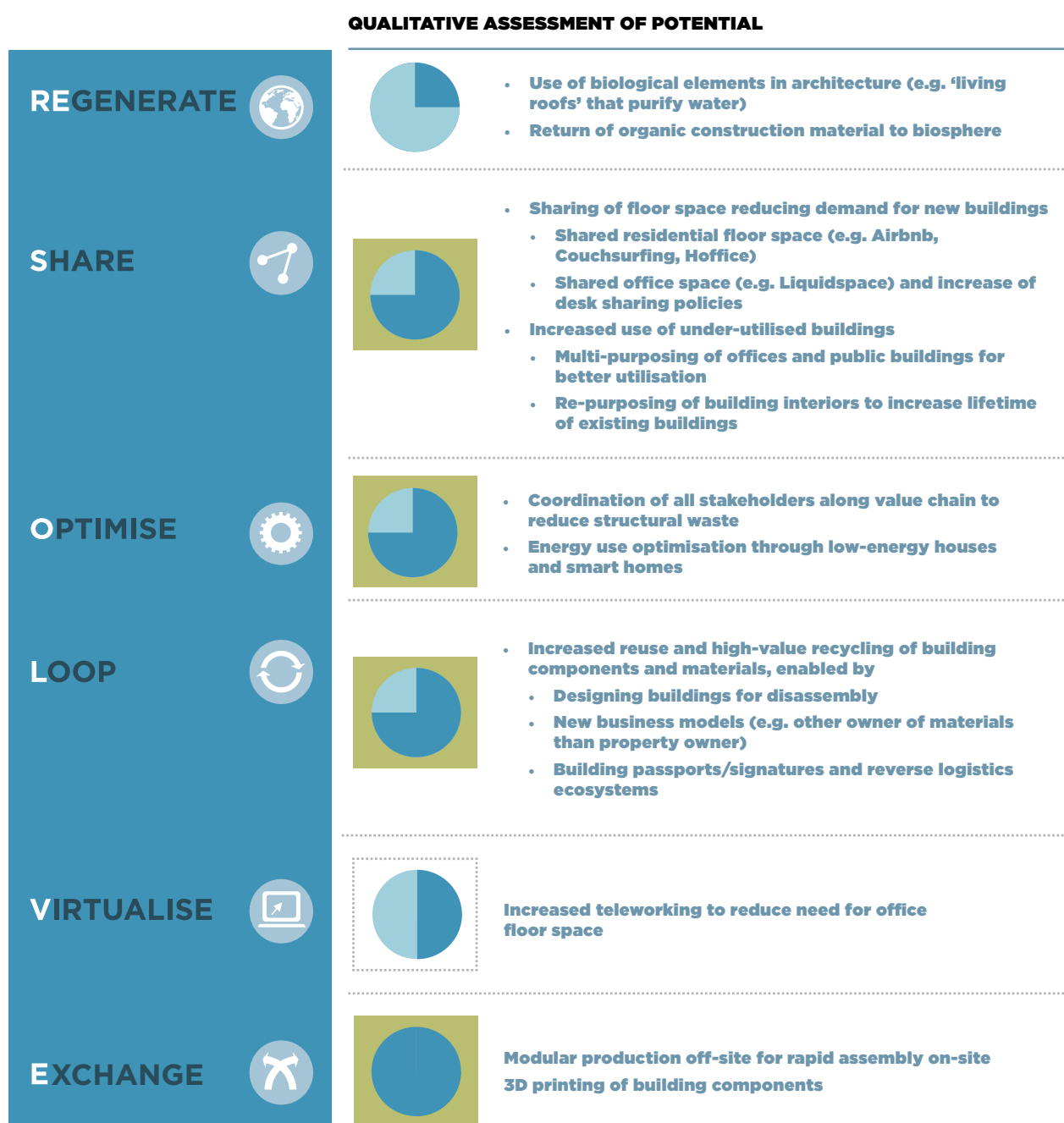
3 Share of waste not recycled.

SOURCE: Ellen MacArthur Foundation.

B Opportunity prioritisation and sector impact assessment

This appendix describes the assumptions and calculations behind the opportunity prioritisation and impact assessment for each focus sector in the Denmark case study. The methodology for the assessment is described more detail in Sections 2.2.1 – 2.2.3 of the toolkit report. It begins with a qualitative assessment and prioritisation using the ReSOLVE framework, followed by a quantitative impact assessment (where possible). Figure B1 provides a detail of this qualitative assessment for the construction sector.

Figure B1: Qualitative assessment of potential of opportunities for the Construction & Real Estate sector in the Denmark pilot



SOURCE: Ellen MacArthur Foundation



The ten prioritised opportunities in the Denmark case study span one or more actions in the ReSOLVE framework, as described below.

Food and beverage:

- Value capture in cascading bio-refineries (Loop; implicitly Regenerate if more organic materials are returned to the bio-cycle). Impact assessment described in Figure B3.
- Reduction of avoidable food waste (Optimise). Impact assessment described in Figure B4.

Construction and real estate:

- Industrialised production and 3D printing of building modules (Optimise, Exchange). Impact assessment described in Figure B5.
- Reuse and high-value recycling of components and materials (Loop). Impact assessment described in Figure B5.
- Sharing and multi-purposing of buildings (Share; implicitly Virtualise as an enabler). Impact assessment described in Figure B6.

Machinery:

- Remanufacturing and new business models (Loop; implicitly Share as opportunity is partly enabled by performance models that imply access over ownership and design for upgradability). Impact assessment described in Figure B7.

Packaging:

- Increased recycling of plastic packaging (Loop). Calculation of additional plastic material recycling described in Figure B8.
- Bio-based packaging where beneficial (Regenerate).

Hospitals:

- Performance models in procurement (Loop, Share). Impact assessment described in Figure B9.
- Waste reduction and recycling in hospitals (Loop, Optimise).

A quantitative impact assessment was conducted for seven of these opportunities, following the method described in Section 2.2.3 in the toolkit report. The driver tree in Figure B2 can illustrate this method and its key components are outlined below.

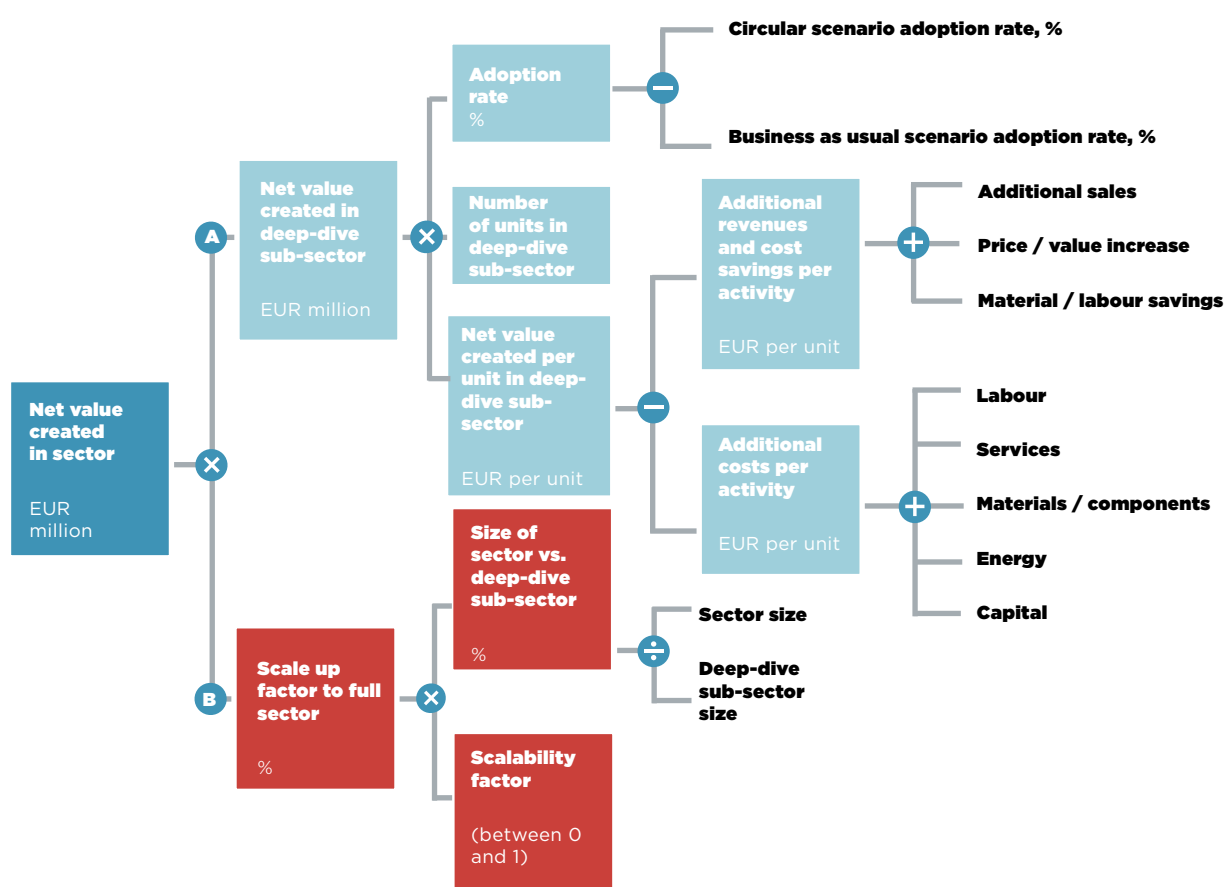
Branch A. Net value created in deep dive sub-sector. The net value creation is defined as a product of the overall adoption rate of the circular economy opportunity, the number of ‘units’ addressed, and the net value created per unit.

- Adoption rate. The adoption rate is a quantitative answer to the question ‘How widely will this opportunity have been adopted in a circular scenario?’ where 100% means full realisation of the potential. In the Denmark pilot, the adoption rates were always expressed as a difference between the circular scenario (2035 and 2020 horizons) and a ‘business as usual’ scenario (where some adoption rate is typically also greater than zero). This allows the model to take into account that circular economy opportunities will probably be adopted to some extent even in a non-circular scenario.
- Number of units in deep dive sub-sector. The number of units is used to denote any quantity used as the basis of the quantification in the subsector. The unit could be (an estimated) number of products, or a volume of material flow (such

as tonnes of organic waste). It could also be a monetary unit, such as ‘value of purchased goods’ or ‘output of new buildings’.

- Net value created per unit. Circular activities bring two kinds of direct financial benefits to businesses: (i) cost savings from materials, components or labour (for example due to parts recovery or virtualisation), and (ii) increased revenues (from additional sales and/or a higher unit price). Additional costs include increased labour costs, increased material/component costs (for example to design more robust products), and increased energy and capital expenditure, for example to set up bio-refineries or remanufacturing plants. These elements can all be assessed separately (as was done in the Denmark pilot), or, alternatively, for a high-level estimate, in one value (e.g. 5% net cost savings per unit). They can also be assessed for consumers rather than businesses (as in, for example, the reduction of avoidable food waste).

Figure B2: Schematic overview of sector-specific impact quantification



SOURCE: Ellen MacArthur Foundation

Branch B. Scale-up factor. The scale-up factor is used to bring the net impact estimated for the deep-dive sub-sector to the full sector (and adjacent sectors). The calculation is driven by the relative size of the adjacent sub-sectors compared to the deep dive sub-sector, and a ‘scalability’ factor introduced to reflect the relative applicability of the circular economy opportunity in different sub-sectors. The final scale-up factor is the sum of each individual scale-up factor for all sub-sectors present.

- Relative size of sub-sector. This calculation is based on the relative economic size of the individual sub-sectors, for example calculated by comparing output or gross value added.

- Scalability factor. This value, set between 0 and 1, is introduced to adjust the scaling based on how applicable an opportunity is to an adjacent sub-sector compared to the deep-dive subsector. For example, a scalability factor of 0.2 means that the impact is estimated to be 20% of the impact estimated for the deep-dive sub-sector.

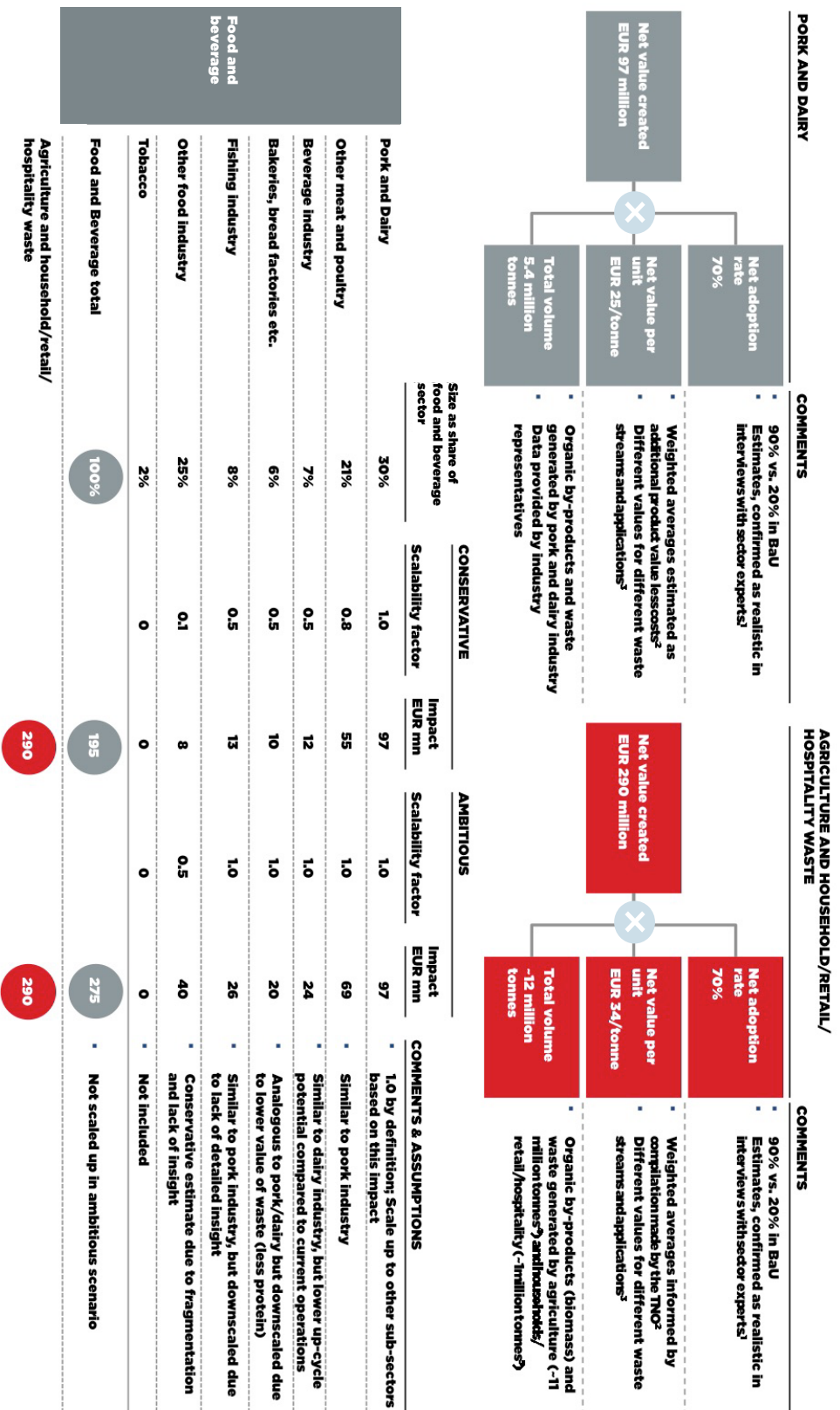
Figures B3–B9 summarise the assumptions, estimates and scaling for each of impact assessments, along with the sources used. An overview of the types of sources for estimates per opportunity is provided in Figure B10. These assumptions should be read in light of the scenario description detailed in Figure 8.

While the quantification of circular economy opportunities follow the approach in Figure B2 in general, variations were introduced to account for differences in the nature of each opportunity. A calculated example of one of the opportunities is given in the section below. In Figures B3–B7, the ‘mini’ driver trees shown contain ‘Branch A’ of the driver tree, while the tabulated scale-up below is a representation of ‘Branch B’.

It should also be noted that due to variations in the use of scale-factors between the conservative and ambitious circular economy scenarios, the relative contribution of each opportunity to the total sector-specific presented in figures B3–B9 are different from those given in Figure 10, which are averages of these two scenarios.

Figure B3: Value capture in cascading bio-refineries

Impact assessment summary, 2035



NOTE: Results estimated for impact of industries inside Denmark only. This sector-specific impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling. BAU = business as usual.

SOURCES:

1 Five company / industrial organisation interviews and five sector expert interviews.

2 Additional price per tonne dependent on type of by-product/waste and its application. Energy production as biofuel/biogas estimated to generate additional EUR 20-30/tonne. New chemicals estimated to generate EUR 70-80/tonne. Costs estimated to 40-50% of product value.

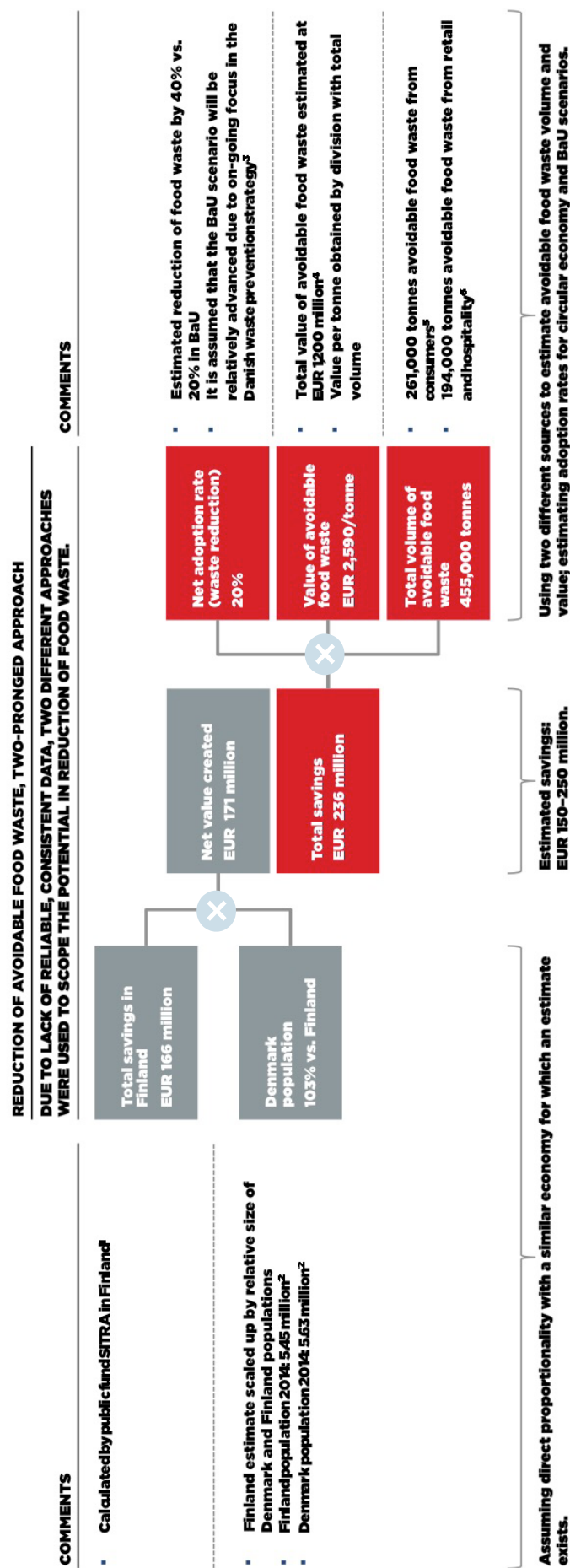
3 The Netherlands Organisation for Applied Scientific Research. Opportunities for a Circular Economy in the Netherlands (2013). Pricing estimates derived from approximate current and future prices for a 34 waste / by-product streams.

4 Danish EPA, Organiske restprodukter - vurdering af potentielle og behandlet mængde (2014); Kortlægning af madaffald i servicesektoren (2014); Kortlægning af dagrenovation i Danmark - Med fokus på etageboliger og madspild (2014).

5 Estimate, taken as 80% of waste generated by the food and beverage industry per EUR of GVA (from Statistics Denmark). See also M. Gylling et al., The 10+ million tonnes study: increasing the sustainable production of biomass for biorefineries, University of Copenhagen (2013), concluding that the agricultural sector could produce an additional 10 million tonnes of by-products for use in bio-refineries.

Figure B4: Reduction of avoidable food waste

Impact assessment summary, 2035



NOTE: Results estimated inside Denmark only. This sector-specific impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling. BaU = business as usual.

SOURCES:

1 SITRA, Assessing the circular economy potential for Finland (2015).

2 Eurostat.

3 Danish Government, Denmark without waste I (2013); Denmark uden affald II (2015).

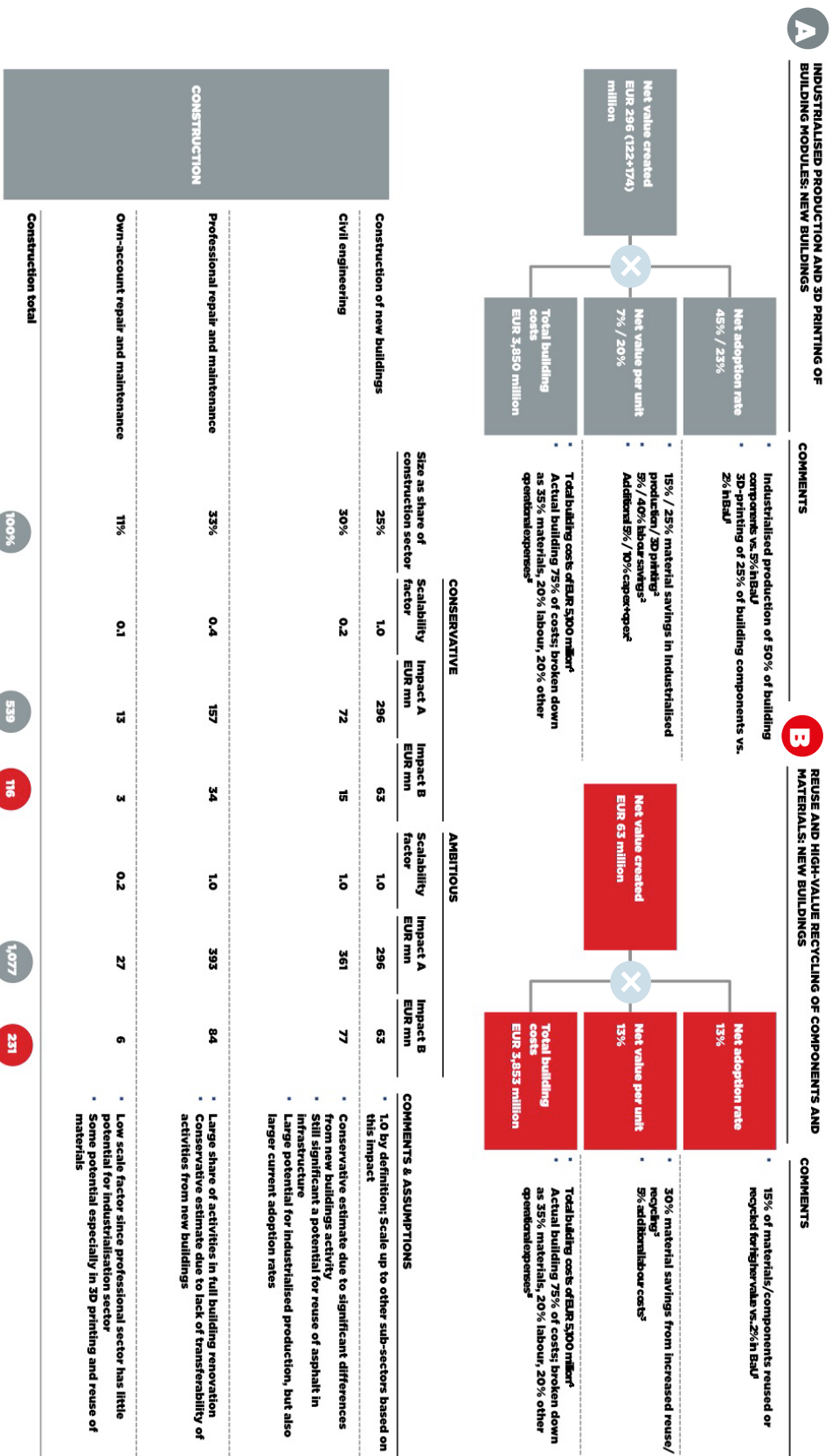
4 A. Halloran et al., Addressing food waste reduction in Denmark (Food policy 49, 2014).

5 Danish Environmental Protection Agency, Kortlægning af dagsrenovation i Danmark – Med fokus på etageboliger og madspild (2014).

6 Danish Environmental Protection Agency, Kortlægning af madaffald i servicesektoren: Detailhandel, restauranter og storkøkkener (2014).

Figure B5: Industrialised production and 3D printing of building modules; reuse and high-value recycling of components and materials

Impact assessment summary, 2035



NOTE: Results estimated for impact of industries inside Denmark only. This sector-specific impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling. BaU = business as usual.

SOURCES:

1 Estimate, informed by three company interviews and three sector expert interviews.

2 Estimates based on reported savings by the Broad Group and Winsun, consolidated in expert interviews. 3D printing savings estimated as 50% of Winsun's reported savings, since there is still very little data to exemplify cost savings. Actual savings will vary on a case-by-case basis and be dependent on the size and complexity of components being 3D printed. See also Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, *Growth Within: A Circular Economy Vision for a Competitive Europe* (2015); www.archdaily.com/289496/; <http://www.whbm.com/index.php?siteid=3>

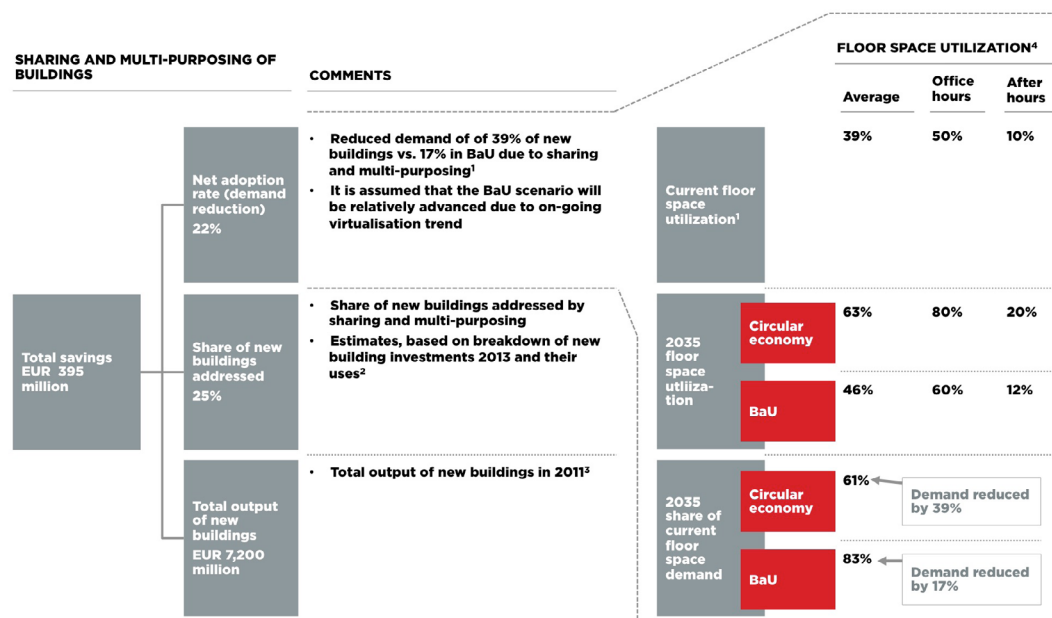
3 Estimates, informed by literature and expert interviews. See, e.g. US Environmental Protection Agency, Using Recycled Industrial Materials in Buildings (2008); Skive municipality, Afslutningsrapport Projekt Genbyg Skive (2015).

4 Statistics Denmark.

5 P.-E. Josephson & L. Saukkorilpi, Waste in construction projects: call for a new approach (Chalmers University of Technology, 2007); M. Hogan, The Real Costs of Building Housing (SPUR, 2014).

Figure B6: Sharing and multi-purposing of buildings

Impact assessment summary, 2035



NOTE: Results estimated for impact inside Denmark only. This sector-specific impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling. BaU = business as usual.

SOURCES:

1 Estimate, informed by literature: GSA Office of Government-wide Policy, Workspace utilisation and allocation benchmark (2011); Cushman & Wakefield, Office space across the world (2013); vasakronan.se/artikel/det-digitala-arbetslivet-ar-har; SITRA, Assessing the circular economy potential for Finland (2015); Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, *Growth Within: A Circular Economy Vision for a Competitive Europe* (2015).

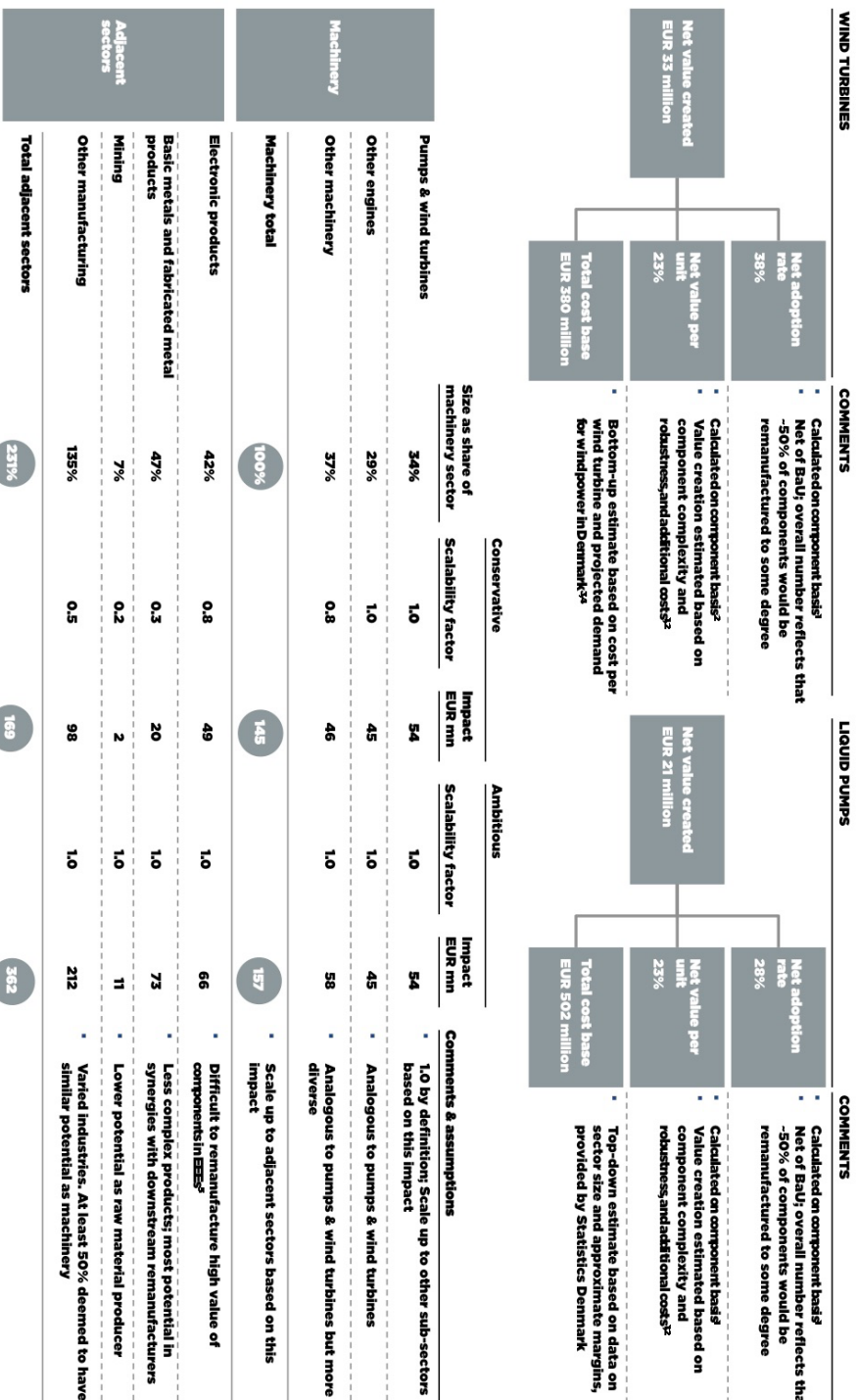
2 Statistics Denmark; 100% of commercial buildings; 10% of residential, small residential, small non-residential buildings; 50% of public buildings and sports buildings.

3 Statistics Denmark.

4 Office hours = 10 hours per day, After hours = 4 hours per day. Current utilization during office hours taken as 20% higher than reported by GSA.

Figure B7: Remanufacturing and new business models

Impact assessment summary, 2035



NOTE: Results estimated for impact of industries inside Denmark only. This sector-specific impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling. BaU = business as usual.

SOURCES:

- Five sector experts were interviewed for the analysis of cost breakdown and value potential; findings tested on high level with six Danish company and industry representatives.
- Towards the Circular Economy Vol. 1, Ellen MacArthur Foundation (2012): Assessing Circular Economy potential for Finland, SITRA/McKinsey (2014).
- Cost breakdown and technical complexity per component gathered from, a.o.: LCA analysis on Vestas V112 model, PE (2011); E.ON Wind Turbine Technology and Operations Factbook (2013); Windpower Engineering & Development (2012), <http://www.windpowerengineering.com/design/mechanical/understanding-costs-for-large-wind-turbine-drivetrains>; EWEA (2009).
- Wind power demand: Coarse grained estimates based on projections by BTM/Navgant, McKinsey & Co., and DWIA.
- However, larger secondary value may be derived from successfully remanufactured / refurbished EEEs, as stated by, e.g. Ricoh.

Figure B8: Increased recycling of plastic packaging

Impact assessment 2013

	Packaging waste generated ¹	Baseline collection rate ¹	Baseline recycling yield ²	2035 collection rate ³	2035 recycling yield ⁴	Net additional recycling ⁵
Businesses	LDPE	47	41%	80%	85%	21
	HDPE	13	62%	80%	85%	3
	PET²	N/A	N/A	N/A	N/A	N/A
	PP	10	69%	80%	85%	2
	PS+EPS	7	58%	80%	85%	2
	Other	6	93%	80%	93%	1
	Total	83	53%	80%	86%	29
Households	LDPE	58	3%	50%	68%	29
	HDPE	15	5%	50%	68%	7
	PET	7	90%	95%	90%	-
	PP	12	5%	50%	68%	6
	PS+EPS	9	5%	50%	68%	4
	Other	1	65%	50%	68%	0
	Total	101	10%	50%	69%	48

NOTE: This sector-specific impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling.

SOURCES:

1 Total volumes: Danish Environmental Protection Agency, Statistik for emballageforsyning og indsamling af emballageaffald 2012 (2015). Volume distribution and recycling rates are reconciled from 2008 data provided by the Danish Environmental Protection Agency.

2 Accurate data for PET not included in used data set. The the recycling rate is therefore assumed not to change, thus giving a zero contribution to the 2035 scenario.

3 Estimates, based on interviews with sector experts from the waste management industry and the Danish Environmental Protection Agency.

4 Estimates, based on interviews with sector experts and ambition levels presentet in the Denmark without waste strategy. Danish Government, Denmark without waste. Recycle more, incinerate less (2013).

5 Calculated as the sum of additional volume collected by 2035 at 2035 yield and the additional yield of the collected baseline volume.

Figure B9: Performance models in procurement in the hospital sector

Impact assessment summary, 2035

Product category	Share of purchasing volumes ¹	Adoption rates (vs. BaU)	Cost savings per unit ³	Total cost savings
Diagnostic imaging and radiation equipment	28%	✗ 50% (10%)	✗ 30%	= 40%
Laboratory, observation and test equipment	32%	✗ 50% (10%)	✗ 24%	= 36%
IT equipment	9%	✗ 50% (10%)	✗ 30%	= 13%
Surgical equipment	22%	✗ 20% (0%)	✗ 15%	= 8%
Medical apparel and textiles	9%	✗ 80% (60%)	✗ 15%	= 3%
Total	100% = EUR 983 mn	✗ 46% (12%) ⁴	✗ 25% ⁴	= 100% = EUR 83 mn

NOTE: This sector-specific impact does not include indirect effects, e.g. on supply chains, that are captured in the economy-wide CGE modelling. BaU = business as usual.

SOURCES:

1 Statistics Denmark, Danish Regions

2 Estimates, informed by 4 company interviews; 4 hospital / sector expert interviews

3 Savings rate depends on product category. Based on expert interviews with healthcare equipment providers and case studies from performance contracts in other industries (e.g. white goods, automotive, printers). The distribution of savings between hospitals and suppliers has not been modelled. It could be argued that it is skewed towards hospitals in the short term since suppliers want to create incentives for hospitals to set up performance contracts, but could equilibrate at a more even split in the long-term as the model gets established and consolidated.

4 Weighted averages of product categories

Figure B10: Key sources for assumptions & estimates for each circular economy opportunity

Circular economy opportunity		Addressable value pool[1]	Value creation and costs		Adoption rate
Food & beverage	1	Value capture in cascading bio-refineries	Literature/reports, Interviews, Danish EPA	Literature/reports, interviews	Literature/reports, Interviews
	2	Reduction of avoidable food waste	Danish EPA	Literature/reports, interviews	Interviews
	3	Industrialised production and 3D printing of building modules	Literature/reports, interviews	Interviews	Interviews, Danish EPA
Construction & Real estate	4	Reuse and high-value recycling of components and materials	Literature/reports, interviews	Interviews	Interviews, Danish EPA
	5	Sharing and multi-purposing of buildings	Literature/reports	Interviews	Interviews
	6	Remanufacturing and new business models	Literature/reports, DBA	Interviews, literature/reports	Interviews, literature/reports
Machinery	7	Increased recycling of plastic packaging	Danish EPA	Literature/reports, interviews	interviews, Danish EPA
	8	Bio-based packaging where beneficial	Interviews	N/A	N/A
Plastic packaging	9	Performance models in procurement	Danish Regions, interviews	Literature/reports, interviews	Interviews
	10	Waste reduction and recycling	N/A	N/A	Interviews
Hospitals					

1 Sizes of product categories or sub-sectors provided by Statistics Denmark

Legend:

- Literature/reports – Published studies from institutes, businesses or academia
- Interviews – company experts and/or external experts
- Danish EPA / DBA – data and/or interviews from Danish EPA or DBA
- Danish regions – data on public expenditure from Danish regions
- N/A – data not collected (no quantification made)

Impact assessment: Value capture in cascading bio-refineries

The following summarizes the impact quantification for the pork and dairy sub-sectors of the food and beverage sector, as summarised in Figure B3. It should be noted that the estimated valorisation is an addition or supplement to current valorisation pathways, which is reflected both in the adoption rate and net value added per unit volume. Only existing technologies (at R&D or early commercial stage) have been considered as part of this opportunity.

- Adoption rate. Overall, the technologies required to produce high-value products (e.g. proteins, nutraceuticals, or food ingredients) are at R&D or pilot stage, wherefore the 2020 adoption rate was set to 20% (vs. 0% in the BaU scenario). By 2035, however, it is reasonable that all these enabling technologies, along with capital to build capacity, will be available in a circular scenario, leading to a 90% adoption rate assumption (vs. 20% in BaU). These assumptions were stress-tested with experts and also seen to correlate well with the recent TNO report on the Dutch economy.
- Total volume and different waste streams. The total waste volume from both industries was broken down into sub-components to reflect different value creation opportunities for different types of waste. Each waste volume and its composition were estimated using direct data and interviews with industry experts, and was assumed to be constant over the modelled time period.
 - Pork industry: ~3.9 million tonnes per year, divided as 94% wastewater slurry, 1% bone meal, fat, grease and mycosa, 1% hair, bristles and hooves, and 4% manure, gut content and other waste.
 - Dairy industry: ~1.5 million tonnes per year, divided as 89% whey and other former foodstuffs, and 11% other waste.
- Net value per unit volume. Two main sources of value were considered: extraction or synthesis of (bio)chemicals, or energy through either biofuel or direct energy extraction.
 - For modelling purposes, these two value creation pathways were separated into the 'Food and beverage' (FBV) sector, the 'Chemical industry, plastics and pharmaceuticals' (CHM) sector and the 'Gas and heat' (GDT) sector. (See Appendix C for details on sector categorisation in the Danish economy.)
 - The value creation was expressed in terms of EUR/tonne waste or by-product material, and was individually estimated for each identified waste stream (see above) and value creation activity. Initial pricing estimates were derived from approximate current and future prices for 34 waste / by-product streams in the recent TNO report and discussed with experts before finalized.
 - The value creation was expressed as a price 'delta' compared to current prices, taking into account that most waste is currently valorised in some way. The price 'deltas' thus reflect the increase in value creation that can be unlocked through improved technologies and processes. In some cases, the 'deltas' were increased between the 2020 and 2035 scenario, to reflect an increase in maturity for technologies that require a longer time to develop. The price delta per waste stream and sector is summarised in Figure B12.
 - At the same time, an estimate of volume allocation to the three sectors was conducted, based on assumptions on technological maturity and demand-pull from the respective sectors. It is assumed that a fraction of the waste / by-product streams is valorised by the pork / dairy processors themselves. This fraction is generally increased from 2020 to 2035, as valorising by-products becomes an increasingly important part of the food processor's

business model. The volume allocation per waste stream and sector is summarized in Figure B11.

- Costs were expressed as percentages of the value created per waste stream.
 - For the CHM and GDT sectors, the costs were as follows: Materials 10%, Labour 10%, Services 5%, Capital 25% (reflecting an expected raw material price increase due to the higher value of waste-derived products the need for capital expenditure to build new plant capacity). The material cost is booked as additional revenue for the pork/dairy processors (as the waste / by-product streams are sourced from them).
 - For the FBV sector, the costs were as follows: Labour 10%, Capital 25% (assuming no material sourcing or external services needed as bio-refining becomes an integrated part of existing operations).

As an example, consider wastewater slurry valorisation from the pork industry (3.7 million tonnes).

By 2020, a 20% adoption rate entails that ~750 thousand tonnes are processed to add additional value compared to business as usual. The assumed price deltas for the CHM and GDT sectors are 30 and 20 EUR/tonne, respectively. The volume distribution is 10% vs. 90%, i.e. most of the wastewater will go to generate biofuels and heat. The pork industry does not generate any additional value from this waste stream, but will get revenue of 10% (3 and 2 EUR/tonne respectively) from selling the wastewater to these adjacent industries. In addition, 80% of the volume valorised by the CHM sector is cascaded to the GDT sector for additional valorisation. After subtracting the 50% cost base, the CHM sector generates a net value of EUR 1.1 million. The GDT sector generates EUR 6.7 million plus EUR 0.6 million from material streams cascading from the CHM sector. Finally, the Pork industry generates an additional EUR 1.6 million from the price premium of the material streams sold to the CHM and GDT sectors. The net value created from the wastewater slurry is thus EUR 10 million. Adding up the other five material streams from pork and dairy gives a net value creation of EUR 16.2 million.

By 2035, the net adoption rate is 70% (90% vs. 20% in BaU), meaning that ~2.8 tonnes are processed. The shift in volume share towards more valuable products and the higher value per tonne yields EUR 15.6 million for the CHM sector, 30.6 million for the GDT sector (21.9 million from direct material allocation and 8.7 million from cascaded material from the CHM sector), and 11.7 million from the pork industry (including inhouse valorisation and revenues from selling wastewater to CHM and GDT). The net value created from the wastewater slurry is thus EUR 57.9 million. Adding up the other five material streams from pork and dairy (totalling 70% of 5.4 million tonnes) gives a net value creation of EUR 97 million, corresponding to an average net value of 25 EUR/tonne (as illustrated in figure B3).

Figure B11: Pork and Dairy – Price ‘delta’ per sector and waste stream

		2020 scenario			2035 scenario		
EUR / tonne		Food processor	Chemical Industry	Gas & heat	Food processor	Chemical Industry	Gas & heat
PORK	Wastewater slurry	-	30	20	32	40	28
	Bone meal, fat, grease, mucosa	-	-	20	8	10	20
	Hair, bristles, hooves	80	100	20	480	600	20
	Manure, gut, other	-	-	20	8	10	20
DAIRY	Whey & former feedstuffs	40	50	20	40	50	28
	Other waste	40	50	20	40	50	28

NOTE: Prices are relative to estimates of current prices per waste stream

Figure B12: Pork and Dairy – volume allocation per sector and waste stream

		2020 scenario			2035 scenario		
Percent		Food processor	Chemical Industry	Gas & heat	Food processor	Chemical Industry	Gas & heat
PORK	Wastewater slurry	0%	10%	90%	10%	30%	60%
	Bone meal, fat, grease, mucosa	100%	0%	0%	60%	40%	0%
	Hair, bristles, hooves	10%	20%	70%	70%	30%	0%
	Manure, gut, other	0%	0%	100%	40%	30%	30%
DAIRY	Whey & former feedstuffs	20%	10%	70%	40%	20%	40%
	Other waste	0%	20%	80%	0%	50%	50%

C Economy-wide impact quantification

Economy-wide impact assessment methodology

The economy-wide impact assessment was conducted using NERA Economic Consulting's N_{ew} ERA global model. A multi-sector, multi-region trade, dynamic computable general equilibrium model. The model uses standard macro and microeconomic theory to represent the flow of goods and factors of production within the economy. A simplified version of these interdependent economic flows is shown in Figure C1. It illustrates the flow of goods, services and payments in a typical CGE set up between the different economic agents in the domestic and international markets.

In the model, there is a representative household in each region. Households supply factors of production, including labour and capital, to firms. In return, firms provide households with payments for the factors of production. Firm output is produced from a combination of productive factors and intermediate inputs of goods and services supplied by other firms. The final output of individual firms can be consumed within Denmark or exported. The model also accounts for imports into Denmark. Goods and services in the model are treated as 'Armington' goods and services, that is, imported and domestically produced goods and services are assumed to be only imperfect substitutes.

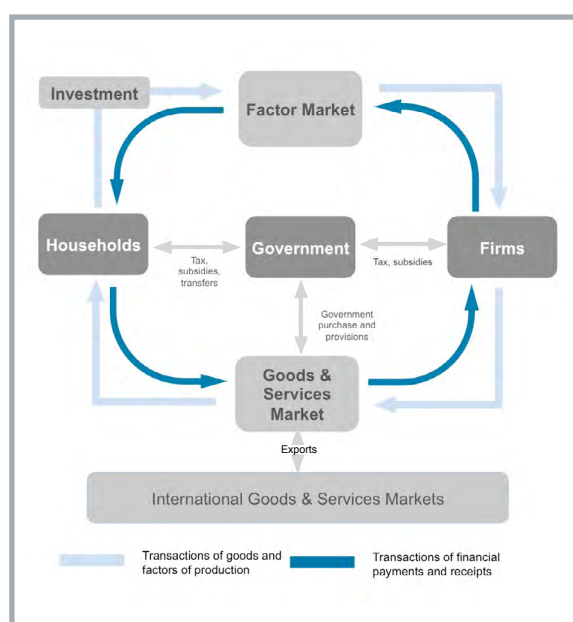
In addition to consuming goods and services, households can accumulate savings, which they provide to firms for investments in new capital. Taxes are collected by a passive government, which recycles tax receipts back to the households as lump-sum transfers.

Another feature of the CGE framework is that all markets are required to clear, meaning that the sum of regional products and factors of production must equal their demands, and that the income of each household must equal its factor endowments plus any net transfers received. In other words, there can be 'no free lunches'. The model assumes general equilibrium, which requires that for all sectors, regions and time periods, there is a global equilibrium where supply and demand are equated simultaneously, as producers and households anticipate all future changes. The mechanism by which this is achieved is through price changes.

To analyse the economic impact of scenarios (e.g. structural change from increased circularity in the economy), CGE models such as the N_{ew} ERA model represent the interactions and feedback effects in the exchange of goods and services simultaneously between consumers, producers and government and across sectors, regions and time. They are therefore particularly useful to assess both the direct and indirect effects of structural changes and are able to analyse scenarios of changes to the economy with potentially large impacts that have not been implemented in the past.

Limited work has been done to date in modelling the circular economy in a CGE framework. Our review of the literature identified just two sources that would qualify as economic impact assessments of the circular economy using hybrid or CGE frameworks.¹ At the time of writing, to our knowledge, there are no CGE models that can fully

Figure C1: Overview of a Computable general equilibrium (CGE) model



¹ *Assessment of Scenarios and Options towards a Resource Efficient Europe*, European Commission (2014), and *A National CGE modeling for Resource Circular Economy*, Korea Environment Institute (2006).

represent the attributes of a truly circular economy. These include: inputs and material substitutions; changes in resource productivity and production technology; new circular economic sectors, their services and products; priced externalities; and the generalised changes in the stocks and flows of goods, capital, labour and materials.

CGE model description

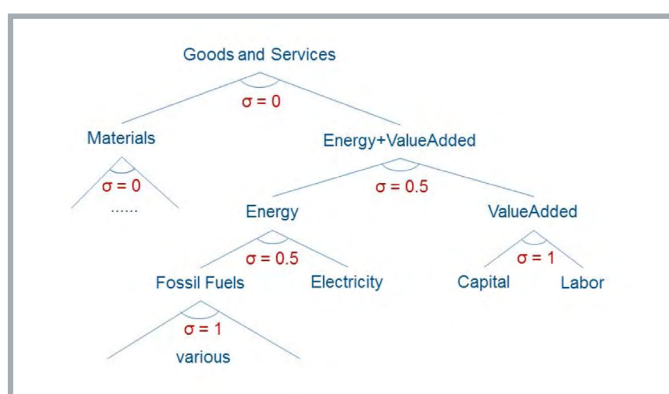
The CGE model used for the analysis represents five world regions: Denmark and its main trading partners, which have been aggregated as the Rest of Europe, China, Oil exporting countries and Rest of the world. Different aggregations of the economic sectors were used for Denmark and the other regions. In Denmark there are 21 economic sectors (16 non-energy and 5 energy sectors), while in the rest of the world 17 economic sectors (12 non-energy and 5 energy) were represented. From a time perspective, the model was set up to span between 2015 and 2035 and was run in 5-year time increments. These sectoral and geographic dimensions are summarised in Figure C2.

Figure C2: Sectoral and geographical aggregates in the CGE Model in the Denmark pilot

SECTOR	DESCRIPTION	REGION	
		Denmark	EU, China, OPEC, RoW
GAS	Natural gas works	Yes	Yes
OIL	Refined oil products	Yes	Yes
COL	Coal transformation	Yes	Yes
CRU	Crude oil	Yes	Yes
ELE	Electricity, gas and heat		Yes
ELY	Electricity	Yes	
GDT	Gas and heat	Yes	
MEP	Machinery and electronic products	Yes	Yes
CNS	Construction - New buildings and infrastructure	Yes	Yes
CNS-Repair	Construction - Repair and maintenance of buildings	Yes	
FBV	Food and beverages	Yes	Yes
CHM	Chemical industry, plastics and pharmaceuticals	Yes	Yes
AGR	Agriculture, forestry and fishing	Yes	Yes
FAB	Basic metals and fabricated metal products	Yes	Yes
MIN	Mining	Yes	Yes
AOG	Other manufacturing	Yes	Yes
WRH	Services - wholesale, retail and hospitality	Yes	Yes
SER	Services		Yes
RPD	Services - Repair of machinery and other durables	Yes	
RNT	Services - Renting of buildings	Yes	
HSP	Services - Hospitals	Yes	
SOT	Services - other	Yes	
TRN	Transport	Yes	Yes
WTR	Sewerage and waste management	Yes	Yes

Producer behaviour in the model is characterised by a ‘production function’. A production function represents how different inputs are used to manufacture a commodity or service. For example, production of machinery requires capital, labour, energy, and other materials as inputs. Parameters in the production function define the way in which substitution between inputs and outputs changes in response to changes in the relative prices of inputs and outputs. These price-induced substitution relationships are called ‘elasticities’. Figure C3 provides an illustrative representation of a production function. The sigmas (σ) shown are illustrative substitution elasticities between the different inputs. Consumer behaviour, the production of natural resources and regional trade are similarly represented in the CGE model by these ‘nested’ functions.

Figure C3: Generic structure of production functions in the CGE Model



SOURCE: NERA Economic Consulting.

Theoretically, there are several ways to represent the circular economy within a CGE framework and, as with any modelling exercise, choosing between options involves an effort versus quality trade-off. This trade-off will be between the availability of time, effort and data on the one hand, and the required quantity and quality of detail in representing circular economy activities, sectors and flows of goods, materials and externalities, on the other.

Figure C4 presents four potential approaches to represent circularity in a CGE framework and their pros and cons. For policymakers to select which of those approaches is best suited to their needs, there are three important aspects to consider:

1. Detail and precision in representation of economic relations in the circular economy (e.g. are sectors and services associated with circular economy activities to be explicitly modelled, e.g. product dismantlers in the refurbished goods supply chain?).
2. Degree and scope of representation of economic and materials flows (e.g. in addition to monetary flows, does the model need to explicitly represent physical flows of virgin materials, recovered/recycled materials, different by-product and waste types?).
3. Time and effort requirements, (duration of the assessment, access to internal and external experts and modellers) and data and assumption requirements (quantity of primary data readily available to model the required level of detail).

As shown in Figure C4, the approach selected for the Denmark pilot study was chosen as a balanced compromise between the three criteria above.

Figure C4: Potential approaches and trade-offs for representing circularity within a CGE framework

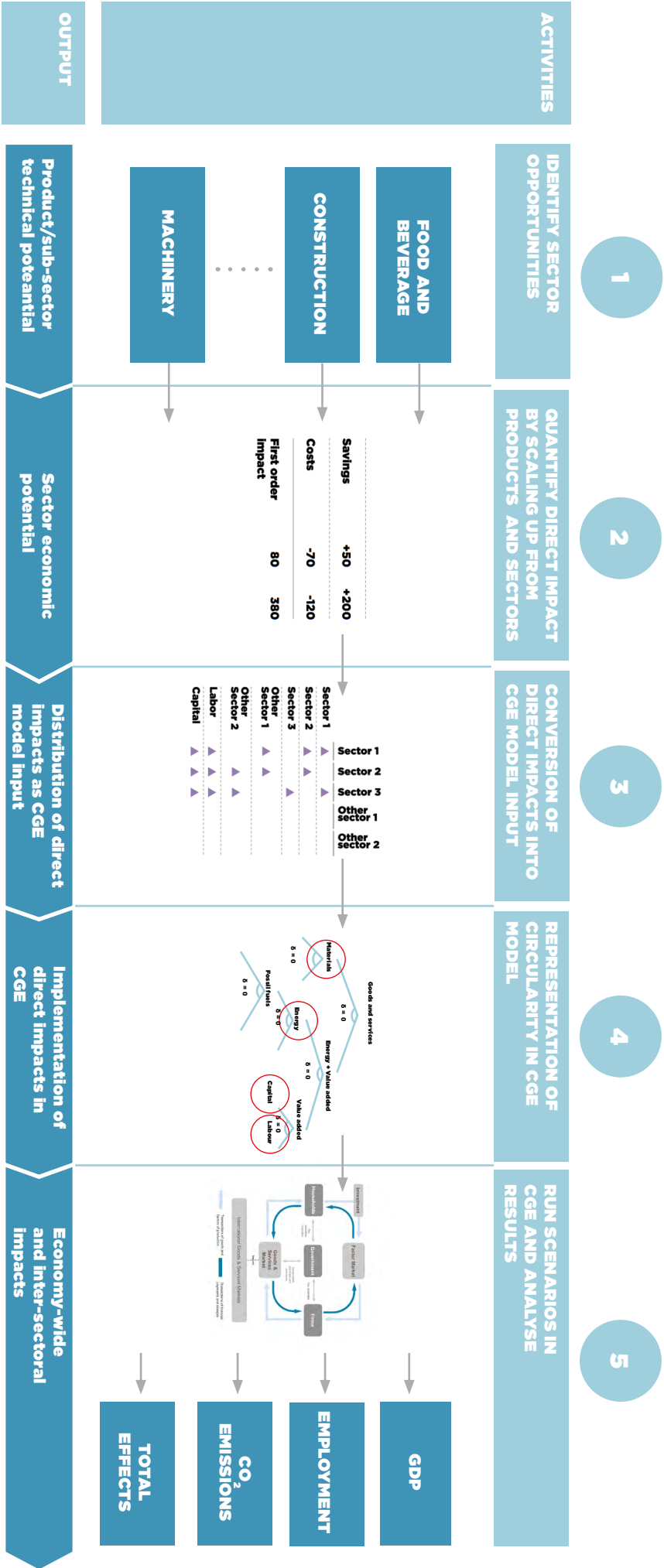
APPROACH DESCRIPTION	PROS	CONS
Use an existing CGE framework to model circularity as an increase in resource efficiency or changes in consumption preferences	Simplest approach to (partially) modelling circularity	<p>Very general representation</p> <p>Impacts depend on exogenous parameters (productivity or preferences)</p> <p>Partial representation or circularity, no structural change</p>
As part of a hybrid approach, re-estimate production functions in existing CGE structure to match the sector specific estimates of circularity	<p>Easy to implement bottom-up cost and output effects</p> <p>Captures direct effects on focus sectors and indirect effects on the economy</p> <p>Limited data requirements and easily replicable</p>	<p>Bottom-up cost and output effects are exogenous</p> <p>Materials flows not explicitly modelled (captured indirectly by financial flows)</p> <p>Only partial representation of structural change (no new technologies or sectors)</p>
Develop CGE structure that includes new circular activities (e.g. regenerate, share) as separate economic activities. Works with hybrid approaches.	<p>Does not require quantifying effects in an ad hoc manner</p> <p>Approximate size and some effects of circular economy can be quantified</p>	<p>Important time and effort requirement</p> <p>Significant requirement of detailed data / assumptions of new activities to calibrate model</p>
Develop CGE structure that represents all materials and value flows and represents all externalities in production and utility functions. Works with hybrid approaches.	<p>Highly detailed representation of circular sectors and flows</p> <p>Size and effects of circular economy quantified</p> <p>Circularity levers endogenously determined</p>	<p>Very time-intensive and complex modelling exercise</p> <p>Substantial data and assumptions requirements</p>
APPROACH SELECTED FOR DENMARK PILOT		

SOURCE: NERA Economic Consulting.

As described in Section 2.3.1 in the toolkit report, the hybrid approach consists of several steps preceding the actual CGE modelling. As illustrated in Figure C5, it begins with representing the impact induced by circular economy scenarios in the focus sectors in the form of an input-output table. These changes are then used to 're-parametrise' production (and utility) functions according to the following procedure:

- Interpolate input effects from cost savings (or increases) as well as output effects of revenue increases per focus sector for intermediate model years 2025 and 2030 based on the sector-specific quantification for years 2020 and 2035.
- Re-parametrise production functions (i.e. estimate new parameter values) to match decreases (or increases) in the values of input factors into the focus sectors relative to the baseline value.
- Re-parametrise production functions to match increases (or decreases) in the values of the output from focus sectors relative to the baseline value.
- Impose these time-varying changes in inputs and outputs for all model years (i.e. the input-output value structure of implementing the circular economy opportunities) by redefining (re-calibrating) the production formulae of all focus sectors.

Figure C5: Overview of a ‘hybrid’ CGE approach



SOURCE: NERA Economic Consulting, Ellen MacArthur Foundation

After re-parametrisation, the model is run and will optimise supply and demand of all commodities and services in the economy via price impacts. The results for the re-parametrised version of the production (and utility) functions now represent the circular economy scenario(s) in the CGE model and can then be compared to the baseline scenario.

Scenario descriptions, key assumptions and sources

- The macro-economic impact modelling was conducted by calibrating the CGE model to a 'baseline' (or business as usual) reference scenario and then quantifying the changes to key macroeconomic indicators after running a 'circular economy' scenario through the model. Two scenarios were assessed, a 'conservative' and an 'ambitious' version of the circular economy.
- As described above, the scenario inputs to the CGE model were modified input-output tables for Denmark for the years 2020 and 2035, where input and output values were adjusted based on the impact from the sector-specific opportunity assessment (see Chapters 2-6 Appendix B and Section 2.2.3 of the toolkit report). The macro-economic model therefore quantified the direct and indirect economy-wide effects that the sector specific structural changes would have on the broader Danish economy.

Baseline scenario. The baseline scenario was developed through the following steps:

- Incorporating the Denmark 2011 input-output table within the GTAP8 dataset and scaling other regions' economic flows by actual GDP growth from 2007 till 2011 such that a globally balanced dataset was achieved.
- Building in exogenously specified regional forecasts, including Danish projections
- Calibrating the baseline: Adjusting model parameters such that they replicate the macroeconomic outlook by targeting GDP, carbon emissions by sector and by fuel, energy price, and energy production projections. This baseline calibration resulted in a projection consistent with the baseline scenario assumptions.

Circular economy scenarios. From a macroeconomic modelling perspective, the key assumptions of the circular economy scenarios (for both the ambitious and conservative cases) were as follows:

- The functional form of the production and utility functions remain the same between the baseline and the circular economy scenarios.
- Behavioural parameter values of the utility function remain the same between the baseline and the circular economy scenarios.
- Energy sector assumptions remain the same between the baseline and the circular economy scenarios (i.e. no explicit modelling of an additional shift towards renewable energy).

Each circular economy scenario is represented by producing an input-output table that represents the changes induced by the circular economy opportunities, quantified as described in section 2.2.3 of the toolkit report. The allocation of changes in input factors (labour, materials, energy and capital) was done based on an analysis of the changes in demand due to the circular economy activities,² and from which sectors' key material inputs are provided in the current (2011) input-output table.

The main difference between the 'conservative' and 'ambitious' scenarios are how the impact assessed for the deep-dive sub-sector is scaled up to adjacent (sub-)sectors. This difference is described in detail in Appendix B.

Several data sources were combined to construct the baseline calibration and circular economy scenario analysis. These are summarised in Figure C6.

² For example: reduced demand for materials and increased demand for labour due to remanufacturing in machinery; reduced demand for labour and increased need for capital for industrialised production and 3D printing of building modules.

Figure C6: Data sources used in the baseline calibration and CGE modelling in the Denmark pilot

Data		Data source	
		Denmark	Rest of World
Benchmark year input/output table		Statistics Denmark	GTAP 8 database
Primary factor and commodity tax rates, output and export tax (subsidy) rates, and import tax rates	GTAP 8 database		
Substitution elasticities for production, consumptions functions	<ul style="list-style-type: none">• GTAP 8 dataset includes Armington elasticities, intra-import elasticity of substitution, factor substitution elasticities, factor transformation elasticities.• Other sources include:<ul style="list-style-type: none">- Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian and M. Babiker, 2005: The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4.- Mikkel Barslund, Ulrik R. Beck, Jens Hauch, Peter B. Nellemann, “MUSE: Model documentation and applications,” Danish Economic Council, Working Paper 2010:4.		
GDP and employment data and projections to 2035	DREAM group	1.A.1.1.1.1 EIA IEO 2013 ¹	
Energy demand data and projections to 2035	Danish Energy Agency (ENS) Statistics Denmark Own calculations		
Energy price data and projections to 2035			
Energy production data and projections			
CO2 emissions data and projection to 2035			

¹ US Energy Information Administration – International Energy Outlook 2013
<http://www.eia.gov/forecasts/archive/ieo13/>
 SOURCE: NERA Economic Consulting.

D Assessment of policy options

An initial mapping of policy interventions to barriers (see Section 2.2.5 in the toolkit report) can result in a large number of policy options. It can be useful as a first step to apply a high-level policy impact and cost assessment. Other factors such as time to implementation, time to achieve outcome, and distributional effects can also be taken into account. Such a high-level qualitative prioritisation can provide input for the subsequent due diligence and impact assessment/cost-benefit analysis in the policymaking process.

An example of such a prioritisation exercise for the ‘Value capture in cascading bio-refineries’ opportunity in the Danish pilot is found in Figure D1. Such a matrix can be the result of an analytical exercise as the one described in this appendix or can be made more directly based on expert input.

Figure D2 provides an overview of the basic arithmetic of the policy assessment tool developed for the Denmark pilot study. The tool is a workbook that contains 87 policy interventions identified to address the barriers to the circular economy opportunities in the five focus sectors. The goal of the tool is to rank the policies by their relative cost-effectiveness using a semi-quantitative scoring function. This is done by scoring each intervention on two dimensions, ‘impact’ and ‘cost’, from which a weighted ‘cost-effectiveness score’ is derived.

The development and implementation of the tool described here is one of many alternatives that policymakers can use as a first step to narrow down a long list of policy options to those with the best potential to address the barriers to circular economy opportunities. It should be noted that the main benefit of this tool was that it facilitated discussion. Ultimately, the final sets of policy options for each sector were determined with the help of significant input from government stakeholders and sector experts. While the approach outlined here is a useful first step, it is underlined that it is not meant as a substitute for adequate due diligence and impact assessment in the standard policy making process.

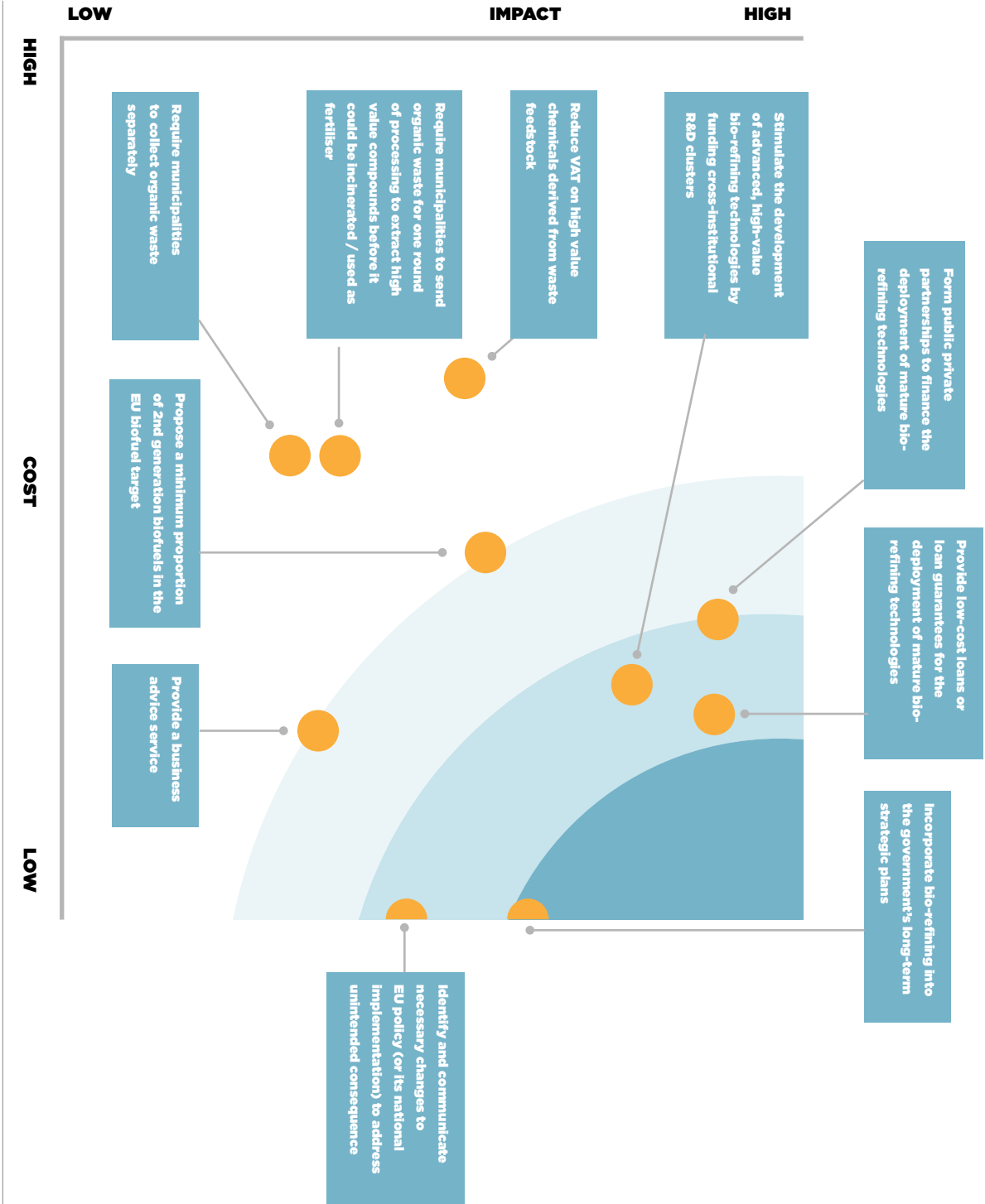
The scoring rules and methodology used to arrive at a prioritised set of policy options are described in detail below. Each policy intervention was scored independently of others, i.e. not allowing them to work in conjunction with any other policy, but keeping in mind their potential to work well as part of a package. All scores are relative, with comparisons made across several dimensions including policy types, circular economy opportunities and sectors to ensure adequate scoring distributions.

Scoring of impact dimension

The ‘impact score’ of a policy is the product of two equally weighted factors: the ‘importance of a barrier’, which builds on the detailed barrier analysis described in Section 2.2.4 of the main report; and the tentative effectiveness of the policy intervention at overcoming the barrier. The methodology, described in detail below, was systematically applied to all policy interventions to obtain a first set of impact scores, which were discussed and iterated in sector ‘deep dive’ sessions with multiple stakeholders.

- **Scoring the ‘importance of barrier’:** Based on expert judgment on the size/importance of the barrier to deliver the circular economy opportunity.
- **Scoring the ‘effectiveness’ in 2020 and 2035:** Based on an expert-guided estimate of how effective the policy intervention would be in addressing the barrier, given existing initiatives, over two time periods, equally weighted:
 - Short-term effectiveness (by 2020) with higher scores given to economic/fiscal incentives (subsidies, taxes, guarantees) and lower scores to information or R&D interventions.

Figure D1: Prioritisation of policy options – ‘Value capture in cascading bio-refineries



SOURCE: Ellen MacArthur Foundation; NERA Economic Consulting

- Long-term effectiveness (by 2035) with the same scores for economic/fiscal incentives and those for information or R&D increased or decreased where relevant.

Scoring of cost dimension

The 'cost' score of a policy is the product of two equally weighted factors:

'administrative

and transaction costs', determined by estimates and expert consultation; and wider economic costs of the intervention. The methodology, described in detail below, was systematically applied to arrive at a first set of cost scores, which were discussed and iterated in sector 'deep dive' sessions with multiple stakeholders.

- **Scoring the 'administrative and transaction costs':** Based on an expert-guided estimate of the combined cost incurred by government to set up and operate the policy and the cost to the private sector of complying with it.
 - Cost incurred by government refers to any foregone revenue or additional spending commitment entered into by the government by virtue of the policy.
 - Cost to the private sector refers to one-off adjustment costs and any increase in the cost of doing business caused by the policy.
- **Scoring the 'wider economic cost':** based on an expert-guided estimate of the cost-benefit trade-off between economic advantages and disadvantages in a sector created by the policy across government, businesses and consumers.
 - An example is a policy that reduces market competition creates advantages for businesses, but disadvantages for consumers. Similarly, a subsidy creates an advantage for its recipients, but disadvantages for the government.
 - The 'economic advantage and disadvantage' component focuses on each particular sector. The scoring has not taken into account the intrinsic benefits of the policy supporting circular economy activities, since they are addressed in the 'impact' score.
 - The 'balance across the economy' component looks at the average net disadvantage in other parts of the economy due to a sector-directed policy, but not on the distribution of advantages and disadvantages, which belongs to the political viability sphere.

The assessment does not incorporate the economy-wide computational general equilibrium modelling of the impact of circular economy opportunities.

The total impact and cost scores are combined to provide a rank between 1 and 3:

1. Impact and cost are both greater than 50 (out of 100), putting the policy on the short-list
2. One or other of the impact and cost scores is 50 or above, putting the policy in a 'supporting policy' category
3. Neither impact nor cost score reaches 50, putting the policy in the unattractive category.

Figure D3 shows a worked example of how the tool was used to provide an initial score for a particular policy option. All of these individual scores that comprise the total impact and total cost scores were subsequently discussed with the project team and Danish government stakeholders and adjusted accordingly.

Figure D2: Snapshot and description of the policy assessment tool

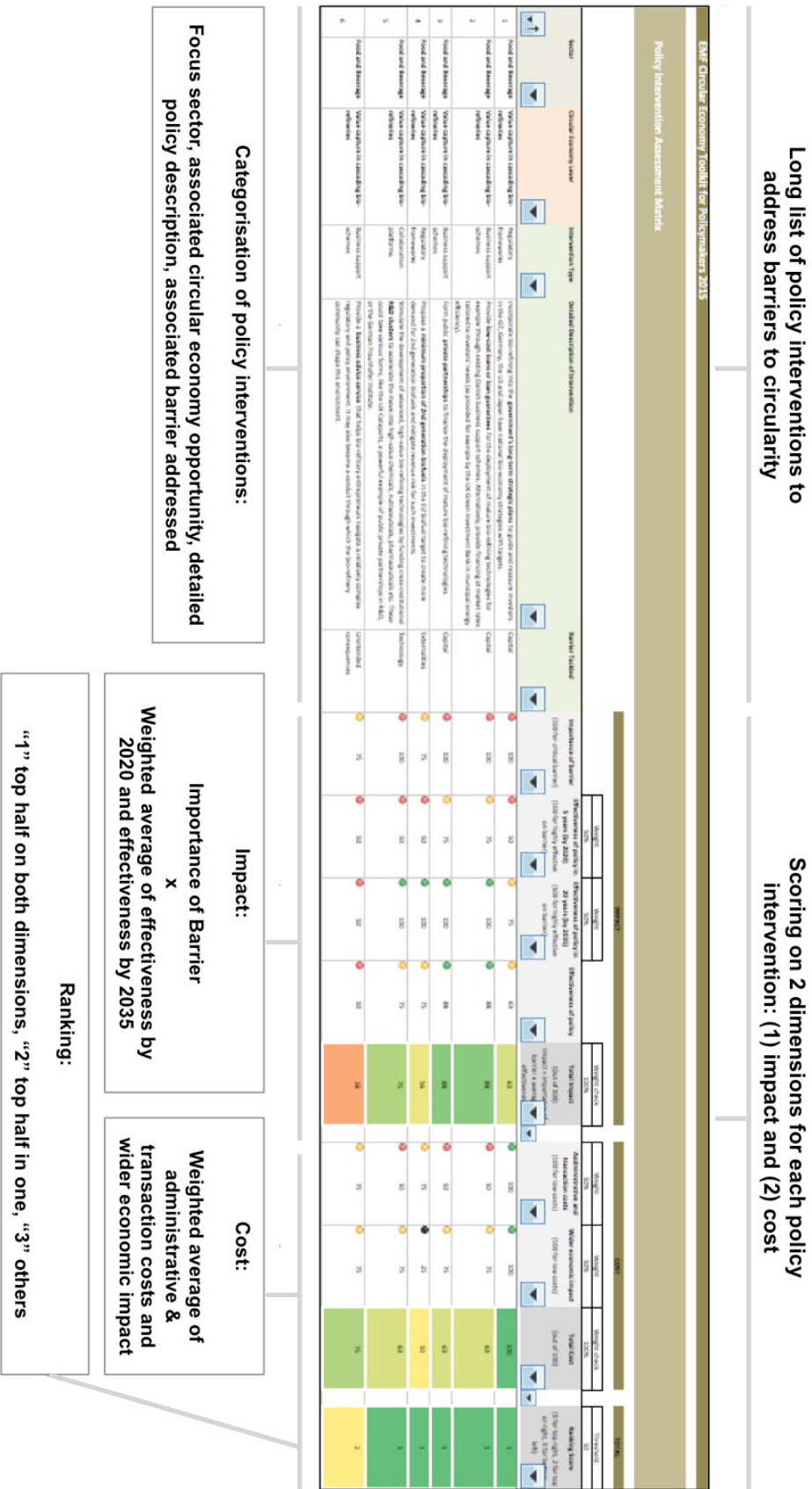
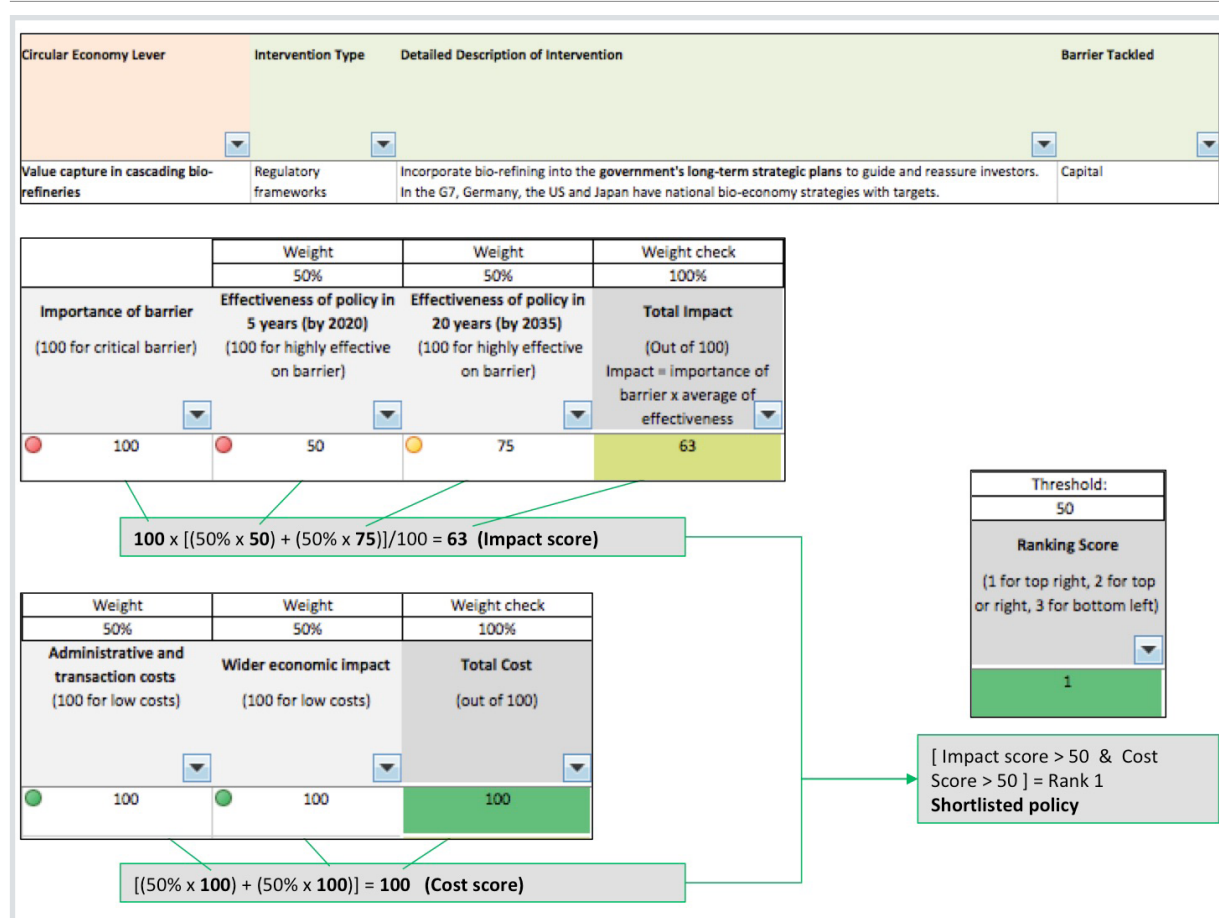


Figure D3: Worked example of the implementation of the scoring methodology.

E Why the circular economy matters

The linear ‘take, make, dispose’ economic model relies on large quantities of cheap, easily accessible materials and energy and is reaching its physical limits. The circular economy is an attractive and viable alternative that businesses are already exploring today.

The circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. This new economic model seeks to ultimately decouple global economic development from finite resource consumption. It enables key policy objectives such as generating economic growth, creating jobs, and reducing environmental impacts, including carbon emissions.

A favourable alignment of factors makes the transition possible. Resource-related challenges to businesses and economies are mounting. An unprecedented favourable alignment of technological and social factors enables the transition to the circular economy.

As many circular economy opportunities have a sound underlying profitability, businesses are driving the shift towards the circular economy. Yet there are often non-financial barriers limiting further scale-up or holding back pace. Policymakers therefore can play an important role to help overcome these barriers and to create the right enabling conditions and, as appropriate, set direction for a transition to the circular economy. The toolkit aims to complement existing literature by offering policymakers an actionable step-by-step methodology to design a strategy to accelerate the transition towards the circular economy.

The following is an adapted version of Chapter 1.1 of the toolkit report, aimed at providing a basic understanding of the circular economy for the reader. It covers both ideas and insights developed in the past and more recent thinking, including the ReSOLVE framework developed by the Ellen MacArthur Foundation and the McKinsey Center for Business and the Environment.

From linear to circular – Accelerating a proven concept

CIRCULAR ECONOMY – AN INDUSTRIAL SYSTEM THAT IS RESTORATIVE AND REGENERATIVE BY DESIGN

The linear ‘take, make, dispose’ model, the dominant economic model of our time, relies on large quantities of easily accessible resources and energy, and as such is increasingly unfit for the reality in which it operates. Working towards efficiency – a reduction of resources and fossil energy consumed per unit of economic output – will not alter the finite nature of their stocks but can only delay the inevitable. A deeper change of the operating system is necessary.

The notion of the circular economy has attracted attention in recent years. The concept is characterised, more than defined, as an economy that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. It is conceived as a continuous positive development cycle that preserves and enhances natural capital, optimises resource yields, and minimises system risks by managing finite stocks and renewable flows. It works effectively at every scale.

The circular economy provides multiple value creation mechanisms that are decoupled from the consumption of finite resources. Consumption should in a true circular economy only happen in effective bio-cycles; elsewhere use replaces consumption. Resources are regenerated in the bio-cycle or recovered and restored in the technical

cycle. In the bio-cycle, life processes regenerate disordered materials, despite or without human intervention. In the technical cycle, circular economy technologies and business models aim to maximise the value extracted from finite stocks of technical assets and materials, and thereby address much of the structural waste in industrial sectors. In the biological cycle, a circular economy encourages flows of biological nutrients to be managed so as not to exceed the carrying capacity of natural systems, and aims to enhance the stock of natural capital by creating the conditions for regeneration of, for example, soil.

In a diverse, vibrant, multi-scale system, restoration increases long-term resilience and innovation.³ The systems emphasis in circular economy matters, as it can create a series of business and economic opportunities, while generating environmental and social benefits. The circular economy does not just reduce the systemic harm engendered by a linear economy; it creates a positive reinforcing development cycle.

The circular economy rests on three key principles, shown in Figure E1.

- **Preserve and enhance natural capital** by controlling finite stocks and balancing renewable resource flows—for example, replacing fossil fuels with renewable energy or using the maximum sustainable yield method to preserve fish stocks.
- **Optimise resource yields** by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles – for example, sharing or looping products and extending product lifetimes.
- **Foster system effectiveness** by revealing and designing out **negative externalities**, such as water, air, soil, and noise pollution; climate change; toxins; congestion; and negative health effects related to resource use.

These three principles of the circular economy can be translated into a set of six business actions: Regenerate, Share, Optimise, Loop, Virtualise, and Exchange – together, the ReSOLVE framework (see Figure E2). For each action, there are examples of leading companies that are already implementing them.

Each of the six actions represents a major circular business opportunity that, enabled by the technology revolution, looks quite different from what it would have 15 years ago or what it would look like in a framework for growth in the linear economy. In different ways, these actions all increase the utilisation of physical assets, prolong their life, and shift resource use from finite to renewable sources. Each action reinforces and accelerates the performance of the other actions.

The ReSOLVE framework offers businesses and countries a tool for generating circular strategies and growth initiatives. Many global leaders have built their success on innovation in just one of these areas. Most industries already have profitable opportunities in each area.

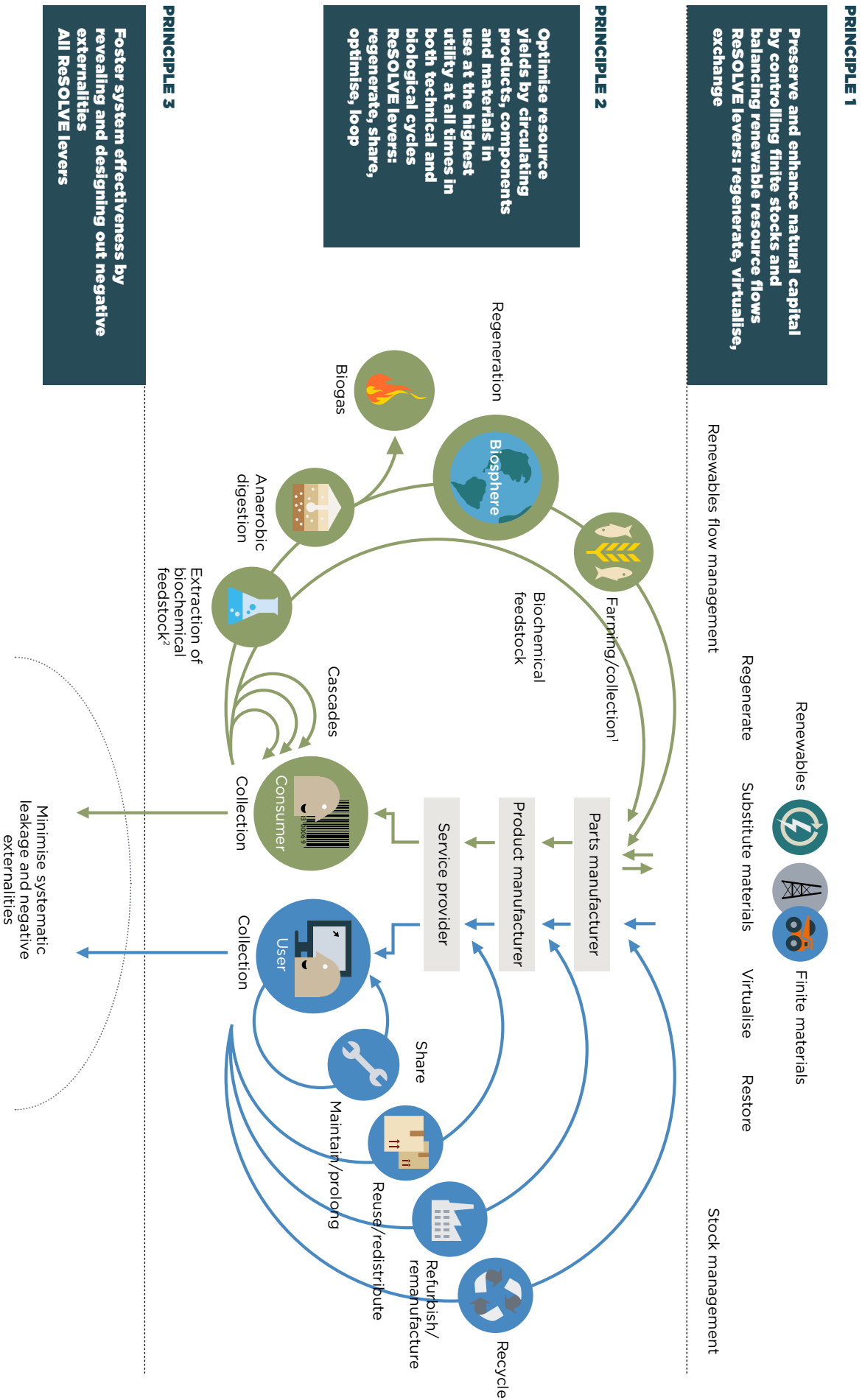
A short description of these levers, and examples of businesses that are implementing them, follows below.

REgenerate. Shift to renewable energy and materials; reclaim, retain, and regenerate health of ecosystems and return recovered biological resources to the biosphere. Cumulative new investments in European renewable energy represented USD 650 billion over the 2004–13 period.⁴ The Savory Institute has influenced the regeneration of more than 2.5 million hectares of lands worldwide.

³ John Fullerton, (Capital Institute) *Regenerative Capitalism: How Universal Principles and Patterns Will Shape Our New Economy*, (2015).

⁴ Angus McCrone, *Global Trends in Renewable Energy Investment 2014* (Frankfurt School-UNEP Collaborating Centre for Climate & Sustainable Energy Finance, the United Nations Environment Programme (UNEP) and Bloomberg New Energy Finance, 2014).

Figure E1: Circular economy – an industrial system that is restorative and regenerative by design



¹ Hunting and fishing

² Can take both post-harvest and post-consumer waste as an input

SOURCE: Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, *Growth Within: A Circular Economy Vision for a Competitive Europe* (2015).
Drawing from Braungart & McDonough, *Cradle to Cradle* (C2C).

Share. Keep product loop speed low and maximise utilisation of products, by sharing them among different users (peer-to-peer sharing of privately owned products or public sharing of a pool of products), by reusing them through their entire technical lifetime (second hand), and by prolonging their lifetime through maintenance, repair, and design for durability. BlaBlaCar is one famous car example growing at 200% per annum with 20 million registered users in 19 countries. BMW and Sixt's Drive Now offer by-the-minute rental of cars that can be collected and dropped anywhere in a city centre. Lyft matches passengers needing a lift with drivers of their own cars willing to provide one through a smartphone app. In housing, Airbnb has more than one million spaces listed in more than 34,000 cities across more than 190 countries.

Optimise. Increase performance/efficiency of a product; remove waste in production and supply chain (from sourcing and logistics, to production, use phase, end-of-use collection etc.); leverage big data, automation, remote sensing and steering. All these actions are implemented without changes to the actual product or technology. A well-known illustration of this lever is the lean philosophy made famous by Toyota.

Loop. Keep components and materials in closed loops and prioritise inner loops. For finite materials, it means remanufacturing products or components and recycling materials. Caterpillar, Michelin, Rolls Royce, Philips or Renault are just a few companies exploring this direction. For renewable materials, it means anaerobic digestion and extracting biochemicals from organic waste. The Plant is an example of closed loop, zero-waste food production located in Chicago.

Virtualise. Dematerialise resource use by delivering utility virtually: directly, e.g. books or music; or indirectly, e.g. online shopping, autonomous vehicles, virtual offices. Google, Apple, and most OEMs plan to release driverless cars on the market in the next decade.

Exchange. Replace old with advanced non-renewable materials, apply new technologies (e.g. 3D printing or electric engines) and choose new products/services (e.g. multimodal transport). For instance, in 2014 Chinese company WinSun 3D-printed ten houses, each about 195 square metres, in 24 hours.

BENEFITS OF THE CIRCULAR ECONOMY

The transition towards the circular economy can bring about the lasting benefits of a more innovative, resilient and productive economy. The principal benefits to moving to the circular economy are as follows:

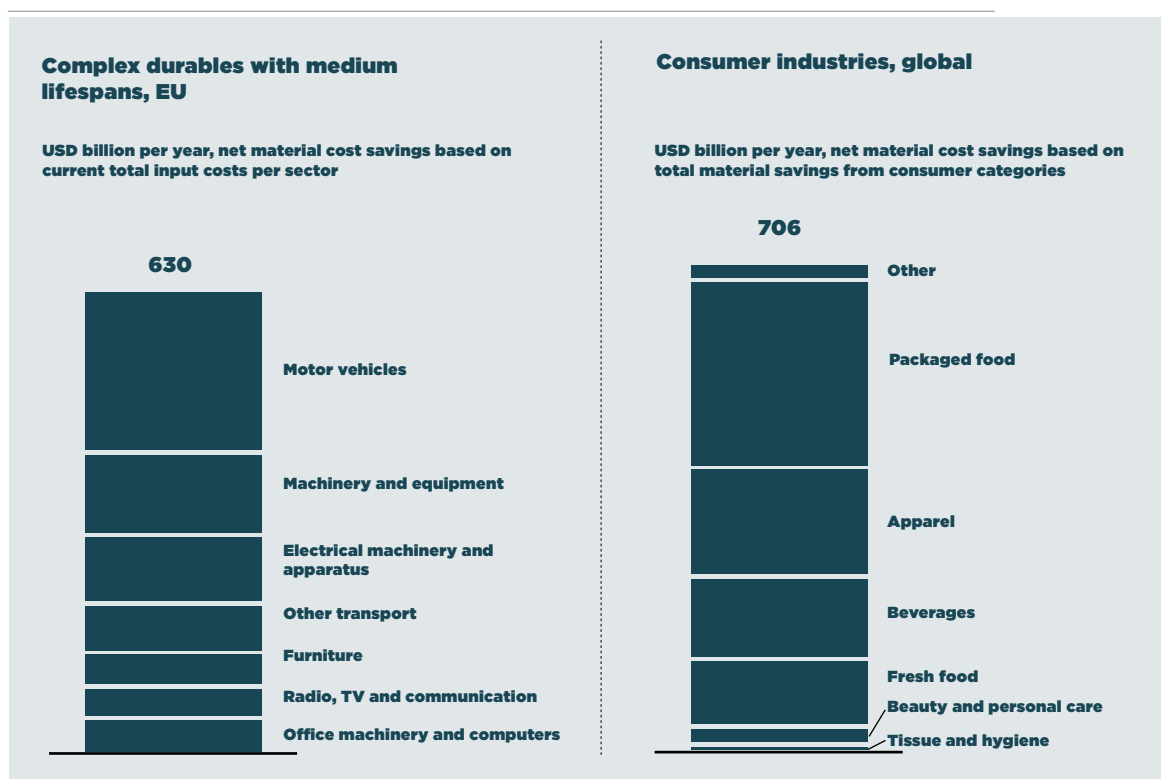
- **Substantial net material savings and reduced exposure to price volatility:** based on detailed product-level modelling, the Ellen MacArthur Foundation has estimated that, in the medium-lived complex products industries, the circular economy represents net material cost savings at an EU level for an 'advanced' scenario of up to USD 630 billion annually; in fast-moving consumer goods (FCMG) at the global level net materials savings could reach USD 700 billion annually – see Figure E3.
- **Increased innovation and job creation potential:** circularity as a 'rethinking device' has proved to be a powerful new frame, capable of sparking creative solutions and stimulating innovation. The effects of a more circular industrial model on the structure and vitality of labour markets still need to be further explored, but initial evidence suggests that the impact will be positive (see below).
- **Increased resilience in living systems and in the economy:** land degradation costs an estimated USD 40 billion annually worldwide, without taking into account the hidden costs of increased fertiliser use, loss of biodiversity and loss of unique landscapes. Higher land productivity, less waste in the food value chain

and the return of nutrients to the soil will enhance the value of land and soil as assets. The circular economy, by moving much more biological material through the anaerobic digestion or composting process and back into the soil, will reduce the need for replenishment with additional nutrients. This is the principle of regeneration at work.

The circular economy can be an important lever to achieve key policy objectives such as generating economic growth, creating jobs, and reducing environmental impact.

Multiple studies have already demonstrated how the circular economy can contribute at a national, regional and supranational level to objectives such as generating economic growth, creating jobs, and reducing environmental impact. While using different methodologies and performed on different sectoral and geographical scopes, these studies have consistently demonstrated the positive impacts of the circular economy: growing GDP by 0.8–7%, adding 0.2–3.0% jobs, and reducing carbon emissions by 8–70% (see Figure 4).

Figure E2: The economic opportunity of the circular economy



NOTE: Rough estimates from advanced scenario

SOURCE: Towards the Circular Economy 1, 2 by the Ellen MacArthur Foundation

CIRCULAR ECONOMY LITERATURE

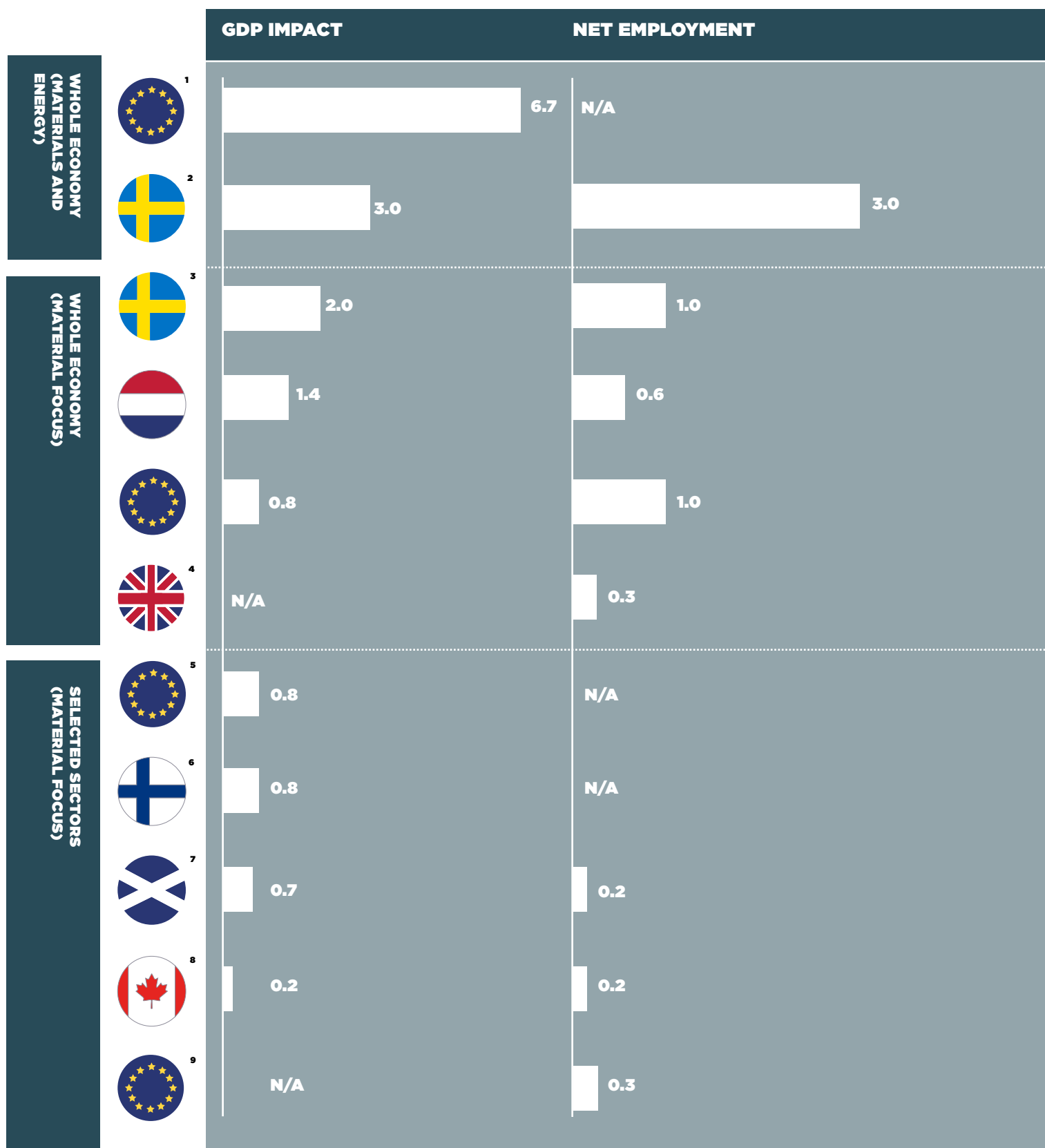
The circular economy concept has deep-rooted origins and cannot be traced back to one single date or author. Its practical applications to modern economic systems and industrial processes, however, have gained momentum since the late 1970s as a result of the efforts of a small number of academics, thought-leaders, and businesses. The general concept has been refined and developed by the following schools of thought, which all treat the economy as a complex adaptive system and draw on insights from living systems especially:

- Regenerative design (Prof. John T. Lyle);
- Performance economy (Prof. Walter Stahel);
- Cradle to Cradle (Prof. Michael Braungart and William McDonough);
- Industrial ecology (Prof. Roland Clift, Thomas E. Graedel);
- Biomimicry (Janine Benyus);
- Natural capitalism (Amory Lovins);
- Blue Economy (Gunter Pauli).

To learn more about the concepts that lie behind the circular economy framework, a good starting point is Chapter 2 of *Towards the Circular Economy I* by the Ellen MacArthur Foundation (2012). For a broader discussion of the three principles and the ReSOLVE framework, see the report *Growth Within: A Circular Economy Vision for a Competitive Europe*.⁵ For a more general discussion of the interplay between the circular economy, employment, education, money and finance, public policy and taxation, see the book *The Circular Economy – A Wealth of Flows* by Ken Webster, Head of Innovation at the Ellen MacArthur Foundation.

5 Ellen MacArthur Foundation, Stiftungsfonds für Umweltökonomie und Nachhaltigkeit (SUN) and McKinsey Center for Business and Environment, *Growth Within: A Circular Economy Vision for a Competitive Europe* (2015).

Figure E3: Estimated potential contribution of the circular economy to economic growth, job creation and reduction of greenhouse gas emissions



1 2030 scenario.

2 Full scenario; GDP impact equal to trade balance effect.

3 'Material efficiency scenario'; GDP impact equal to trade balance effect.

4 Net job creation from increased reuse, remanufacturing, recycling, bio-refining and servitisation.

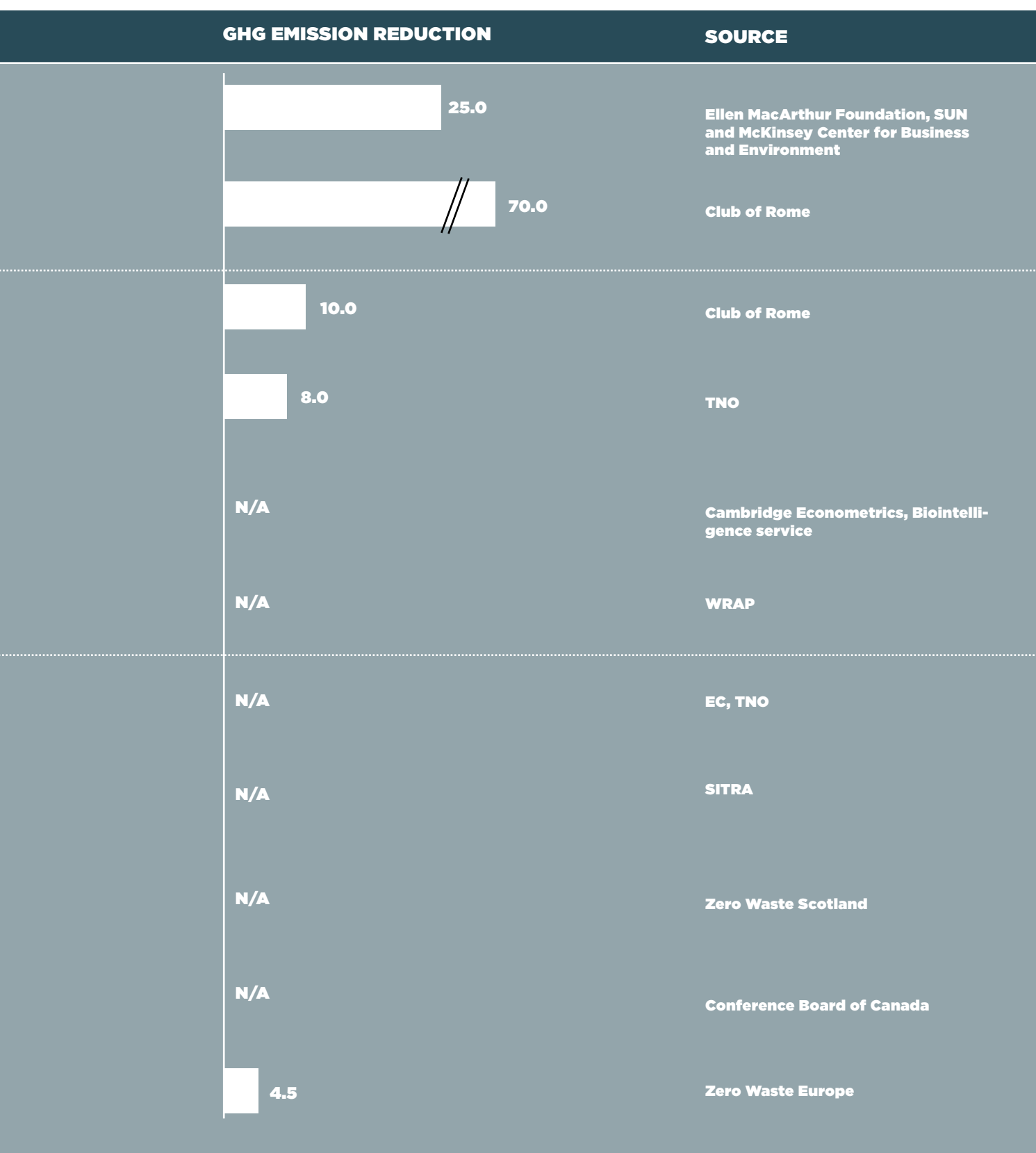
5 Built environment.

6 Forestry, pulp and paper, machinery, equipment and electronics, built environment, food waste, P2P sharing.

7 Remanufacturing industry.

8 Ontario; Waste management and recycling industry.

9 Waste management and recycling industry; compiled from several reports, see http://ec.europa.eu/environment/circular-economy/index_en.htm, http://ec.europa.eu/smart-regulation/impact/planned_ia/docs/2014_env_005_waste_review_en.pdf



SOURCE: NL: TNO, Opportunities for a circular economy in the Netherlands (2013); EU (1): Ellen MacArthur Foundation, SUN and McKinsey Center for Business and Environment, Growth Within: A Circular Economy Vision for a Competitive Europe (2015); EU (2): Cambridge Econometrics / Biointelligence Service / EC, Study on modelling of the economic and environmental impacts of raw material consumption (2014); SWE: Club of Rome, The circular economy and benefits for Society (2015); UK: WRAP, Employment and the circular economy: job creation in a more resource efficient Britain (2014); FIN: SITRA, Assessing circular economy potential for Finland (2014); EU, built environment: TNO / EC, Assessment of scenarios and options towards a resource efficient Europe: an analysis for the European built environment (2013); SCO: Zero Waste Scotland, Circular economy evidence building programme: Remanufacturing study (2015); EU, waste management: Zero Waste Europe, EU circular economy package: Questioning the reasons for withdrawal (2015); CAN: Conference Board of Canada, Opportunities for Ontario's Waste: Economic Impacts of Waste Diversion in North America (2014)

ABOUT THE ELLEN MACARTHUR FOUNDATION

The Ellen MacArthur Foundation was established in 2010 with the aim of accelerating the transition to the circular economy. Since its creation the charity has emerged as a global thought leader, establishing circular economy on the agenda of decision makers across business, government and academia. The charity's work focuses on four interlinking areas:

EDUCATION: INSPIRING LEARNERS TO RE-THINK THE FUTURE THROUGH THE CIRCULAR ECONOMY FRAMEWORK

We are creating a global teaching and learning platform built around the circular economy framework, working in both formal and informal education. With an emphasis on online learning, the Foundation provides cutting edge insights and content to support circular economy education and the systems thinking required to accelerate a transition.

BUSINESS AND GOVERNMENT: CATALYSING CIRCULAR INNOVATION AND CREATING THE CONDITIONS FOR IT TO FLOURISH

Since our launch, we've emphasised the real-world relevance of our activities and understand that business innovation sits at the heart of any transition to the circular economy. The Foundation works with Global Partners (Cisco, Google, Kingfisher, Philips, Renault, and Unilever) to develop circular business initiatives and to address challenges to implementing them.

INSIGHT AND ANALYSIS: PROVIDING ROBUST EVIDENCE ABOUT THE BENEFITS OF THE TRANSITION

We work to quantify the economic potential of the circular model and develop approaches for capturing this value. Our insight and analysis feeds into a growing body of economic reports highlighting the rationale for an accelerated transition towards the circular economy, and exploring the potential benefits across different stakeholders and sectors.

COMMUNICATIONS: ENGAGING A GLOBAL AUDIENCE AROUND THE CIRCULAR ECONOMY

The Foundation communicates cutting edge ideas and insight through its circular economy research, reports, case studies and books disseminated through our publications arm. We utilise new and relevant digital media to reach audiences who can accelerate the transition, globally. In addition, we aggregate, curate, and make knowledge accessible through Circulate, an online location dedicated to providing up to date news and unique insight on the circular economy and related subjects.

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