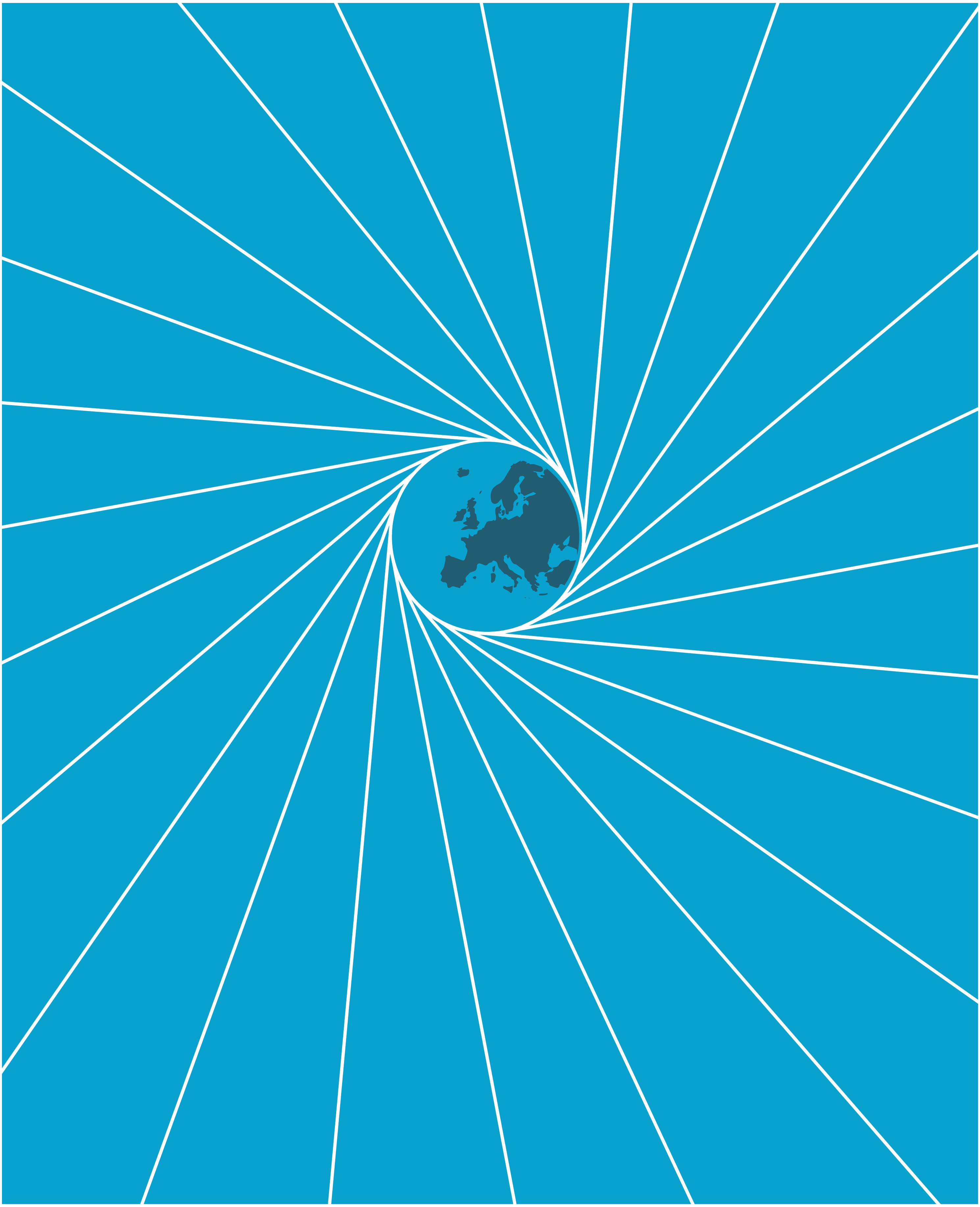
GROWTH WITHIN: A CIRCULAR ECONOMY VISION FOR A COMPETITIVE EUROPE



ELLEN MACARTHUR FOUNDATION

SUN

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PREFACE

The circular economy is gaining increasing attention in Europe and around the world as a potential way for our society to increase prosperity, while reducing dependence on primary materials and energy. The European Commission is expected to propose a "circular economy package" by the end of 2015, and many business leaders embrace the circular economy as a path to increasing growth and profitability. At the same time, a lively debate is going on about the attractiveness of a circular economy for different stakeholders and its implications for employment, growth, and the environment.

This report aims to contribute to a fact base to inform this debate, especially in Europe. The report suggests what a circular European economy could look like and compares its potential impact with the current development path. The report models potential European economic and environmental outcomes in both scenarios. It also examines how a more circular way of satisfying human needs could play out in three of the largest and most resource-intensive European value chains: mobility, food, and the built environment. In aggregate, the circular scenarios suggest that the opportunity for Europe's economy could be large.

The report does not aim to provide final answers or projections for a circular economy—this would be impossible given the major uncertainties involved in the transition. Rather, the report tries to identify and describe major differences that circularity could bring to the European economy and offers directional quantification of the most important differences. In doing so, the report builds on previous circular economy research, including work by the Ellen MacArthur Foundation and the McKinsey Center for Business and Environment.

This report is the product of a knowledge partnership between the Ellen MacArthur Foundation, Stiftungsfonds für Umweltökonomie und Nachhaltigkeit (SUN), the new environmental economics branch of the Deutsche Post Foundation, and the McKinsey Center for Business and Environment.

We encourage policy-makers inspired by the vision presented in this report to read the Ellen MacArthur Foundation's new and complementary report, Delivering the circular economy: A toolkit for policy-makers. The toolkit offers an actionable, step-by-step methodology to help transition towards a circular economy.

We are grateful to our numerous partners and advisors for their insights and support throughout this project, as acknowledged in the pages that follow. This report has truly been a collaborative effort by business, policy-makers, and academia.

We hope you find this report informative and useful. We invite you to engage with us on this timely opportunity.

Best regards,

Dame Ellen MacArthur
Founder, Ellen MacArthur Foundation

Dr. Klaus Zumwinkel
Chairman, Deutsche Post Foundation

Dr. Martin R. Stuchtey
Director of the McKinsey Center for Business and Environment

FOREWORD

The circular economy represents a tremendous opportunity for Europe. With its system-wide perspective, the circular economy has the potential to help us make better decisions about resource use, design out waste, provide added value for business, and proceed along a secure route to society-wide prosperity and environmental sustainability for future generations. Most importantly, under the right rules, the circular economy can shift the economic mix to increase the number of jobs at the same time.

I welcome the findings of the report *Growth Within*. Its title is reassuring and accurate. The report proposes *growth within* an effective flow of materials, energy, and information using appropriate policy guidance and novel business models that are enabled by the information technology revolution.

The aim of keeping products and materials at their highest value is part of a transition towards a restorative and regenerative economic cycle that moves us from wasteful resource use to a model that recognises and enables added value contributed by human enterprise and application. This may be a very profound shift—it may be a change of era where the fundamentals of Europe's economy are reworked.

Growth Within looks deeply into three key European sectors—food, mobility, and the built environment—examining their potential and offering a way forward guided by circular economy principles. While the report clearly indicates the numerous challenges in achieving rapid progress, it also offers examples of success and frameworks for what is possible.

Importantly, the report points out how often many of these changes reinforce each other. The tracking of materials, components, and products eases the shift from ownership to new business models with flexible and affordable access to value added services. The maintenance and refurbishment of products can require more human input. Potential shifts of fiscal incentives towards renewables can encourage the use of labour. All these changes deliver important benefits to the environment—resource productivity, restored natural capital, and better product design. *Growth Within* is both timely and encouraging. It warrants careful reading and serves as a call to action.

Frans van Houten
CEO and Chairman of the Board of Management and Executive Committee, Philips
June 2015

IN SUPPORT OF THE REPORT

"The smart rebound of the European economy will require game-changing strategies, breaking the paradigms prevailing since the industrial revolution. A priority is to go beyond the linear economy, where stakeholders are in traditional silos. In addition to preserving natural resources, shifting to a circular economy offers an opportunity to create new sources of wealth. The emergence of innovative models leads to collaborative dynamics across industries, cities, and communities that reveal new fields of sustainable value creation, such as selling services instead of products, recovering resources from waste, sharing assets, and producing green supplies. Europe offers the perfect ground for a circular economy to truly take shape and for launching disruptive models. It represents a unique opportunity but will require true vision and leadership."

Laurent Auguste, Senior EVP Innovation & Markets, Veolia

"The circular economy should be a central political project for Europe, as it offers the potential to set a strong perspective on renewed competitiveness, positive economic development, and job creation. Growth within: a circular economy vision for a competitive Europe makes a strong case for business models centred on use, rather than consumption, and regenerative practices that have, on top of economic advantages, beneficial impacts for society as a whole."

Ida Auken, Member of Parliament, Denmark

"Acatech looks forward to further discussions on the huge potential and numerous opportunities that a circular economy can offer. Let's continue to work together to provide for an innovative, efficient, and sustainable economy for future generations. This report gives an insight into how a circular economy can transform the future for the benefit of the economy and generations to come."

Reinhard Hüttl, President, acatech

"The circular economy opens up new horizons for the automotive industry. The stake of the resources issue has long been an integral part of our competitiveness, and the pursuit of profitable growth requires us to meet the challenges of climate change and urban pollution by responding with solutions of sustainable mobility for all. The Ellen MacArthur Foundation, through several economic reports, stimulates new thinking within economic players and beyond by involving all stakeholders. Renault is an industrial actor that already implements some of the principles of a circular economy. Numerous cases exemplify industrial performance gains within the remanufacturing process and in the incorporation of recycled materials in new products, as well as with attractive commercial offers for electric vehicles, and in the reuse of second life parts to extend the service life of our products. Other actions are planned which will enable us to envision new opportunities for value creation."

Thierry Bolloré, Chief Competitive Officer, Renault Group

"Europe is in the middle of a transformation towards a circular economy powered by Cradle to Cradle; a socio-economic system which is smart, cross-sectoral and full of positively defined opportunities and challenges. Step by step we leave the linear economy behind, so we are able to safeguard our future without using concepts that are only trying to make the unfixable errors in our old system right. Especially during those transition periods, we need to ask fundamental questions and further develop and sharpen the concept of a circular economy in order to understand its true meaning and the options for practical realisations. It is not just about materials, but it also concerns designing high-quality products, the use of renewable energy, effective water management and social equity. Real innovation and effectiveness increases prosperity and liveability in Europe, which is beneficial for everyone."

Michael Braungart, Academic Chair "Cradle to Cradle for Innovation and Quality" RSM, Erasmus University Rotterdam; Scientific Director, EPEA

IN SUPPORT OF THE REPORT CONTINUED

"On a planet of finite resources, the circular economy is not optional, it is inevitable. Its implementation will provide world economies with unprecedented opportunities, through the creation of reverse logistics networks, new processes, and new industries using the recovered resources. Resource efficiency will allow us to rethink the concept of urban mining. Countries will be able to create industries in fields that were previously not viable. Relatively simple changes to existing legislation can enable this shift in mindset on short timescales. Restructuring economies to become circular will moreover bring with it enormous environmental benefits."

Hermann Erdmann, CEO, REDISA

"We might be recycling in Europe but we certainly aren't optimising - that's the key outtake for me from this 'Growth Within' report. From a business perspective, that presents an enormous opportunity for Europe. As one of the world's largest home improvement companies with a restorative ambition and a founder partner to the Ellen MacArthur Foundation, Kingfisher believes there's much merit in circular principles that move us from wasteful resource use towards keeping products and materials at their highest value as long as possible. We know this is not something any one business can do on its own – it requires collaboration throughout entire value chains. A transition requires investment in macro infrastructure. Growth Within sets out the European opportunity presented by a circular economy with policy makers the enablers to a transition – it starts by agreeing a common circular economy definition and then ensuring all polices align with other European regulations to achieve the vision."

Richard Gillies, Sustainability Director, Kingfisher

"Moving towards a truly circular economy will not be achieved in one step. However, this report represents tangible progress on the journey towards a more sustainable, efficient, and resilient future. Arup is in this for the long haul, because, even if it takes a generational shift to get there, the direction of travel represents a far better future for our shared society."

Gregory Hodkinson, Global Chairman, Arup

"By combining efficiency and effectiveness—doing the right things—the European economy would experience win-win-win. Lower costs, less carbon emissions, and more employment. Very good news in a situation where environment and resource concerns too often have been seen mainly as a cost and threat to competitiveness."

Anders Wijkman, Co-President, Club of Rome

"The potential of the circular economy for business is immense. The analysis conducted for this report on three of the largest sectors in Europe depicts real opportunities for businesses to increase growth and profitability, fostering innovation through novel business models. At the same time, we see clear evidence here that a circular economy also offers solutions to address climate change, showing us once again that we do not need to choose between the environment and the economy."

Jeremy Oppenheim, Programme Director, The New Climate Economy

"In densely populated Europe, locked in old traditional resource-intensive production and consumption models, being import-dependant and facing growing and volatile resource prices and an increasingly higher share of resource costs in the cost structure of our companies, resource efficiency and a circular economy are the best ways to improve our competitiveness and to create conditions to keep industry in Europe."

Janez Potčnik, Co-Chair for UNEP International Resource Panel

"Why waste what can be used in a sensible manner?"

Pieter Winsemius, Former Minister of Housing, Spatial Planning, and the Environment in the Netherlands and current Chairman of the Richard Krajicek Foundation

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This report has been sponsored by SUN (Stiftungsfonds für Umweltökonomie und Nachhaltigkeit) and authored by the Ellen MacArthur Foundation and the McKinsey Center for Business and Environment.

SUN—Stiftungsfonds für Umweltökonomie und Nachhaltigkeit GmbH (Foundation for Environmental Economics and Sustainability). The Deutsche Post Foundation established SUN as a non-profit organisation in September 2014 in order to strengthen its international activities supporting institutions, programmes, and projects dealing with the challenges and opportunities of globalisation and enhanced cross-border activities. SUN promotes research on environmental protection, international understanding, and development cooperation.

The Ellen MacArthur Foundation was created in 2010 to accelerate the transition to a circular economy. The Foundation's work focuses on three areas: insight and analysis, business and government, and education and training. With Knowledge Partner, McKinsey & Co, the Foundation works to quantify the economic potential of the circular model and to develop approaches for capturing this value. The Foundation collaborates with Global Partners ***(Cisco, Kingfisher, Philips, Renault, Unilever)***, and its CE100 network (businesses, governments & cities), to develop circular business initiatives and build capacity. The Foundation is creating a global teaching and learning platform on the circular economy as well, encompassing work with leading universities, schools and colleges, and online events such as the Disruptive Innovation Festival.

The McKinsey Center for Business and Environment is working with businesses, governments, and non-profit organisations to tackle system-level sustainability and resource-productivity-related challenges. The Center's core belief is that growth in the 21st century will not be about managing trade-offs between making profits and preserving the environment. Instead, new technologies and business models will allow companies, cities, and countries to use natural resources more productively and to leverage that ability as a new source of value and influence. The Center provided analytical support and overall project management for this project.

Institute for the Study of Labor (IZA) was established in 1998 in Bonn, Germany. IZA is a private, independent economic research institute focused on the analysis of global labour markets. It operates an international network of about 1,500 economists and researchers spanning more than 50 countries. The institute provides a wide array of publications and events, contributes its findings to public debates, and advises policy-makers on labour market issues. IZA is a non-profit organisation supported by the Deutsche Post Foundation.

In collaboration with IZA, Christoph Böhringer, Professor of Economics at Oldenburg University, and Thomas F. Rutherford, Professor of Agricultural & Applied Economics, at the University of Wisconsin, led the economic modelling for this report. Professor Jens Horbach, University of Applied Sciences Augsburg, Dr. Klaus Rennings, Centre for European Economic Research (ZEW), and Dr. Katrin Sommerfeld, Centre for European Economic Research (ZEW), led the research on the link between a circular economy and employment.

We are grateful for the support and guidance of our Steering Committee and Advisory Board members.

Steering committee

Klaus Zumwinkel *Chairman of Deutsche Post Foundation*
Janez Potočnik *Co-Chair of the UNEP International Resource Panel*
Alexander Spermann *Director of Labor Policy Germany, IZA*
Ellen MacArthur *Founder Ellen MacArthur Foundation*
Andrew Morlet *CEO, Ellen MacArthur Foundation*
Martin R. Stuchtey *Director of the McKinsey Center for Business and Environment*
Per-Anders Enkvist *Partner in the McKinsey Center for Business and Environment*

Advisory board

Laurent Auguste *Senior EVP Innovation & Markets, Veolia*
Ida Auken *Member of Parliament, Denmark*
Thierry Bolloré *Chief Competitive Officer, Renault Group*

Michael Braungart *Academic Chair "Cradle to Cradle for Innovation and Quality" RSM, Erasmus University Rotterdam; Scientific Director, EPEA*
Hermann Erdmann *CEO, Redisa*
Richard Gillies, *Sustainability Director, Kingfisher*
Gregory Hodkinson *Chairman, Arup*
Reinhard Hüttl *President, acatech*
Jeremy Oppenheim *Programme Director, The New Climate Economy*
Anders Wijkman *Co-President, Club of Rome*
Pieter Winsemius *Former Minister of Housing, Spatial Planning and the Environment in the Netherlands, and current Chairman of the Richard Krajicek Foundation*

Experts consulted

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Alexander Affre *Director, Industrial Affairs, Business Europe*
Werner Bosmans *Policy Adviser, DG Environment;* **Said El Khadraoui** *Policy Analyst, European Political Strategy Center;* **Paola Migliorini** *Eco-Innovation and circular economy, DG Environment;* **Kestutis Sadauskas** *Director for Green Economy, DG Environment;* **Astrid Schomaker** *Director Strategy, DG Environment;* **Kurt Vandenberghe** *Director for Climate Action and Resource Efficiency, DG Research and Innovation, European Commission*
Jamie Butterworth *Partner, Circularity Capital*
Chris Crozier *CEO at Kusaga Taka Consulting*
Rudi Daelmans *Manager CSR;* **Anette Timmer** *Director Corporate, Communications and CSR, Desso B.V.*
Edouard de Mautort *Bouygues Immobilier, PPP project manager*
Laur Fisher *Project Manager, Climate CoLab, MIT Center for Collective Intelligence*
Vicente Guallart *Chief Architect, Barcelona City Council*
Stefan Heck *Consulting Professor, Precourt Institute for Energy, Stanford University*
Louis Lindenberg *Global Packaging Sustainability Director, Unilever*
Jean-Philippe Hermine *Stategic Environmental Planning VP;* **Laurent Claude** *Circular Economy Business Developer, Renault Group*

Paul King *Managing Director Sustainability*, *Lend Lease Europe*
Jock Martin *Head of Integrated Environmental Assessments, EEA*
Johannes Meier *CEO, European Climate Foundation*
Jerry Sanders *CEO, SkyTran*
Hugo Spowers *CEO, RiverSimple*
Walter Stahel *Co-Founder, Product Life Institute*
Jasper Steinhausen *Business Developer & Owner, Ouroboros AS*
Pavan Sukhdev *Founder-CEO, GIST Advisory and UNEP Goodwill Ambassador*

Core project team

Ellen MacArthur Foundation
Ellen MacArthur, *Founder*
Andrew Morlet *CEO*
Jocelyn Blériot *Executive Officer – Communications & Policy Lead*
Ken Webster *Head of Innovation*
Ashima Sukhdev *Project Manager*

McKinsey Center for Business and Environment
Martin R. Stuchtey *Director of the McKinsey Center for Business and Environment*
Per-Anders Enkvist *Partner*
Morten Rossé *Expert Associate Principal*
Helga Vanthournout *Senior Expert*
Adrien Vincent *Associate*
Sander Defruyt *Junior Associate*

Production

Editor: Susan Gurewitsch, *2engage*
Design: Graham Pritchard, *Graham Pritchard Design*

EXECUTIVE SUMMARY

Europe's economy has generated unprecedented wealth over the last century. Part of the success is attributable to continuous improvements in resource productivity – a trend that has started to reduce Europe's resource exposure. At the same time, resource productivity remains hugely underexploited as a source of wealth, competitiveness and renewal. This study provides new evidence that a circular economy, enabled by the technology revolution, allows Europe to grow resource productivity by up to 3 percent annually. This would generate a primary resource benefit of as much as €0.6 trillion per year by 2030 to Europe's economies. In addition, it would generate €1.2 trillion in non-resource and externality benefits, bringing the annual total benefits to around €1.8 trillion versus today.

This would translate into a GDP increase of as much as 7 percentage points relative to the current development scenario, with additional positive impacts on employment. Looking at the systems for three human needs (mobility, food, built environment) the study concludes that rapid technology adoption is necessary but not sufficient to capture the circular opportunity. Instead, circular principles must guide the transition differently from those that govern today's economy. Pursued consistently, the economic promise is significant and the circular economy could qualify as the next major European political economy project.

Europe's economy remains very resource-dependent. Views differ on how to deal with this issue against an economic backdrop of low and jobless growth, and a struggle to reinvigorate competitiveness and absorb massive technological change.

Proponents of a circular economy argue that it offers Europe a major opportunity to increase resource productivity, decrease resource dependence and waste and increase employment and growth. They maintain that a circular system would improve competitiveness and unleash innovation and they see abundant circular opportunities that are inherently profitable but remain uncaptured.

Others argue that European companies are already capturing most of the economically attractive opportunities to recycle, remanufacture, and reuse. They maintain that reaching higher levels of circularity would involve an economic cost that Europe cannot afford when companies are already struggling with high resource prices. They further point out the high economic and political cost of the transition.

This report looks at these issues and provides a fact base for decision-makers contemplating the transition to a more circular economy. The insights of the report rest on extensive desk research, more than 150 interviews, economic modelling, the largest comparative study to date of the employment impacts of a circular economy transition, and deep analysis of three human needs that together account for 60 percent of European household spend and 80 percent of resource use — mobility, food, and housing. The research and analysis yielded nine major conclusions.

1. The European economy is surprisingly wasteful in its model of value creation and - for all practical purposes – continues to operate a take-make-dispose system. In 2012, the average European used 16 tonnes of materials. Sixty percent of discarded materials were either landfilled or incinerated, while only 40 percent were recycled or reused as materials. In value terms, Europe lost 95 percent of the material and energy value, while material recycling and waste-based energy recovery captured only 5 percent of the original raw material value.[1] Even recycling success stories like steel, PET, and paper lose 30-75 percent of the material value in the first use cycle. On average, Europe uses materials only once.

The sector analysis also found significant waste in sectors that many would consider mature and optimised. For example, the average European car is parked 92 percent of the time; 31 percent of food is wasted along the value chain; and the average European office is used only 35-50 percent of the time, even during working hours. And use cycles are short. The average manufactured asset lasts only nine years (excluding buildings).

In total, this way of producing and using products and resources costs Europe €7.2 trillion every year for the three sectors analysed at depth in this report (mobility, food and built environment). Out of this total, actual resource costs are at €1.8 trillion, other related cash-costs, which includes all other household and government expenditure on the three deep-dives, are at €3.4 trillion and externalities, such as traffic

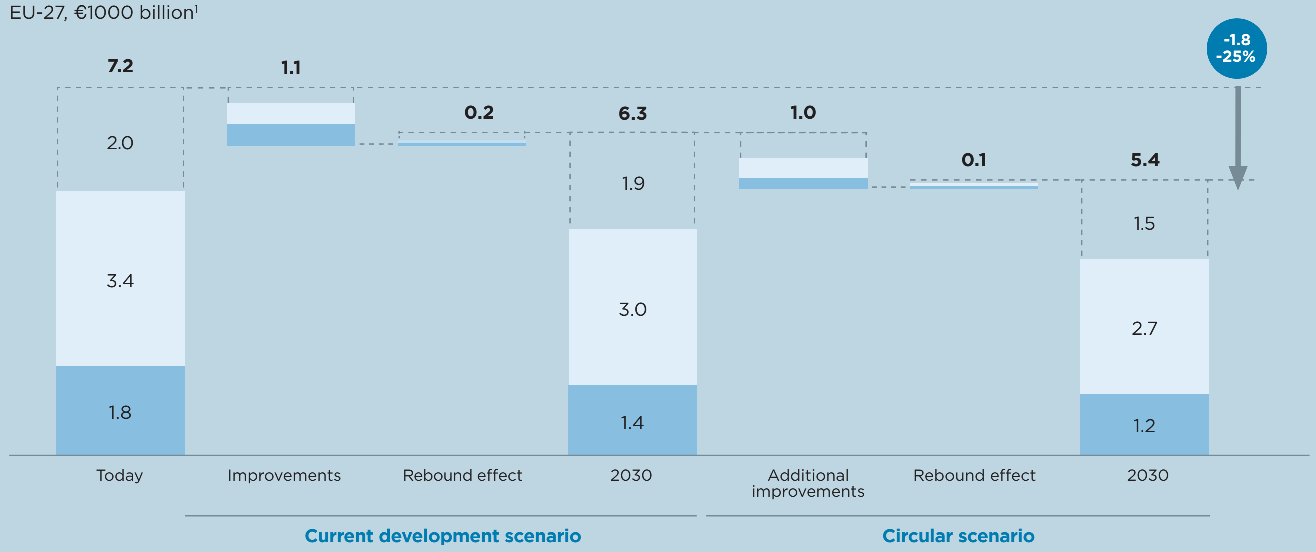


FIGURE A **THE CIRCULAR ECONOMY OPPORTUNITY – 2030 SCENARIOS**
Mobility, food and built environment, EU27, societal perspective 2030

Primary resource costs[2] Other cash-out costs[3] Externalities[4]

Annual primary resource costs, other cash-out costs and negative externalities
EU-27, €1000 billion[1]

1 All numbers rounded to €100 billion 2 Primary resources include virgin automotive and construction material, virgin synthetic fertiliser (€535/tonne), pesticides, agriculture land and water use (€0.20/m³), fuel (€1.64/litre gasoline, €1.45/litre diesel, €0.91/litre of heating oil, €68/tonne of coal, €0.067/kWh of natural gas), land for residential and office buildings and non-renewable electricity (€0.20/kWh) 3 Other cash-out costs include all household and government expenditures on mobility, food, residential housing and office space, excluding the primary resource costs 4 Externalities include CO2 (€29/tonne), traffic congestion, non-cash health impacts of accidents, pollution and noise, land opportunity costs, opportunity costs related to obesity, adverse health effects due to indoor environment and transport time (related to urban planning) NOTE: Numbers may not sum up due to rounding
Source: See page 34

congestion, CO2, pollution and noise etc. are at €2.0 trillion, Figure A.

2. A wave of disruptive technologies and business models could help the European economy to improve resource productivity and reduce total annual costs for the three sectors by €0.9 trillion in 2030. However, non-captured system benefits and rebound effects could constrain the gain (with unclear employment implications). The digital and broader technology revolution could have the same disruptive impact on elements of the three sectors studied in the next decades as it has already had on many information sectors. The average cost per car-kilometre could drop up to 75 percent, thanks to car-sharing schemes, autonomous and driver-less driving, electric vehicles, and better materials. In food, precision agriculture could improve input efficiency of water and fertilisers by at least 20-30 percent, and combined with no-tillage farming it could bring as much as 75 percent reduction in machinery and input costs. In buildings, industrial and modular processes could lower construction costs 50 percent compared to on-site traditional construction; and passive houses could reduce energy consumption by 90 percent.

If these new technologies and business models are so promising, should Europe not just let this development run its course? Probably not, for two reasons. First, the public sector and policy-makers strongly influence these sectors today—for example, through infrastructure investments, public transport, zoning laws, building standards, and agricultural subsidies. If technology deeply changed these sectors, current public interventions might not optimally steer future outcomes at a system level. Europe faces a real risk that urban planning, mobility systems, and food systems could not integrate the new technologies effectively, with much structural waste remaining.

Second, rebound effects will be significant. Resource productivity increases in the study sectors have historically met an elastic demand response. When relative prices decrease, consumers use more individualised transport, floor space, and food. This volume effect for the three study sectors could be 5-20 percent by 2030, which would increase prosperity, but, if not managed well, could exacerbate externalities and resource challenges.
With these drawbacks, the study finds, the current development path could decrease the total cost in the three sectors by €0.9 trillion annually by 2030 versus today, or a reduction of 12 percent, from €7.2 trillion to €6.3 trillion (Figure A).

3. Europe could instead integrate these new technologies and business models into the economy in a way that maximizes value extracted from asset and material stocks applying the rules of the circular economy – achieving *growth within*. Well-integrated, the new technologies and business models could address much of the structural waste in mobility, food, and buildings and create new consumer choices. Increasing utilisation and longevity would have significant economic upside and go far towards avoiding negative system effects.

EXECUTIVE SUMMARY CONTINUED

The report calls this notion *growth within* because it focuses on getting much more value from the existing stock of products and materials. *Growth within* could be an important source of additional consumer utility and growth for Europe. This circular economy would provide multiple value creation mechanisms decoupled from the consumption of finite resources. The concept rests on three principles: preserve and enhance natural capital, optimise yields from resources in use, and foster system effectiveness (minimise negative externalities).

Pursuing this opportunity in an ambitious way would represent a big shift in Europe's economic priorities. Today, Europe has no established metrics for the utilisation of key infrastructure and products, for their longevity, or for success in preserving material and ecosystem value. Articles, policy seminars, statements, and targets for these topics are rare, compared with the pervasive focus on improving flows, as measured by GDP.

4. Shifting towards a *growth within* model would deliver better outcomes for the European economy and yield annual benefits of up to €1.8 trillion by 2030. This report includes indicative benefit curves to suggest how much various circular economy levers could reduce European resource use and what the economic effects could be. While the results of such modelling are indicative, rely on multiple assumptions, and call for more research, pursuing opportunities that are already profitable or will likely be profitable within the next five years could reduce annual net European resource spend in 2030 as much as 32 percent, or €0.6 trillion versus today.

These resource benefits also come with a significant economic multiplier effect. Benefits in other related cash-costs could be as much as €0.7 trillion. Externality cost could decrease up to €0.5 trillion. This makes the total annual benefit €1.8 trillion by 2030, twice the benefit of the current development path. The current total costs of €7.2 trillion would be decreased to €5.4 trillion.

The modelling also suggests that benefits would continue to grow rapidly towards 2050. Regenerating, sharing, optimising, looping, virtualising, and exchanging for new and better technologies seem especially powerful levers.

5. Equilibrium modelling results and a comparative labour study suggest that for the total European economy at large, the circular economy could produce better welfare, GDP, and employment outcomes than the current development path. The modelling[2] for 2030 suggests that the disposable income of European households could be as much as 11 percentage points higher in the circular scenario relative to the current development path, or 7 percentage points more in GDP terms.

The increased GDP results arise from increasing consumption, while correcting market and regulatory lock-ins that prevent many inherently profitable circular opportunities from materialising fully. These results are higher than reported from most other recent studies on the economic impacts of a circular and resource-efficient economy. For instance, the recent report "Study on modelling of the economic and environmental impacts of raw material consumption" conducted by Cambridge Econometrics and Bio Intelligence Service, concluded on a slightly positive GDP impact. The key reason for the difference is that this report assumes a substantially higher pace of technology change in the big product and resource sectors going forward compared to what has been observed in the past - for the reasons explained above - whereas most other reports assume a similar pace as witnessed historically.[3]

This project included the largest academic meta-study to date on the relationship between employment and the circular economy.[4] The review of 65 academic studies indicates that, while more research is needed, ***"existing studies point to the positive employment effects occurring in the case that a circular economy is implemented."*** This impact on employment is largely attributable to increased spending fuelled by the lower prices expected across sectors and to the labour-intensity of recycling activities and higher skilled jobs in remanufacturing. But not all would benefit from the economy-wide impact of the circular model on growth and employment. Some companies, sectors, and employment segments are likely not to act quickly enough and would lose out. If European leaders decided to shift towards a more circular economy, managing the transition would have to be a top priority.

6. A circular economy could greatly benefit the environment and boost competitiveness and resilience. A circular economy would decouple economic growth from resource use. Across the three study sectors, CO_2 emissions would drop as much as 48 percent by 2030 (31 percent on the current development path) and 83 percent by 2050 (61 percent on the current development path), compared with 2012 levels.[5] Electric, shared, and autonomous vehicles, food waste reduction, regenerative and healthy food chains, passive houses, urban planning, and renewable energy would be the principal sources of emission reduction across the three sectors.

Today, materials and components constitute 40-60 percent of the total cost base of manufacturing firms in Europe[6] and often create a competitive cost disadvantage. Europe imports 60 percent of its fossil fuels and metal resources, and the EU has listed 20 materials as critical in terms of security of supply. In the circular scenario, primary material consumption measured by car and construction materials, synthetic fertiliser, pesticides, agricultural water and land use, fuels and non-renewable electricity, and land for real estate could drop as much as 32 percent by 2030 and 53 percent by 2050.

7. A transition to the circular economy would involve considerable transition costs, but if well-managed could create an opportunity for economic and industrial renewal. The transition would involve considerable costs, such as R&D and asset investments, stranded investments, subsidy payments to promote market penetration of new products, and public expenditure for digital infrastructure. While, it is hard to find an appropriate cost comparable for such an economy-wide change project, some examples could shed light on parts of the needed transition. For example, the British government has estimated that creating a fully efficient reuse and recycling system would cost around €14 billion,[7] which would translate into €108 billion scaled to a Europe-wide level. The renewables transition in Germany cost €123 billion in feed-in tariffs to renewable plant operators from 2000 to 2013.[8] It remains to be assessed to what extent these costs are additional relative to other development scenarios and to what extent they could act as a stimulus. For instance, the European Commission's agenda for establishing a digital single market and an energy union could create the core infrastructure for a regenerative and virtualised system.

Shifting to the circular model could contribute significantly to achieving Europe's growth, employment and environmental objectives, as shown above. It also offers an opportunity for renewal, with many previously underleveraged opportunities coming in focus. This means, Europe could simplify governance and achieve structural reform. In its most ambitious form, making the transition to a circular economy could even become the second major European political economy project, after creating the internal market.

8. If Europe wanted to accelerate the shift towards a circular economy, it could build a strong foundation by launching four efforts. Shifting to the new model starts with acknowledging the systemic nature of the change. All sectors and policy domains will be affected and aligned action is required. Such a shared agenda could contain four building blocks:

- Europe-wide quest for learning, research, and opportunity identification
- Development of a value-preserving materials backbone—a core requirement for strengthening European industrial competitiveness
- Initiatives at the European, national, and city levels to enable inherently profitable circular business opportunities to materialise at scale
- Development of a new governance system (a new "cockpit") to steer the economy towards greater resource productivity, employment, and competitiveness.

9. The timing is opportune. Essential enabling technologies are maturing and scaling fast. Investments in transitioning to a circular economy could deliver a stimulus to the European economy. Europe is in the midst of a pervasive shift in consumer behaviour. Business leaders are implementing product-to-service strategies and innovative business models. At least for now, resource prices are easing, paving the way for correcting market and regulatory distortions.

Building a circular economy would require a large and complex effort to address the hurdles and transition costs associated with all of the major opportunities. The effort would require actions at the local, national, regional, and global levels. The extensive analysis conducted for this report remains indicative and requires further work, but it does suggest that a circular economy could produce significant societal, economic, and environmental outcomes, while acknowledging the transition cost.

This report is intended to provide a fact base for European leaders on the trade-offs involved in a transition to a circular economy and potential ways forward.

FINDINGS AND CONCLUSIONS

As the European Union passes the half-way mark towards its Europe 2020 goals for smart, sustainable and inclusive growth and improving Europe's competitiveness, new economic challenges and opportunities are still emerging—disruptive technologies, jobless growth, competition for global resources, and mounting environmental concerns. How can Europe respond? Is the traditional linear economic model up to the task, or should Europe shift to a more circular model?

Proponents of a circular economy argue that a virtual, regenerative and resource productive model could decrease resource dependence and waste and increase employment and growth. They maintain that this system would improve competitiveness and unleash innovation. They cite abundant circular opportunities that are inherently profitable but remain uncaptured.

Opponents argue that European companies are already capturing most of the economically attractive opportunities to recycle, remanufacture, and reuse. They maintain that reaching higher levels of circularity would involve an economic cost that Europe cannot afford when companies are already struggling with high resource prices.

This report looks at the issues and provides a fact base for decision-makers contemplating the transition to a more circular economy. The insights of the report are based on extensive desk research, more than 150 interviews, economic modelling, the largest comparative study of employment impact to date, and deep analysis of three human needs that together account for 60 percent of European household spend[9] and 80 percent of resource use[10] — mobility, food, and housing.

The report addresses five questions:

1. Is Europe's current resource model effective?
2. Will the technology revolution solve Europe's resource issues?
3. What would a circular economy in Europe look like?
4. What economic outcomes could a circular model achieve in Europe?
5.If Europe decided to shift towards a circular model, how could policy-makers and business leaders accelerate the transition?

The report concludes that the current development path offers intrinsic wealth effects and would avoid some transition costs involved in moving to a circular economy. However, analysis also suggests that the circular path is realistic and could improve European competitiveness and create better economic, social, and environmental outcomes than the current development path.

In a circular economy, improving the value captured from existing products and materials, not just increasing their flow, would increasingly drive growth. We call this model *growth within*. Realising the potential of *growth within* would require systemic changes to Europe's economic governance.

1. THE EUROPEAN ECONOMY HAS BEEN VERY SUCCESSFUL BUT IS WASTEFUL IN ITS USE OF RESOURCES

Europe has been very successful in creating and distributing income to people. But like the world economy, the European economy operates in a linear take-make-dispose resource model that generates significant waste.

Since the start of the industrial revolution in the early 1800s, Europe's economy has created unprecedented prosperity. European GDP per capita has grown by a factor of 18 in real terms since 1820, or an average of 1.6 percent a year.[11] This remarkable economic success has meant a better life for hundreds of millions of Europeans.

Economic research has historically attributed this growth primarily to labour and capital productivity improvements. But these improvements explain only about half of the empirically observed economic growth, and economists have long attributed the rest to broad technology improvements (the so-called "Solow" residual).[12]

Several economists are now exploring the importance of better resource use and are concluding that resource use has contributed significantly to economic growth. One study found that, between 1960 and 1990, resource use contributed 50 percent of economic growth in Germany, Japan, and the US.[13] Another study found that the use of resources, broadly defined, explained almost perfectly the Solow residual in the US during the 20th century.[14]

Essentially, people have learned to replace and complement human labour with resources on a massive scale. Between 1900 and 2009, industrialisation led to a ten-fold increase in global material use and a seven-fold increase in domestic energy consumption in Europe.[15] This growth in resource use happened despite significant improvements in resource productivity. For example, Europe's oil productivity, expressed as GDP generated from each unit of oil equivalent, roughly doubled over the last 50 years.

But this high level of resource use is also problematic, especially for Europe. Europe is the world's largest net importer of resources at €760 billion a year, 50 percent more than the US.[16]

Europe imports about 60 percent of its fossil fuels and metal resources,[17] and the EU has put 20 materials on its critical list in terms of security of supply.[18]

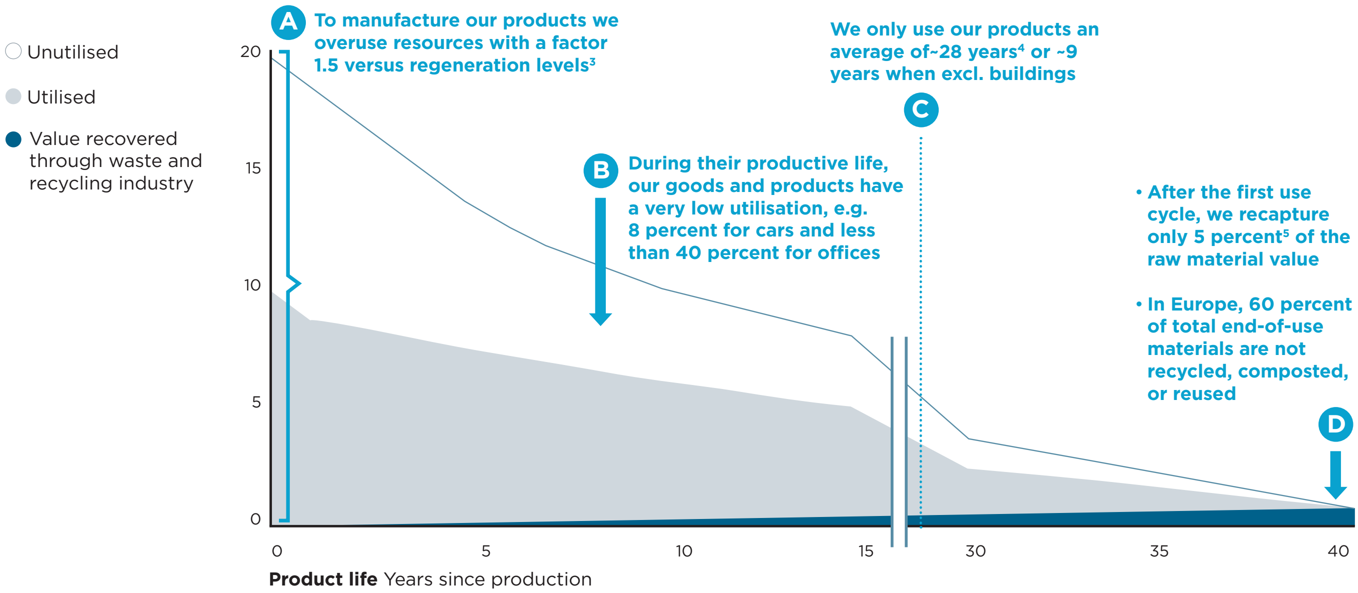
This high dependence on imported resources exposes Europe to price volatility and geopolitical uncertainties. It also creates a competitive problem for European manufacturing. Materials and imported components account for 40-60 percent of the total cost base of manufacturing firms, and European companies frequently suffer competitive disadvantages due to high resource prices.[19]

The analysis of the mobility, food, and built environment value chains shows that Europe's resource use remains surprisingly wasteful, often due to market and regulatory failures. The results are economic losses and depletion of natural capital that could substantially limit the ability to generate prosperity in the medium-to-long term.

1.1 Economic losses due to wasteful resource use

Europe overuses resources by a factor of 1.5-2 versus regeneration levels,[20] with increasingly obvious negative impact. Over their active lifetime, products are utilised, on average, less than 50 percent across sectors, even with a generous definition of utilisation.[21] On average across sectors, European manufactured goods—from furniture to electronic equipment—have a lifetime of about nine years (approximately 28 years, including the building sector) (Figure 1).

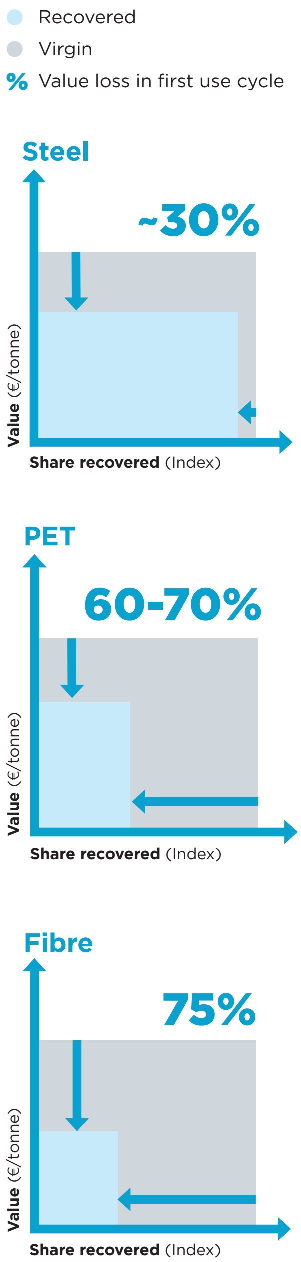
FIGURE 1 **VALUE LOSS OF SELECTED MANUFACTURED GOODS ACROSS THE EUROPEAN ECONOMY**[1]
Value of manufactured products, % of GDP, EU[2], 2012



1 Year 0 starting value based on industry value added (Eurostat,2012) for manufacturing and European raw material input, linear depreciation assumed with average lifetime of 40 years for buildings, 15 years for machinery and equipment, 10 years for transport equipment, 8 years for furniture, 7 years for fabricated metal products and 5 years for electric and electronic equipment; 2 EU27 minus UK, Portugal, Bulgaria, Ireland, Luxembourg and Malta; 3 Indicative, based on Europe's footprint per person compared to earth's capacity per person; 4 Value-weighted average life time; 5 This material value retention ratio is defined as the estimated material and energy output of the European waste management and recycling sector, divided by the output of the raw material sector (adjusted for net primary resource imports and 30 percent embedded resource value in net imported products).
Source: Eurostat; Global Footprint Network; International footprint consortium

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 2 **VALUE LOSS IN SELECTED MATERIAL CATEGORIES**



Source: Expert interviews

Ongoing research commissioned by the German Federal Environment Agency shows that lifespans for consumer electronics and electrical appliances are decreasing, due to consumer preferences, technical obsolescence, and occasionally (but not systematically) planned obsolescence.[22] While innovation is healthy, the issue arises because the economic value disappears almost entirely after the short first lifecycle.

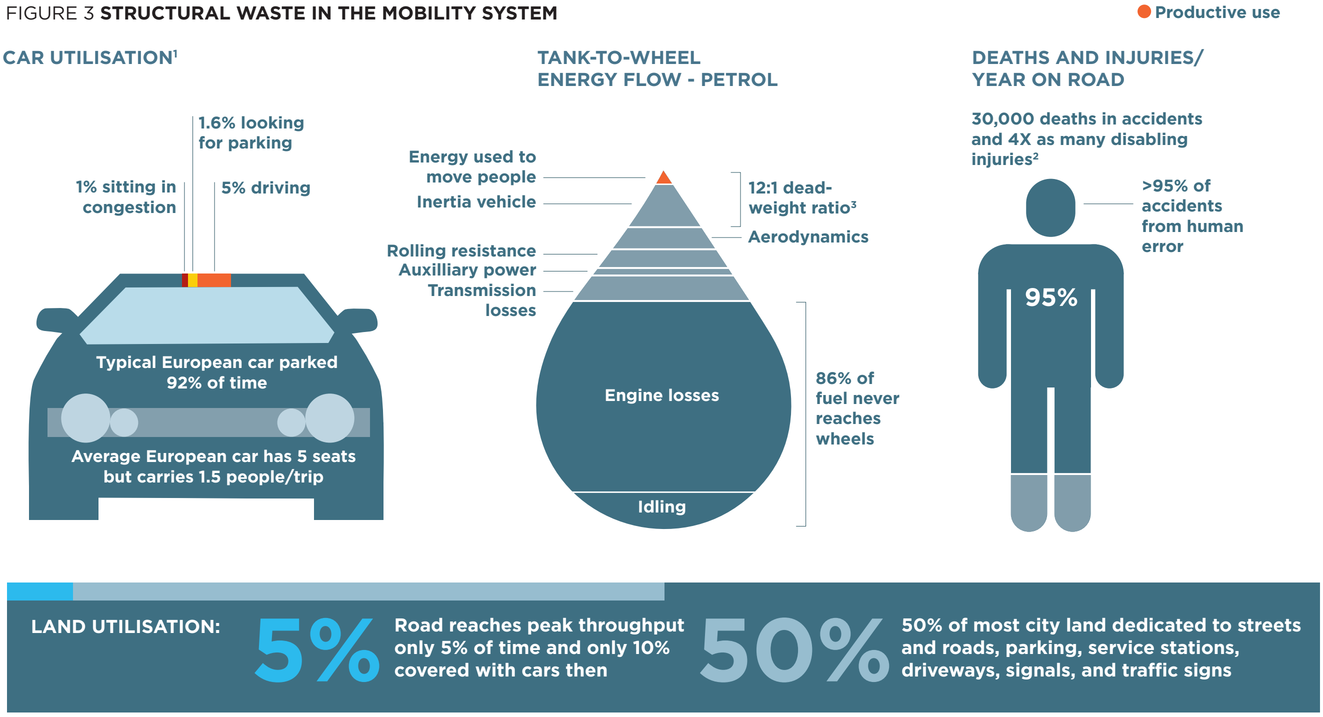
Some, but not a lot of, value remains in materials and energy. Total material recycling and waste-based energy recovery in 2012 rescued only 5 percent of the value of raw materials, while 95 percent of material and energy value was lost after the first use cycle.[23] Even recycling success stories like steel, PET, and paper lose 30-75 percent of their material value after first use (Figure 2). In tonnage terms, only 40 percent of materials in the EU28's municipal solid waste system is recycled in any way; 25 percent is incinerated with energy recovery; and the rest goes to landfills.[24] For all practical purposes, Europe still uses resources once and then discards them.

Structural waste is prevalent in the large, mature sectors on which this study focused. Consider mobility, a century-old sector, where very capable manufacturers have optimised products continuously. This sector captures 15 percent of the average European household's spending.[25]

The European car is parked 92 percent of the time—often on valuable inner-city land (Figure 3). When the car is used, only 1.5 of its 5 seats are occupied. The deadweight ratio often reaches 12:1. Less than 20 percent of the total petroleum energy is translated into kinetic energy, and only 1/13 of that energy is used to transport people. As much as 50 percent of inner-city land is devoted to mobility (roads and parking spaces). But, even at rush hour, cars cover only 10 percent of the average European road. Yet, congestion cost approaches 2 percent of GDP in cities like Stuttgart and Paris.[26]

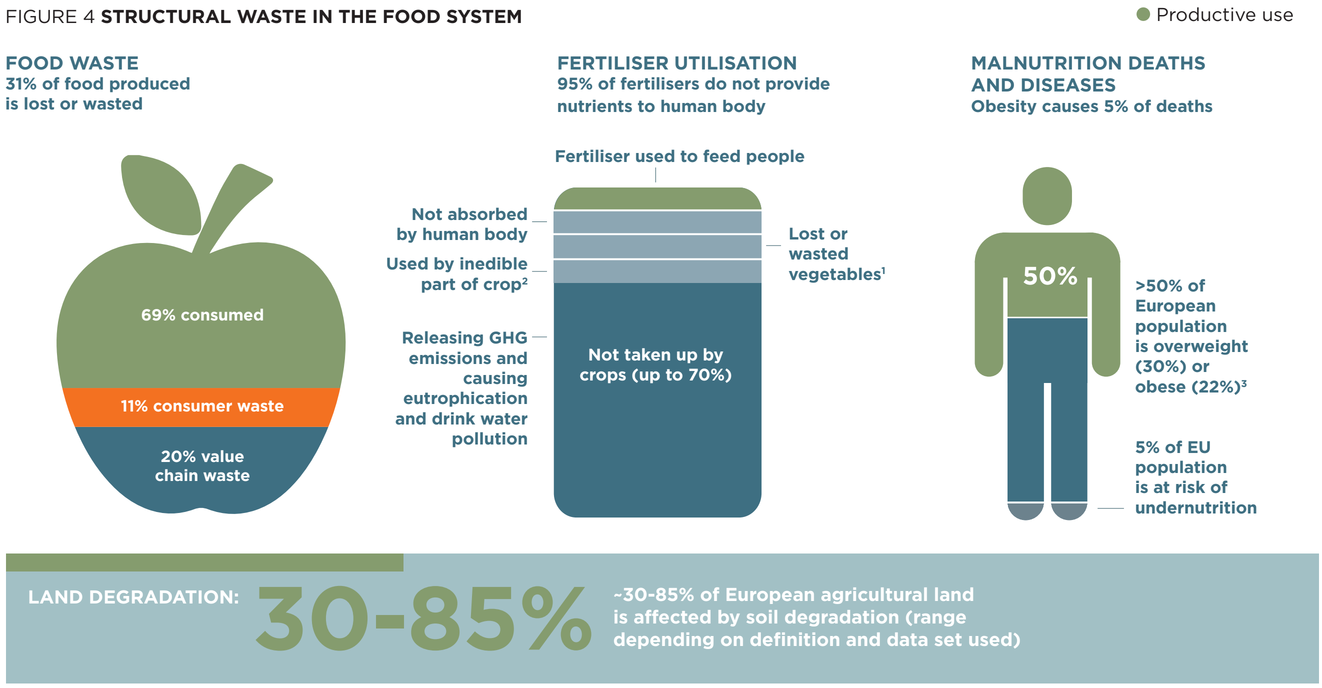
Structural waste also plagues the food value chain. A full 31 percent of European food goes to waste along the value chain, according to research by the United Nation's Food and Agriculture Organization (UN FAO). Categories like fruits and vegetables lose as much as 46 percent of their edible mass.[27]

FIGURE 3 **STRUCTURAL WASTE IN THE MOBILITY SYSTEM**



1 Based on car parked number for France and productive vs unproductive driving time in US. 2 For every death on Europe's roads there are an estimated 4 permanently disabling injuries. 3 Based on average car weight of 1.4 tonnes and average occupation of 1.5 passengers of 75 kg.
Source: EU Commission mobility and transport, accident statistics; www.fueleconomy.gov; EEA car occupancy rates data; S. Heck and M. Rogers, *Resource revolution: How to capture the biggest business opportunity in a century,* 2014; Centre d'études sur les réseaux, les transports, l'urbanisme et les constructions publiques.

FIGURE 4 **STRUCTURAL WASTE IN THE FOOD SYSTEM**



1 In Europe ~46% of edible mass of fruit and vegetables is lost or wasted (FAO, Global food losses and food waste, 2011).
2 On average 23% of vegetable crops is not edible (peels, leaves, ...). 3 BMI >25 (overweight) or >30 (obese).
Source: FAO, *Global food losses and food waste – Extent, Causes and Prevention,* 2011; MGI, *Overcoming obesity: An initial economic analysis,* 2014; WHO website obesity data; EEA, *Towards efficient use of water resources in Europe,* 2012; IFDC; Olle Ljungqvist and Frank de Man, *Under-nutrition - a major health problem in Europe,* 2009; Holly Gibbs and Meghan Salmon, *Mapping the world's degraded lands,* 2015.

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 5 **STRUCTURAL WASTE IN THE BUILT ENVIRONMENT**

CONSTRUCTION	UTILISATION	USAGE	END OF LIFE
• 10-15% of building material wasted during construction • **0-0.5%** productivity increase per year in most European countries 1990-2015, whereas 2% per year achieved in some countries	• 60% of European offices are not used even in working hours • **50%** of residential dwellers report living in too much space	• 20-40% of energy in existing buildings can be profitably conserved • Passive building standards at or near profitability for most new-build segments, but still only constitute a minority of buildings	• 54% of demolition materials landfilled, while some countries only landfill 6% • Most materials unsuitable for reuse as they contain toxic elements

URBAN PLANNING:
- **50% of most city land dedicated to infrastructure**
- **11 million households experience severe housing deprivation**
- **Congestion cost 2% of GDP in many cities**

Source: 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; IEA Statistics © OECD/IEA (http://www.iea.org/stats/index.asp) Energy Statistics and Balances of Non-OECD Countries, Energy Statistics of OECD Countries, and United Nations, Energy Statistics Yearbook; European Commission, *Service contract on management of construction and demolition waste,* 2011.

Key resources for producing food are also wasted. Only 5 percent of fertiliser actually goes into nutrients absorbed by humans, not all of which improve health and well-being. Only 40 percent of irrigation water actually reaches the plants,[28] and soil degradation affects 30-85 percent of European agricultural land (Figure 4). Finally, the average European consumes 40 percent more calories than recommended, and more than 50 percent of the European population is overweight or obese. Again, these numbers represent significant waste—and opportunity.

In the built environment, the average European office is used only 35-40 percent of the time, even during working hours. This includes offices on expensive inner-city land. Retrofitting existing buildings can profitably reduce energy consumption 20-40 percent. Passive and zero-net-energy houses are already making money in several market segments but remain a minority of new buildings. Modular construction techniques can reduce total construction costs 30-60 percent (Figure 5).

These are surprisingly high waste numbers for sectors that are mature and managed professionally. Since mobility, food, and housing together consume 60 percent of the average European household budget, deploying new technologies and business models to reduce such waste offers Europe a tremendous opportunity to improve living standards and increase wealth and consumer choices. In short, today's use of resources does not match today's possibilities.

1.2 Barriers explaining the economic losses

Does this resource waste imply economic losses, or could it be economically rational, reflecting current resource prices and processing costs? For example, people might value immediate access to a car so highly that they would keep a private car, even if it were parked 92 percent of the time. If opportunities to reduce waste are economically attractive, why haven't companies and consumers embraced them?

Indeed, some resource waste is economically rational, but over the last decade technology development, consumer behaviour, and new business models have substantially provided

FIGURE 6 **BARRIERS TO IMPLEMENTATION**

Key barrier · Barrier for scale or speed · Not a barrier

BARRIERS — **ECONOMIC**: Profitability, Capital, Technology, Externalities; **MARKET**: Insufficient public goods infrastructure, Insufficient competition/markets, Imperfect information, Split incentives; **REGULATORY**: Transaction costs, Poorly defined frameworks, Poorly defined targets/objectives, Implementation / Enforcement issues, Unintended Consequences; **SOCIAL**: Capabilities/skills, Custom and habit

CE LEVERS ILLUSTRATIVE	Profitability	Capital	Technology	Externalities	Insufficient public goods infrastructure	Insufficient competition/ markets	Imperfect information	Split incentives	Transaction costs	Poorly defined frameworks	Poorly defined targets/objectives	Implementation / Enforcement issues	Unintended Consequences	Capabilities/skills	Custom and habit
MOBILITY															
Shared electric vehicles	Not a barrier	Barrier for scale or speed	Not a barrier	Key barrier	Barrier for scale or speed	Not a barrier	Barrier for scale or speed	Not a barrier	Barrier for scale or speed	Barrier for scale or speed	Not a barrier	Not a barrier	Key barrier	Not a barrier	Key barrier
Multi-modal systems	Barrier for scale or speed	Key barrier	Not a barrier	Barrier for scale or speed	Barrier for scale or speed	Key barrier	Not a barrier	Not a barrier	Barrier for scale or speed	Not a barrier	Not a barrier	Not a barrier	Key barrier	Not a barrier	Key barrier
FOOD															
Closed nutrient loops	Key barrier	Key barrier	Barrier for scale or speed	Key barrier	Barrier for scale or speed	Not a barrier	Not a barrier	Not a barrier	Not a barrier	Not a barrier	Barrier for scale or speed	Not a barrier	Barrier for scale or speed	Not a barrier	Not a barrier
Regenerative and healthy food chain	Barrier for scale or speed	Barrier for scale or speed	Not a barrier	Key barrier	Not a barrier	Not a barrier	Not a barrier	Not a barrier	Not a barrier	Not a barrier	Barrier for scale or speed	Not a barrier	Not a barrier	Key barrier	Key barrier
BUILT ENVIRONMENT															
Sharing rooms and offices	Not a barrier	Not a barrier	Not a barrier	Not a barrier	Not a barrier	Not a barrier	Barrier for scale or speed	Key barrier	Key barrier	Barrier for scale or speed	Not a barrier	Not a barrier	Key barrier	Not a barrier	Key barrier
Value engineering and Industrial approaches	Not a barrier	Key barrier	Barrier for scale or speed	Not a barrier	Not a barrier	Not a barrier	Key barrier	Not a barrier	Key barrier	Not a barrier	Not a barrier	Not a barrier	Not a barrier	Key barrier	Key barrier

Source: Framework adapted from *Delivering the circular economy: A toolkit for policymakers*, the Ellen MacArthur Foundation (June 2015)

new choices for consumers while changed the economics for mitigating this waste. Addressing the abundant market and regulatory failures would further shift this balance (Figure 6).

Untapped technology. Rapidly falling technology costs are creating major opportunities to reduce waste that have yet to achieve wide currency. For example, the huge drops in the transaction cost of sharing and virtualisation business models enabled by smartphones (e.g., car-sharing and house-sharing) are just starting to permeate the market. The internet of things can keep track of valuable products and materials much more cheaply than in the past, radically increasing opportunities to recover them, and waste management technology is progressing quickly.

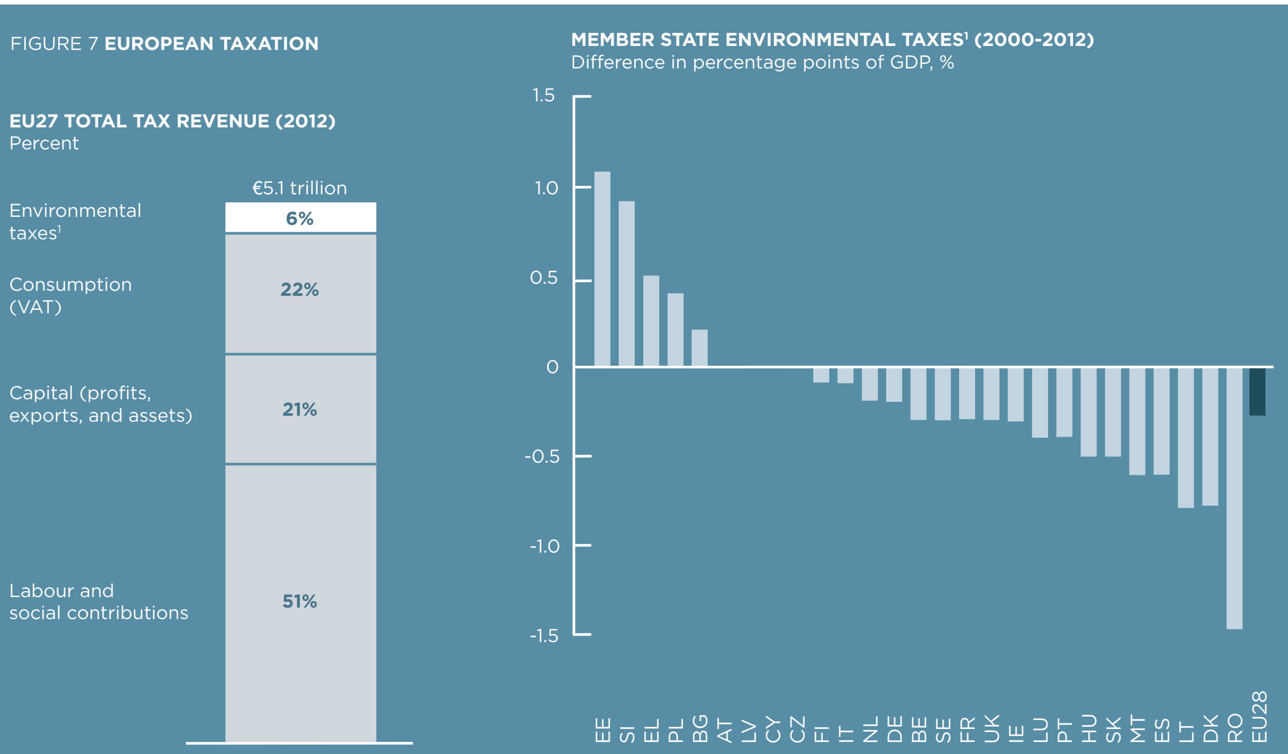
Waste regulations treat waste primarily as an environmental hazard and seek to ensure that waste managers dispose of this waste safely, rather than looking at waste as a source of valuable materials and products. As a result, redesign, recovery, reuse, and trading often face considerable administrative or legal barriers that stop or severely limit these activities. Many products and materials would be profitable to reuse or remanufacture if separated from other waste. But incentives for waste managers seldom encourage adequate separation, so managers mix materials, and the opportunity is lost.

Non-collusive collaboration: Many industries limit opportunities for cooperation in non-competitive areas, such as packaging materials and common infrastructure, for fear of violating competition laws or disclosing sources of competitive advantage.

Unpriced externalities. Several large resource externalities are not priced. Consider CO2. Most academic estimates of the social cost of carbon are an order-of-magnitude higher than the current European carbon price. Similarly, most European cities do not price congestion, despite such obvious side effects as reduced workforce productivity from lost time, air pollution, and requirements for large public infrastructure investments.

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 7 **EUROPEAN TAXATION**



[1] Environmental taxes include taxes on energy, transport, pollution, and resource extraction. “

Source: The Ex’tax Project et al., *New era. New plan. Fiscal reforms for an inclusive, circular economy. Case study the Netherlands*, 2014; Eurostat, *Taxation trends in the European Union*, 2014.

• **Flow-based economic success metrics and policies.** Today, little attention is paid to utilise stocks of manufactured assets. Economic success is measured principally by GDP, a flow-based metric, and most economic policies are designed to grow GDP.

• **An uneven fiscal playing field.** The IMF recently estimated total European direct and indirect subsidies for fossil fuels at €300 billion a year.[29] European environmental taxes are approximately €300 billion a year and dropping as a share of GDP, despite Europe’s desire to reduce resource use. Meanwhile, taxes on labour—input that Europe presumably wants to maximise—represent 51 percent of taxation, with the rest explained by capital and consumption taxes (Figure 7).

• **Customs and habits.** Having grown up with linear production systems and consumption patterns, business executives and consumers seldom look for circular opportunities. Lean manufacturing offers a useful analogy. When this view of production grew popular in the 1980s and 1990s, managers suddenly discovered “new” profit improvement opportunities that had of course long existed. Consumer research shows a yawning gap between intentions and actions. According to a 2014 survey, almost all Europeans (96 percent) think that Europe should use resources more efficiently, but only 21 percent have leased or rented a product instead of buying it, and only 27 percent have used sharing schemes.[30]

1.3 Diminishing returns from natural resources and ecosystems

The depletion of low-cost reserves and, increasingly, the degradation of natural capital are affecting the productivity of economies. While Europe has overcome some natural capital challenges that trouble other economies, such as access to fresh water and inner-city pollution, other challenges remain, notably in the extractive industries and agriculture.
Europe is not running out of resources to mine, but reserves are more expensive to produce and lower in grade, and access is more controversial. Future zinc extraction, for example, will suffer

from lower average concentrations of both zinc (dropping a whole percentage point over the next decade) and valuable by-products like silver, while mining costs will rise because extraction will have to remove and dispose of higher concentrations of iron.

Agricultural productivity growth is dropping in Europe and around the world. Productivity gain has fallen steadily from 2.5 percent a year in the 1970s to 1.3 percent in the 2000s and 0.9 percent in 2010,[31] despite major increases in fertilisers, chemicals, fuels, and other inputs. Today, more nitrogen is fixed synthetically in fertilisers than fixed naturally in all the terrestrial ecosystems combined.[32]

Overall, the extractive sectors are following the lead of some major industrial sectors—starting to generate diminishing returns in a way that creates a drag on overall productivity development.

1.4 In search of growth and employment

These shortcomings are emerging against the backdrop of high unemployment (currently more than 8 percent for labour with non-tertiary education), low growth rates, and an unfulfilled European pledge to strengthen competitiveness. Recognition is growing that addressing these challenges requires more than post-financial-crisis management and government stimuli. The quest has started to locate real sources of competitive cost advantage, renew the mechanisms of value generation, and rebalance factor inputs.

2. A CIRCULAR ECONOMY VISION FOR A COMPETITIVE EUROPE

Does the circular economy offer a promising way to address resource waste and strengthen the European economy? Is circularity a viable vision for Europe? To answer these questions, this study subjected the circular economy vision to three stress tests:

- Do circular principles provide clear guidance for developing the European economy on a path that differs in meaningful ways from the current development path?

- Could a circular path be more cost-effective and competitive than the current path?

- Could a circular economy bring Europe economic and industrial renewal?

2.1 Circular economy principles as a guide to superior economic outcomes

In recent years, the circular economy has figured prominently in political, economic, and business dialogues. But the concept remains eclectic and lacks a scientifically endorsed definition. For the purpose of this economic analysis, the circular economy is defined as an economy that provides multiple value creation mechanisms which are decoupled from the consumption of finite resources (Figure 8). This definition rests on three principles:

- **Preserve and enhance natural capital** by controlling finite stocks and balancing renewable resource flows—for example, replacing fossil fuels with renewable energy or return nutrients

- **Optimise resource yields** by circulating products, components, and materials in use 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.

Narrower notions of the circular economy, limited to material reuse and sometimes regeneration, exist. But the modern economy requires applying all three principles to reintegrate the economy into our planetary system, which is the ultimate ambition of circular thinking. Thus, applying these principles means creating an economy that is restorative and regenerative, that preserves ecosystems and increases their return over time, that creates prosperity, and that fuels growth by capturing more value from existing infrastructure and products.

System change is also crucial to the circular economy. In a circular economy, one system's waste is the next system's input, and the aim is to maximise total utility from the products and materials in use. This requires taking a system view of large value chains.

Metrics can monitor the application of each principle (Figure 9). In a circular economy,

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 8 **OUTLINE OF A CIRCULAR ECONOMY**

PRINCIPLE 1

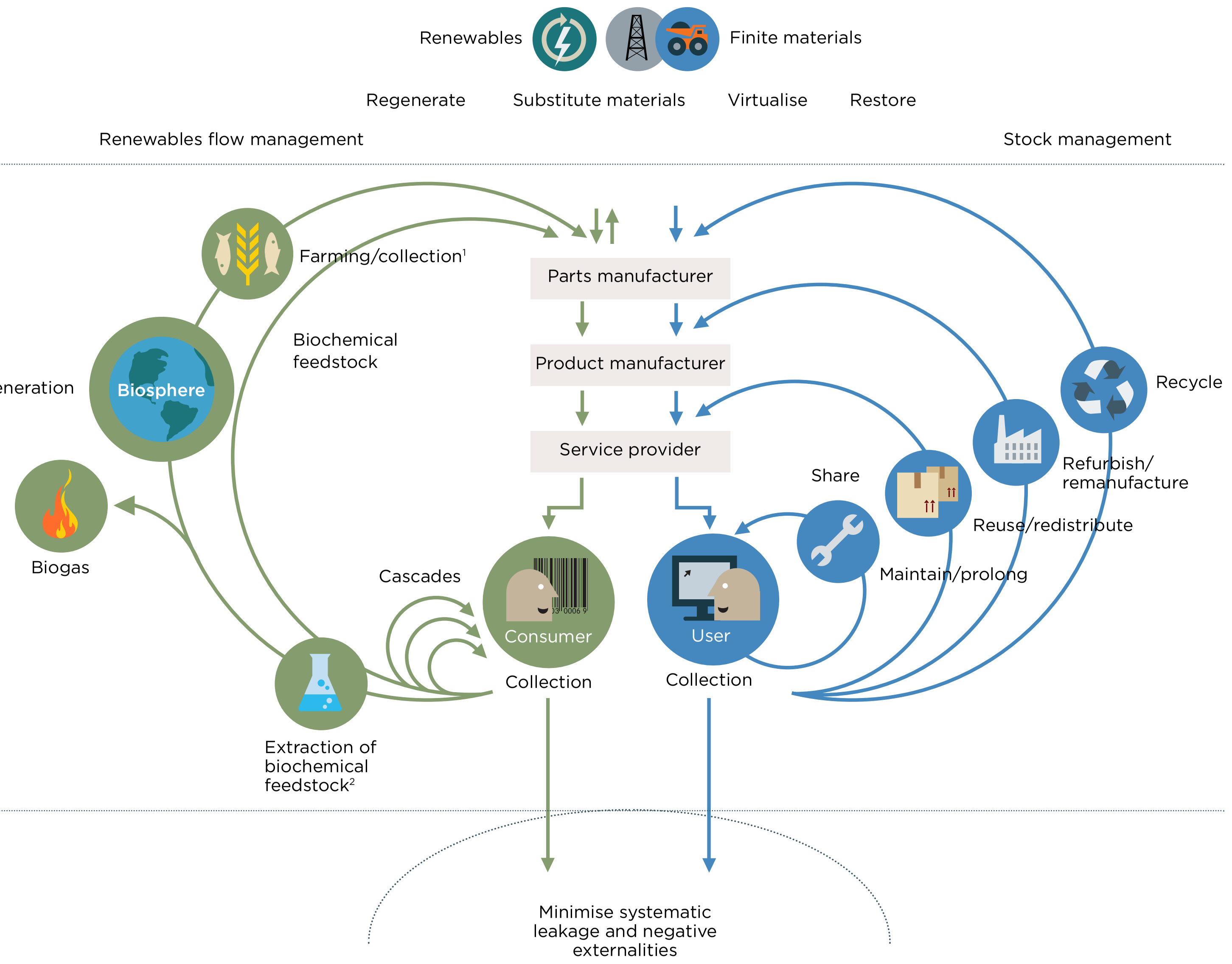
Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows
ReSOLVE levers: regenerate, virtualise, exchange

PRINCIPLE 2

Optimise resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles
ReSOLVE levers: regenerate, share, optimise, loop

PRINCIPLE 3

Foster system effectiveness by revealing and designing out negative externalities
All ReSOLVE levers



1. Hunting and fishing
2. Can take both post-harvest and post-consumer waste as an input

Source: Ellen MacArthur Foundation; McKinsey Center for Business and Environment; Stiftungsfonds für Umweltökonomie und Nachhaltigkeit (SUN); Drawing from Braungart & McDonough, Cradle to Cradle (C2C).

FIGURE 9 **MEASURING THE CIRCULAR ECONOMY**

		PRIMARY METRIC	SECONDARY METRICS
PRINCIPLE 1	Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows	Degradation-adjusted net value add (NVA)[1]	• Annual monetary benefit of ecosystem services, e.g. from biodiversity and soils • Annual degradation • Overall remaining stock
PRINCIPLE 2	Optimise resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles	GDP generated per unit of net virgin finite material input[2]	• Product utilisation • Product depreciation/lifetime • Material value retention ratio (energy recovery, recycling and reman industry) / value of virgin materials (rolling net average last 5 years)
PRINCIPLE 3	Foster system effectiveness by revealing and designing out negative externalities	Total cost of externalities and opportunity cost	• Cost of land, air, water, and noise pollution • Toxic substances in food systems • Climate change, congestion, and health impacts

1 The System of Environmental-Economic Accounting, 2012.
2 Adapted based on the EU's Resource Efficiency Scoreboard (Eurostat, 2014). The adaptation is to deduct recovered materials and only include finite materials.

The three principles of the circular economy can translate into six business actions: Regenerate, Share, Optimise, Loop, Virtualise, and Exchange—together, the ReSOLVE framework. Figure 10 (over page) shows the framework and some companies taking advantage of specific levers.

REgenerate. Shift to renewable energy and materials; reclaim, retain, and regenerate health of ecosystems; and return recovered biological resources to the biosphere. For example, the European power sector is moving rapidly into renewables. New investments totalled $650 billion over the 2004-2013 period.[33] Likewise, Savory Institute's promotion of holistic land management has influenced the regeneration of more than 2.5 million hectares of commercial land worldwide.

Share. Keep product loop speed low and maximise utilisation of products by sharing them among users (peer-to-peer sharing of privately owned products or public sharing of a pool of products), reusing them throughout their technical lifetime (second-hand), and prolonging their life through maintenance, repair, and design for durability. For example, the BlaBlaCar car-sharing scheme is growing 200 percent a year and has 20 million registered users in 19 countries.[34] Airbnb has more than one million spaces for rent in more than 34,000 cities across more than 190 countries.[35]

Optimise. Increase performance/efficiency of a product; remove waste in production and the supply chain (from sourcing and logistics to production, use, and end-of-use collection); leverage big data, automation, remote sensing, and steering. None of these actions requires changing the product or technology, as exemplified by the lean philosophy made famous by Toyota.

Loop. Keep components and materials in closed loops and prioritise inner loops. For finite materials, this means remanufacturing products or components and as a last resort recycling materials, as Caterpillar, Michelin, Rolls Royce, and Renault are doing.[36] For renewable materials, this means anaerobic digestion and extracting bio-chemicals from organic waste. In the UK, 66 percent of sewage sludge is treated in 146 anaerobic digestion plants, and another 175 plants produce bio-energy from solid waste, a number that is growing rapidly.[37]

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 10 **THE RESOLVE FRAMEWORK**

	EXAMPLES
REGENERATE	• Shift to renewable energy and materials • Reclaim, retain, and restore health of ecosystems • Return recovered biological resources to the biosphere
SHARE	• Share assets (e.g. cars, rooms, appliances) • Reuse/secondhand • Prolong life through maintenance, design for durability, upgradability, etc.
OPTIMISE	• Increase performance/efficiency of product • Remove waste in production and supply chain • Leverage big data, automation, remote sensing and steering
LOOP	• Remanufacture products or components • Recycle materials • Digest anaerobic • Extract biochemicals from organic waste
VIRTUALISE	• Books, music, travel, online shopping, autonomous vehicles etc.
EXCHANGE	• Replace old with advanced non-renewable materials • Apply new technologies (e.g. 3D printing) • Choose new product/service (e.g. multimodal transport)

Source: Company interviews; Web search. S. Heck and M. Rogers, *Resource revolution: How to capture the biggest business opportunity in a century*, 2014.

Virtualise. Deliver utility virtually—books or music, online shopping, fleets of autonomous vehicles, and virtual offices. Google, Apple,[38] and most OEMs plan to release driverless cars in the next decade.

Exchange. Replace old materials with advanced non-renewable materials; apply new technologies (e.g., 3D-printing and electric engines); choose new products and services (e.g., multi-modal transport). In 2014 Chinese company WinSun 3D-printed ten houses, each about 195 square metres, in 24 hours.[39]

Each action represents a major circular business opportunity enabled by the technology revolution that 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, creating a strong compounding effect.

These actions could have profound impact across European sectors. Figure 11 shows an indicative prioritisation for 20 major sectors, based on the economic and resource impact of the actions in the ReSOLVE framework. While not definitive, the prioritisation suggests where the greatest potential lies.

The ReSOLVE framework offers companies 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.

2.2 *Growth within*—a circular economy vision

The analysis applied circular economy principles and business actions to three human needs—mobility, food, and shelter—in order to understand how these systems might look different from today and whether they could be cost-competitive. For each system, the analysis defined a potential future state based on technology that will be available within five years and tested this vision in expert interviews. The circular scenario outlined for each system does not represent the most likely development path; it simply describes a technically viable future state.

In summary, analysis suggests that the ReSOLVE framework is very relevant to all three study systems and could help increase cost-competitiveness substantially (Figure 12 over page). For the average European household, capturing all of the improvement

FIGURE 11 **POTENTIAL IMPACT OF ReSOLVE** ● High ● Middle ● Low

ECONOMIC ACTIVITIES	**Regenerate**	**Share**	**Optimise**	**Loop**	**Virtualise**	**Exchange**
Information & Communication services, media and telecommunications	Low	Middle	Middle	Low	High	Low
Scientific R&D, other professional, scientific & technical activities	Low	Middle	Middle	Low	High	Low
Education	Low	Middle	Middle	Low	High	Low
Human health and social work activities	Low	Middle	Middle	Low	High	Low
Administrative & support services	Low	Middle	Middle	Low	High	Low
Arts, entertainment and recreation	Low	Middle	Middle	Low	High	Low
Financial and insurance activities	Low	Middle	Middle	Low	High	Low
Legal & accounting head offices, consulting, architecture, TIC	Low	Middle	Middle	Low	High	Low
Distributive trades (incl. wholesale and retail trade)	High	High	Middle	Middle	High	Middle
Manufacture of wood and paper products, and printing	High	High	Middle	Low	High	Low
Public administration and defence; compulsory social security	Low	High	Middle	Middle	High	Middle
Real estate activities	Low	High	Middle	Low	Middle	Low
Manufacturing of textiles, apparel, leather and related products	High	High	Middle	Low	Middle	Middle
Construction	Low	High	Middle	High	Middle	Middle
Manufacturing of transport equipment	Low	High	Middle	High	High	Middle
Manufacturing of furniture	High	High	Middle	Middle	Low	Low
Water supply, waste & remediation	High	Middle	Middle	Low	Low	Middle
Manufacturing of elec. equipment, computer, electronic and optical products	Low	Middle	Middle	High	Middle	Middle
Manufacturing of machinery and equipment	Low	Middle	Middle	High	Middle	Middle
Manufacturing of rubber, plastics, basic and fabricated metal products	Middle	Middle	Middle	High	Low	High
Transportation and storage	Low	Middle	Middle	High	Low	High
Agriculture, forestry and fishing	High	Low	Middle	Low	Low	High
Manufacturing of food, beverages and tobacco products	High	Low	Middle	High	Low	High
Mining and quarrying	Low	Low	Middle	High	Low	High
Electricity, gas, steam and air-conditioning supply	High	Low	Middle	Middle	High	High
Manufacturing of coke, refined petroleum, chemicals products	Low	Low	Middle	Middle	Low	High
Manufacturing of pharmaceuticals, medicinal chemical, botanical	Middle	Low	Middle	Middle	Low	Middle
Accommodation and food service activities	Middle	High	Middle	Middle	Middle	Low

as TCO savings could reduce mobility costs 60-80 percent, food costs 25-40 percent, and housing costs 25-35 percent by 2050.

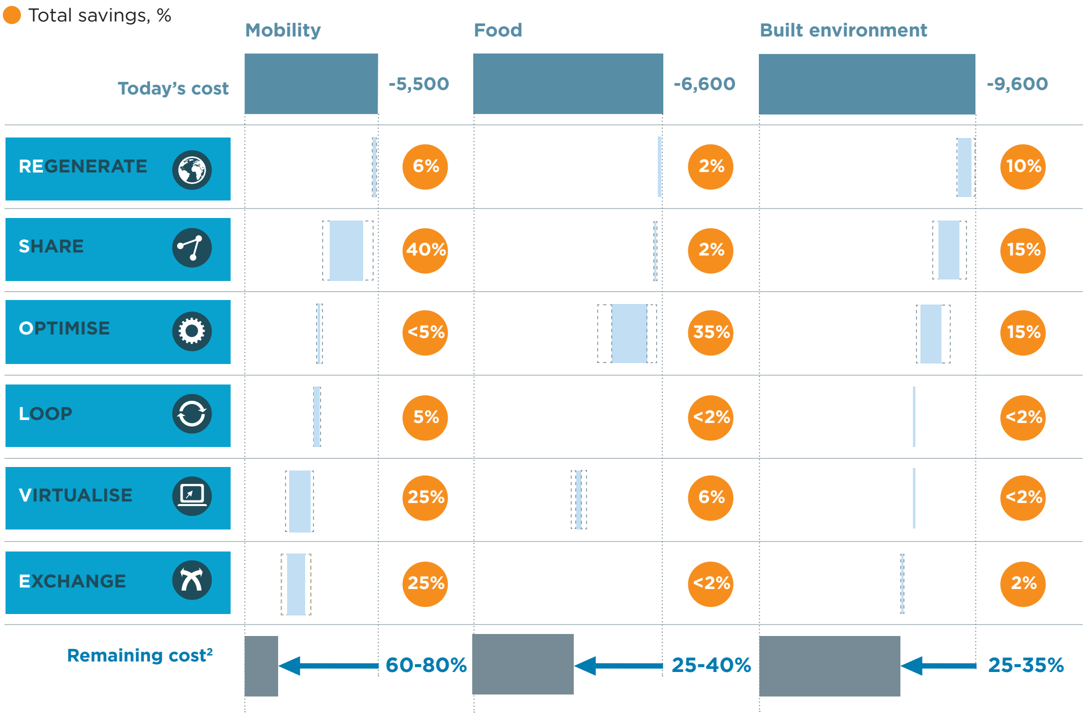
Not all of the technological advances would reduce cost—many might increase performance—and the technology would need time to penetrate the asset stock. But the exhibit shows the transformational power that new technology and business models could have. As mobility, food, and housing represent 60 percent of the average EU household budget and 80 percent of resource consumption, improvements in these big value chains could contribute significantly to Europe's overall economic performance, as detailed in the sector deep-dive chapters.

Mobility. A circular mobility system would offer more choices and be shared, electrified, autonomous, multi-modal, and looped. Individualised mobility would be provided as a service. Better system integration would make most trips multi-modal. Combined, these changes would mean fewer, better-utilised cars, with such positive side effects as less congestion, less land and investment committed to parking and roads, and less air pollution. In this system, cost per average passenger-km could drop by as much as 80 percent by 2050.

Food. A circular food system would be regenerative, resilient, non-wasteful, and healthy. Reconnected nutrient loops would encourage the rehabilitation of degraded land. Farms would be located close to consumers through urban and peri-urban farming. Organic agriculture would minimise the need for fertiliser and pesticides. People would receive high-quality, non-toxic food for a healthier lifestyle, while digital solutions would match supply and demand, creating a less wasteful, on-demand system. Food cost per person could be more than 30 percent lower than today.

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 12 **COST-REDUCTION POTENTIAL**
Total annual cash-out costs per household; EU average 2012, €, Improvement potential for 2050[1]



1 Note that this is not a forecast of how costs will develop. It is an assessment of how costs could develop if Europe aggressively went after this agenda, and if all improvements were captured as cost savings. 2 The total savings are less than the sum of the savings of the separate levers due to overlap

Source: Company and expert interviews; Web search; Eurostat household expenditure data; ACEA, *The Automobile Industry Pocket Guide*, 2015; Todd Alexander Litman, *Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications,* Victoria Transport Policy Institute, 2009; Udo Jürgen Becker et al., *The True Costs of Automobility: External Costs of Cars: Overview on existing estimates in EU-27,* TU Dresden, 2012; ICCT, *European Vehicle Market Statistics Pocketbook,* 2013; ICE database of CO2 embedded in material; Frances Moore and Delavane Diaz, T*emperature Impacts on Economic Growth Warrant Stringent Mitigation Policy,* Nature Climate Change, 2015; MGI, *Overcoming obesity: An initial economic analysis,* 2014; FAO, *Global food losses and food waste – Extent, Causes and Prevention*, 2011; EEA, *Towards efficient use of water resources in Europe,* 2012; EU Commission, *Official journal of the EU, Commission Agriculture and Rural Development, 2012 budget,* 2012; FAOSTAT; Kimo van Dijk, *Present and future phosphorus use in Europe: food system scenario analyses,* Wageningen University, 2014; Josef Schmidhuber, *The EU Diet – Evolution, Evaluation and Impacts of the CAP,* FAO, 2008; Gregor Zupancic and Viktor Grilc, *Anaerobic Treatment and Biogas Production from Organic Waste,* 2012; Joint Research Centre (JRC) of the European Commission et al., *Precision agriculture: an opportunity for EU farmers – potential support with the CAP 2014-2020,* 2014; Laure Itard et al., *Building Renovation and Modernisation in Europe: State of the art review,* TU Delft, 2008; BPIE, *Europe's buildings under the microscope: A country-by-country review of the energy performance of buildings,* 2011; Per-Erik Josephson and Lasse Saukkoriipi, *Waste in construction projects: call for a new approach,* Chalmers University of Technology, 2007; Mark Hogan, *The Real Costs of Building Housing,* SPUR, 2014; Cushman & Wakefield Research Publication, Office space across the world, 2013; Ellen MacArthur Foundation, *Delivering the circular economy toolkit for policymakers,* 2015.

Built environment. A built environment based on circular economy principles would reclaim the inner-city land unlocked by a circular mobility system to create high-quality spaces where people would live, work, and play. The system would integrate green infrastructure (e.g., parks) with durable, mixed-use buildings designed in a modular way and constructed with looped and non-toxic materials.

Buildings would generate, rather than consume, power and food. They would have fully closed water, nutrition, material, and energy loops. They would be highly utilised, thanks to shared and flexible office spaces and flexible, smart, and modular homes. This could lead to a reduction in the cost per square meter of more than 30 percent versus today.

While these sources of growth exist to some extent today, they receive little corporate attention. The historic lack of focus on these sources, the considerable formal and informal barriers, and the rapid development of technology create a tremendous growth opportunity for Europe. We call this opportunity *growth within* because the circular economy focuses on getting much more value from existing economic structures. The circular economy offers a new growth paradigm that Europe would largely control so Europe would face less pressure to compete with low-cost countries in a global marketplace.

2.3 Economic and industrial renewal

The circular economy could provide an opportunity for economic renewal—realigning economic success metrics with social realities, simplifying governance, encouraging long-debated structural reform, and advancing towards competitiveness by reducing resource cost. Transitioning to a circular economy could even become the second major European political economy project after establishing the internal market.

The circular economy represents a radical shift in perspective—from improving value chains to better meeting human needs. This would require tapping connected technologies, redesigned products, new business models, and changes in consumer behaviour to create significant customer value.

Such disruptions would bring renewal to industry. The European Commission has made this renewal a priority and set the goal of increasing industry's share of GDP from 16 percent today to 20 percent by 2020.[40]

To manage the transition well, the incumbent industry would need to:

- **Understand and monitor the new ecosystem,** for example by incubating start-ups.
- **Tap the power within.** Review assets at disposal and maximise their value.
- **Form alliances.** Creating a strong network of partners is crucial when competition is shifting rapidly.
- **Engage the world's talent.** As new competitors would emerge at a global scale, traditional players would have to anticipate new needs and attract the best talent.
- **Avoid inertia.** In a changing environment, maintaining the status quo is risky.

In summary, the analysis suggests that the circular economy could be more cost-effective in meeting human needs than today's linear economy and that it could bring economic and industrial renewal.

FINDINGS AND CONCLUSIONS CONTINUED

3. THE TECHNOLOGY REVOLUTION WILL HELP THE ECONOMY BUT WILL NOT SOLVE RESOURCE AND EXTERNALITY PROBLEMS

Even without application of circular principles, the technology revolution will significantly improve resource productivity and per-unit cost and thus help the European economy. But on the current development path, rebound effects and lack of appropriate system integration will not solve the resource and externalities issues.

Most business leaders are preparing to tap the potential of the technology and digital revolution. On the current development path, electric vehicles, sharing platforms, and autonomous vehicles could create a very different mobility sector in 10-15 years. IT, automation, and satellite positioning are enabling precision farming and whole-farm management. Business models predicated on sharing residential and office space are quickly changing demand patterns, and new modular and 3D-printing construction technologies are lowering costs per square metre 30-60 percent. Analysis suggests that the new technologies could transform several major product sectors, just as many information sectors have already been transformed (for example, retail banking, entertainment, and publishing).

While sometimes painful for incumbents, substantial productivity increases would be good news for Europe's economy, companies, and citizens. But two issues remain.

First, resource productivity increases in the study sectors have historically met an elastic demand response. When relative prices decrease, consumers use more individualised transport, floor space, and food. This rebound effect for the three study sectors could be 5-20 percent by 2030, negating much of the consumer benefits associated with the new technologies (Figure 13). Resource consumption would likely increase less, due to efficiency improvements, but the net effect would still be high levels of resource use, with the side effects of greenhouse gas emissions and other externalities.

Second, history shows that product-level innovation often outpaces system-level innovation. So Europe faces a big risk that urban planning, mobility systems, and food systems would not be able to integrate the new technologies effectively, leaving structural waste untouched. For example, autonomous vehicles would not automatically induce sharing at scale or very high utilisation levels if not integrated into an inter-modal system. Similarly, precision agriculture might create significant synthetic fertiliser savings but would not close nutrient loops, regenerate lands or remove waste from the food value chain.

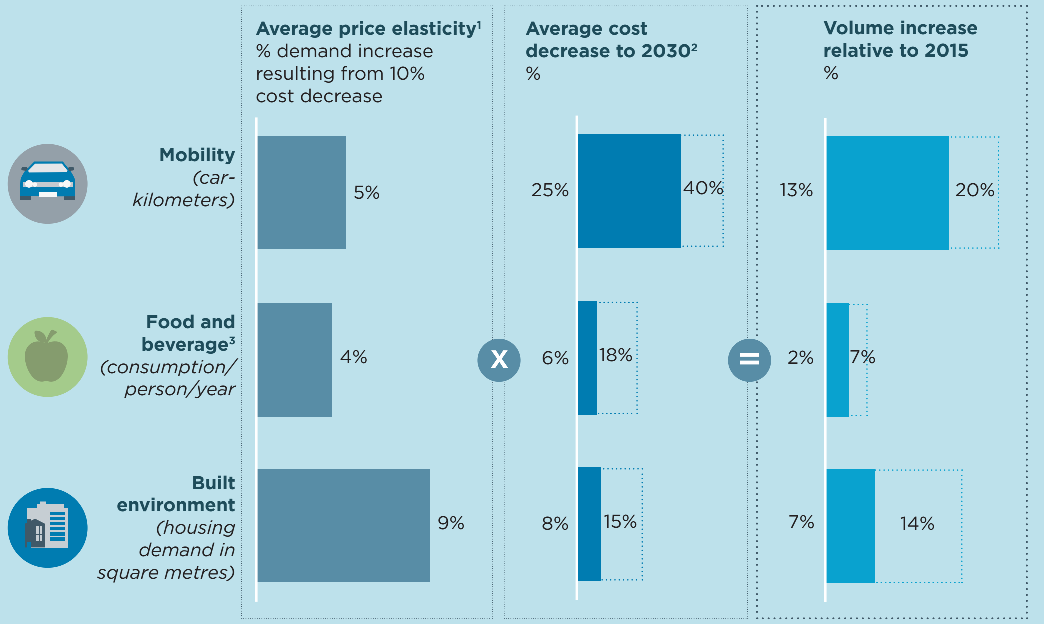
Mobility. The car fleet, which accounts for more than 80 percent of Europe's motorised ground transportation,[41] could change substantially in the next 10-20 years. Sharing, electrification, and interconnectivity are already scaling, and autonomous vehicles could soon be a commercial reality. Higher utilisation of cars in sharing schemes could make lighter materials like aluminium and carbon fibre more attractive. These technologies might lower the cost per passenger-kilometre significantly, 25-40 percent by 2030.

Such reductions in the relative price of individual transportation is likely to increase demand substantially. Many consumers might shift from public transport to private, and new consumer groups (e.g., the young and the old) might make more use of individual transportation.

The research on demand elasticity in transportation is extensive. A meta-study, which reviewed 69 studies in North America, Europe, and Japan, found that, in the long run (after five years), increasing net income 10 percent (or decreasing relative costs 10 percent) raises demand for vehicles and fuel more than 10 percent and traffic 5 percent—the opposite of a saturation effect.[42] This greater volume of vehicles would, in turn, increase congestion and commuting time. In most cities a mere 5 percent increase in traffic volume makes congestion much worse.

In response, cities could take several actions—make public transportation more attractive, develop inter-modal mobility systems, and manage volume in congested areas. But these are complex and expensive efforts; and experience suggests that, on the current trajectory, cities would have a hard time keeping up with fast-moving technology companies.

FIGURE 13 **POSSIBLE VOLUME INCREASES**



1 Long-term elasticity.
2 Estimates detailed in sector-specific analyses for the current development scenario for 2030.
3 Average elasticity for food and beverages; at a more granular level, elasticity varies by type of food/ beverage.

Source: P. Goodwin, J. Dargay and M. Hanly, *Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review,* Transport Reviews, Vol. 24, 2004; J. Follain and E. Jimenez, *Estimating the Demand for Housing Characteristics: A Survey and Critique,* Regional Science and Urban Economics, Vol. 15, 1985; T. Andreyeva, M. W. Long, and K. D. Brownel, *The Impact of Food Prices on Consumption: A Systematic Review of Research on the Price Elasticity of Demand for Food,* Am J Public Health,100(2), 2010.

Economic modelling suggests that the total mobility pay-out cost for an average European household could drop 17 percent by 2030. However, the negative system effects of more congestion and resource consumption could reverse much of these gains, resulting in a net TCO saving of only 5 percent.

Food. The trend is similar in food. New technologies like precision farming could boost farm productivity and reduce waste in the supply chain. This could lower the cost of food—on the current path about 6-18 percent—which could, in turn, increase calorie consumption—already the third largest social burden that costs 3.3 percent of European GDP.[43]

Built environment. The building sector could see similar developments, albeit likely less dramatic and taking longer to materialise. New technologies and business models, including sharing, modular construction, 3D-printing, and smart energy management technologies, might lower cost per utilised square metre. The building sector has considerable unmet consumer demand, especially in cities where many people and offices want larger spaces. If cost fell 10 percent, research suggests that demand would increase around 9 percent, exacerbating urban sprawl, consumption of resources, and pressure on real estate markets.

The looming transformation could happen fast. Consider the European electricity industry, another asset-intensive sector. Known for its long-lived assets, this industry changed fundamentally in only six or seven years. Since 2008 growth in the supply of renewable technology has outpaced feeble growth in electricity demand, leaving incumbent technologies with negative growth and markets with over-supply. This, in turn, has led to sharply dropping electricity prices, bleak long-term growth prospects for incumbents, and major write-downs.

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 14 **SCENARIO DESCRIPTIONS**

	CURRENT DEVELOPMENT PATH	CIRCULAR SCENARIO
	A development path based on current trends and expected disruptive technology breakthroughs, where the current system is optimised in terms of cost and convenience, without making real system level changes	A development path based on a dedicated choice for a systems-based approach to redesign current systems along circular principles, leveraging available and emerging disruptive technologies.
MOBILITY	Car technology would evolve rapidly, reducing cost and improving the customer experience (e.g. autonomous driving), but the individual car would remain the dominant mode of transportation. A lack of incentives for OEMs would slow down the adoption of some resource efficiency levers.	The mobility system would have multiple mobility options at its core, would incorporate on-demand, automated car mobility as a flexible, but predominantly last-mile solution. OEMs would have strong incentives to offer mobility services. Higher rates of utilisation would drive vehicle design with remanufacturing, durability, efficiency and easy maintenance into account.
FOOD	The food value chain would become more efficient, thanks primarily to resource-efficient agricultural practices and food waste reduction, but would not capitalise on the opportunities represented by rehabilitation of degraded land, closed loop farming, organic agriculture, and peri-urban farming. Due to this lack of a systemic shift, changes in diet and health outcomes would be limited.	On top of efficiency and waste reduction improvements, the food system would close the nutrient loops, preserve natural capital and create a market for rehabilitating degraded land and fish stocks. Consumers would have ready access to local, fresh, organic, high-quality food that would encourage healthier dietary choices.
BUILT ENVIRONMENT	Sharing, tele-working, and energy efficiency would advance rapidly, supported by the digital revolution, while modularity and industrial processes would progress more slowly. Relatively little system optimisation (urban planning) would lead to a continuation of Europe's high land-take rate.	A development with urban planning at the center would create a smart built environment that took advantage of high-value unlocked land in urban areas to create more affordable, durable, modular and shareable buildings. Reducing Europe's land-take rate, this path would protect land from degradation and fragmentation.

1 Including car and construction materials, synthetic fertilizer, agriculture water use, fuel and non-renewable electricity

Source: Company and expert interviews; Eurostat household expenditure data; ACEA, *The Automobile Industry Pocket Guide*, 2015; Todd Alexander Litman, *Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications*, Victoria Transport Policy Institute, 2009; Udo Becker et al., *The True Costs of Automobility: External Costs of Cars: Overview on existing estimates in EU-27*, TU Dresden, 2012; ICCT, *European Vehicle Market Statistics Pocketbook*, 2013; ICE database of CO2 embedded in material.

Combined, the rebound effects could reverse much of the consumer benefits and resource savings by increasing consumption, congestion, urban sprawl, and prices. As established in previous reports by the Ellen MacArthur Foundation, technology can act as a powerful enabler of a circular model, but Europe would need to leverage the technology carefully to realise its full potential.

4. A CIRCULAR ECONOMY COULD PRODUCE BETTER OUTCOMES

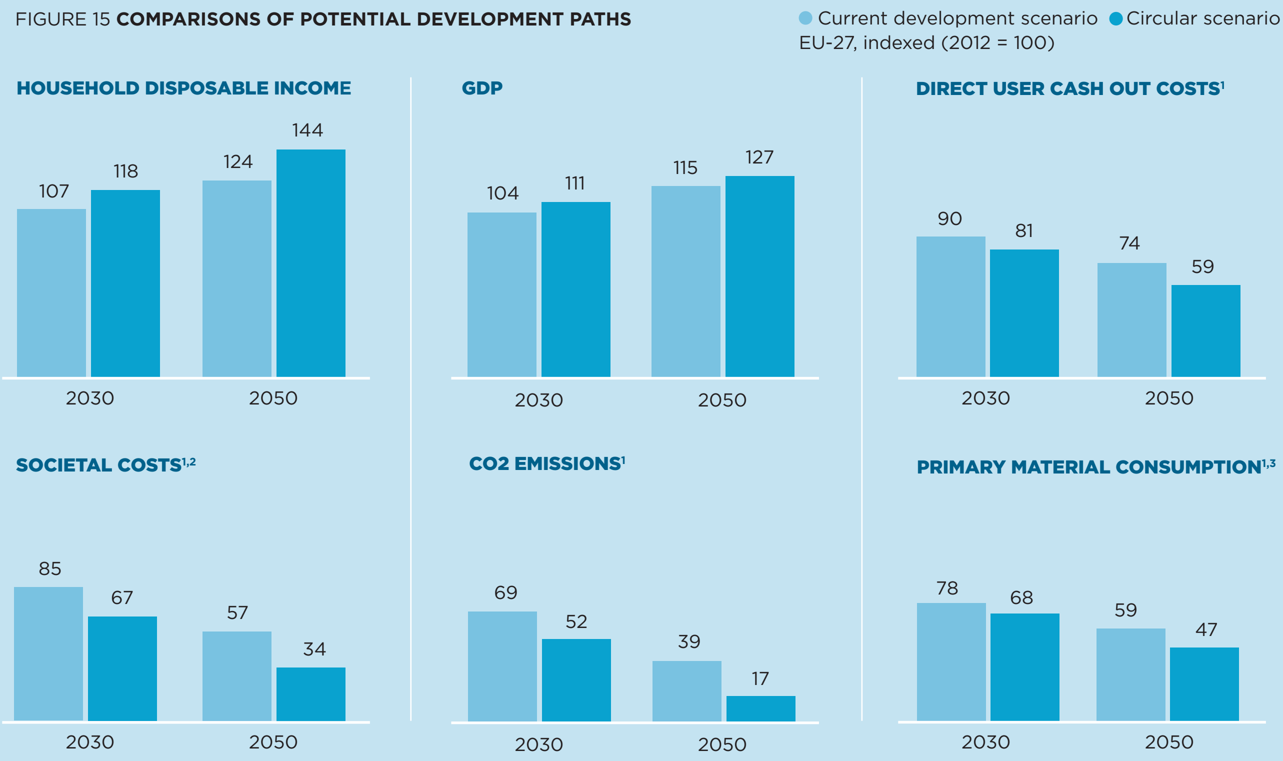
To explore whether shifting to a circular model could create better societal, economic, and environmental outcomes, the analysis modelled two scenarios for Europe: the current development path and a circular path (Figure 14).

Both scenarios included the quantification of welfare, GDP, and resource and environmental impacts. The modelling suggests that moving towards a circular European economy would produce better outcomes for GDP, employment, and greenhouse gas emissions (Figure 15).

4.1 Economic outcomes

The circular economy scenario could increase the disposable income of an average European household through reduced cost of products and services and a conversion of unproductive to productive time (e.g. reduction in congestion cost). This could result in increased consumption and thereby higher GDP growth. Economic modelling[44] across the three study sectors suggests that today's disposable income of an average European household could increase as much as 18 percent by 2030 and 44 percent by 2050 in a circular scenario, compared with 7 and 24 percent in the current development scenario.

FIGURE 15 **COMPARISONS OF POTENTIAL DEVELOPMENT PATHS**



1 Numbers only cover mobility, food, and built environment 2 Including cash out costs (e.g., health costs, governance, infrastructure) and externalities (e.g., congestion, CO2, productivity losses) 3 Including virgin automotive and construction material, virgin synthetic fertiliser, pesticides, agriculture land and water use, car and heating fuel, land for residential and office buildings and non-renewable electricity.

European GDP could increase as much as 11 percent by 2030 and 27 percent by 2050 in a circular scenario, compared with 4 percent and 15 percent in the current development scenario, driven by increased consumption due largely to correcting market and regulatory lock-ins that prevent many inherently profitable circular opportunities from materialising. Thus, in a circular scenario, GDP could grow with 7 percentage points more by 2030 than the current development path and could increase the difference to 12 percentage points by 2050.

These results are higher than reported from most other recent studies on the economic impacts of a circular and resource-efficient economy. For instance, the recent report "Study on modelling of the economic and environmental impacts of raw material consumption" conducted by Cambridge Econometrics and Bio Intelligence Service, concluded on a slightly positive GDP impact. The key reason for the difference is that this report assumes a slightly substantially higher pace of technology change in the big product and resource sectors going forward compared to what has been observed in the past - for the reasons explained above - whereas most other reports assume a similar pace as witnessed historically.

While using different methodologies and examining different sectors and geographies, other studies have consistently demonstrated the positive macroeconomic impact of a circular economy (Table 1).

These results are consistent with industry observations. Many sectors already include one or a few innovative companies that are significantly more circular than their competitors and are profiting. In the automotive sector, Renault's remanufacturing plant in France extends the life of vehicle components, retaining value and saving on energy, while reducing waste. In the aviation sector, Rolls Royce and others have moved to a performance-based model for jet engines. In healthcare, Philips recently expanded its medical imaging

FINDINGS AND CONCLUSIONS CONTINUED

TABLE 1 **SELECTED LITERATURE ON THE MACROECONOMIC IMPACT OF THE CIRCULAR ECONOMY**

Opportunities for a Circular Economy in the Netherlands (2013)[46]	This report analyses the opportunities and obstacles that the Netherlands would face in moving towards a more circular economy and offers policy proposals to accelerate the process. The report estimates overall annual impact of the circular economy in the Netherlands of €7.3 billion, creating 54,000 jobs. The current value of the circular economy for 17 product categories in the metal and electrical sectors is €3.3 billion, and the Netherlands could achieve additional annual market value of €573 million. The use of the 34 most important waste streams already represents value of €3.5 billion. An estimated investment of €4–8 billion in new technologies could create added value of €1 billion a year for the circular economy in bio-refining, bio-gas extraction, and sorting of household waste.
The Circular Economy and Benefits for Society (2015)[47]	This report calls greatly enhanced resource efficiency a prerequisite for the global economy to stay within the planetary boundaries. The report finds that, combined with efforts to increase energy efficiency and the use of renewable energy, organising manufacturing along the lines of a materially efficient circular/performance-based economy in Sweden would add 100,000 jobs (2–3 percent of the labour force), improve the trade balance more than 3 percent of GDP, and reduce CO2 emissions 70 percent. Similar studies for the Netherlands and Spain are underway, but results were not published in time to include in this report.
Study on modelling of the economic and environmental impacts of raw material consumption (2014)[48]	This technical report provides a quantitative analysis of different resource productivity targets for Europe, using GDP per unit of raw material consumption. Improvement targets range from 1 percent to 3 percent a year (cumulative 15–30 percent by 2030). The modelling results suggest that improvements of 2–2.5 percent a year could have net positive impact on EU-28 GDP. The results also show that annual resource productivity improvement of 2 percent could create two million jobs.
Employment and the circular economy: Job creation in a more resource efficient Britain (2015)[49]	This report explores how to address the UK's use of labour and scarce natural resources. The report suggests that the circular economy could create 200,000–500,000 gross jobs, reduce unemployment by 50,000–100,000, and offset 7–22 percent of the expected decline in skilled employment by 2022, depending on whether the development of the circular economy followed its current trajectory or took a more transformative path.

equipment refurbishing plant and is offering a growing number of hospitals performance models, rather than conventional lease or purchase contracts. But such efforts remain exceptions to the broad rule of the linear take-make-dispose economy, where people use products once and then discard them.

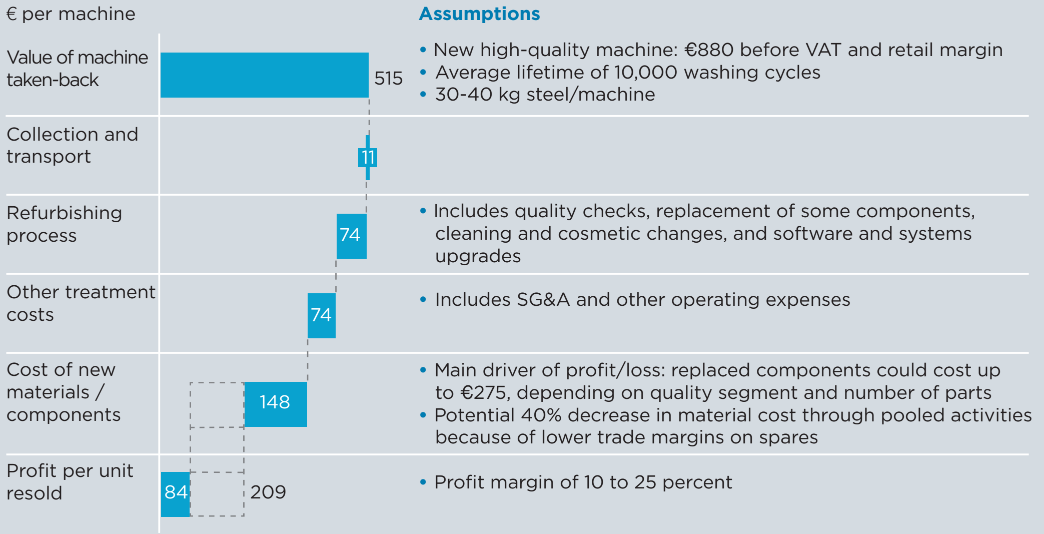
Previous work by the Ellen MacArthur Foundation found profitable circular opportunities in electronics, household appliances, light commercial vehicles, and many other sectors.[50] Consider the profitability of recovering and refurbishing washing machines, which can reduce resource requirements substantially and boost the profit margin to 10 or even 25 percent (Figure 16). This activity becomes still more attractive coupled with rentals and performance models like Bundles—high-end, connected washing machines with easy installation and maintenance that are available in the Dutch market through contracts with Miele.

4.2 Environmental opportunities

The circular economy could be a strong decoupling force, decreasing Europe's consumption of virgin resources (e.g., for steel, concrete, energy, water, and other commodities). Across the three study sectors, CO2 emissions could drop as much as 48 percent by 2030 and 83 percent by 2050, compared with 2012 levels.[51] Primary material consumption measured by car and construction materials, real estate land, synthetic fertiliser, pesticides, agricultural water use, fuels, and non-renewable electricity could drop as much as 32 percent by 2030 and 53 percent by 2050.

Mobility. By 2030, with roughly half of passenger-kilometres covered in a system-optimised way, mobility emissions alone could fall as much as 55 percent. By 2050, the sector could be almost decarbonised (95 percent), as the vehicle and public transport fleet would be electrified and powered by renewable

FIGURE 16 **ECONOMICS OF REFURBISHING HIGH-END WASHING MACHINES**



Source: Ellen MacArthur Foundation, *Towards the Circular Economy, Report Vol. 1*, 2012.

energy. Some minor emissions would remain in production but would be reduced by extending the average car's lifetime and looping materials, decreasing the extraction of virgin materials (95 percent) to achieve an almost fully circular system.

Food. The food sector could also experience significant resource savings. Today, 16 million tonnes of synthetic fertiliser go into the agricultural system every year. The circular development path could reduce this number as much as 80 percent by 2050 by cutting waste and closing nutrient loops. Combined with storing more carbon in restored lands and reducing demand for livestock due to less waste and shorter transport systems, this decrease could reduce overall CO2 emissions up to 60 percent.

Today, European agriculture withdraws 73 cubic kilometres of water each year. Stemming the 25 percent conveyance loss, applying precision irrigation techniques, and reducing food waste could cut water consumption as much as 70 percent by 2050.

Built environment. Significant resource savings could also materialise here. The circular scenario could reduce urban sprawl up to 30,000 square kilometres by 2050, compared with the current development scenario. CO2 emissions could fall as much as 85 percent below 2012 levels, or 50 percent compared with the current development scenario.

Repurposing infrastructure space for mixed-used housing and green areas would make cities more attractive and liveable. Such improvements could also improve air quality and quality of life and reduce noise and transport time between home and office. By 2050, these costs could drop up to 60 percent from current levels.

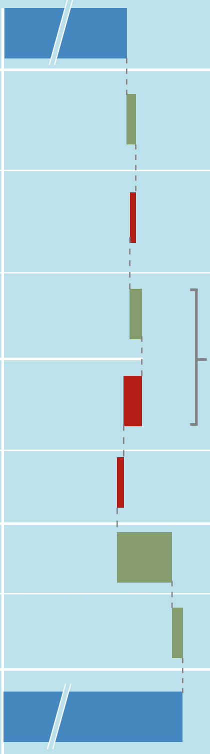
4.3 A positive employment opportunity

This research included an academic meta-study of the relationship between employment and the circular economy.[52] After reviewing 65 academic studies, the authors concluded that, while more research is needed, ***"existing studies point to the positive employment effects occurring in the case that a circular economy is implemented."*** This impact on employment is largely attributable to increased spending fuelled by the lower prices expected across sectors.

Many studies have also explored the employment effects of individual components of the circular economy. For example, a meta-study of 23 peer-reviewed studies on the employment impact of renewable energy deployment concluded that the "majority of the studies detect positive employment effects of a higher share of renewables."[53] Studies on

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 17 **QUALITATIVE EMPLOYMENT EFFECTS OF A CIRCULAR ECONOMY TRANSITION**



Baseline	EU employment today	• 218 million jobs in EU-28, 2014 • Unemployment rate: 10.2%
Direct effects	Waste and recycling sectors	• Today ~2,3 million jobs, ~1% of EU jobs[1] New jobs from increased recycling, reverse logistics, secondary markets
	Raw material sectors	• Substitution from raw materials to secondary implies less demand for virgin raw materials • Some of the resulting employment loss outside EU
	Manufacturing sector	• Today, 30 million manufacturing jobs,~14% of EU jobs • New jobs due to upgrade, repair, re-manufacturing activities (labour intensive) • Jobs loss in new products manufacturing • Net effect likely to differ substantially between sectors and companies
Indirect effects	Manufacturing	
	Raw material sectors	• Possible price increase on materials reduce demand • Some of the resulting employment loss outside EU
Induced effects	Increased consumption in all sectors	• Increased consumption driven by lower prices
	"Eco innovation effect"	• New jobs created by innovation and investments from circular economy transition
Circular economy vision	Potential new EU employment base	• Overall positive circular economy effect on jobs • More important are general labour market policies about gender inclusion, retirement age, and structural barriers regarding entry salaries, etc.

1 Includes jobs from waste management, wastewater management and recycled materials - Based on 2008 data.

Source: Eurostat; Ecorys, *Study on the competitiveness of the EU eco-industry - Within the Framework Contract of Sectoral Competitiveness Studies ENTR/06/054 - Final Report Part 1*, 2009; European Environment Agency, *Earnings, jobs and innovation: the role of recycling in a green economy*, 2011; EU Commission, *Memo: Advancing Manufacturing paves way for future of industry in Europe*, 19 March 2014.

the effects of energy efficiency policies have reached similar conclusions, as have studies on the employment effects of innovation. ***"Most of these studies on Germany…find positive effects of product innovations on labour demand."***[54]

Many employment effects contribute to the positive net result found in the academic literature. A circular model would mean a shift from the labour-scarce raw material sectors to the labour-intensive recycling sector. For example, waste disposal generates only 0.1 jobs per 1,000 tonnes, while recycling processing creates two jobs per 1,000 tonnes.[55] Spending is expected to increase across sectors as prices fall, creating new jobs.

Employment in the manufacturing sector would likely shift, from primary manufacturing to remanufacturing, but the net effect of this shift is hard to model.

Longer term, European employment correlates with innovation and competitiveness, which should strengthen in the circular scenario. Figure 17 shows some of the main qualitative effects.

Discussions of the potential employment impact of a circular economy need to take place in the broader context of the European labour markets. Many labour economists would agree that the labour markets need structural reform to address such issues as participation, entry barriers, and flexibility. The goals and pace of such structural reform are arguably a greater determinant of future European employment and unemployment than the circular economy, especially because 70 percent of European employment is in service sectors.[56]

4.4 Circular economy benefit curve

The analysis looked at the potential resource benefits as part of a circular economy benefit curve for each sector to create an integrated view of European resource economics (Figures 18 and 19). While this analysis is directionally correct and sufficient to provide actionable insights for decision-makers, the benefit curves are a work in progress.

The research needs expansion of several fronts. The research to date has taken a societal, rather than an investor, perspective and assumed a zero discount rate. The analysis included some, but not all, externalities, and those included relied on nascent research.[57] The primary resource costs represented only some of the major resources in these three sectors—primary car and construction materials; real estate land; agricultural use of water and land, synthetic fertiliser, and pesticides; fuels; and non-renewable electricity. Other resource costs were included in other cash-out costs. For further details on the methodology behind the benefit curve, see sidebar on page 60.

Today's TCO for mobility, food, and the built environment amounts to €7.2 trillion, or around 55 percent of European GDP—€1.8 trillion in primary resource costs, €3.4 trillion in other cash-out costs, and €2.0 trillion in externalities.

By 2030 technology improvements and new business models could boost productivity and reduce TCO up to 15 percent on the current development path, but rebound effects could offset 20 percent of these savings. The net societal result could be a benefit of 12 percent, or €0.9 trillion. TCO would total €7.4 trillion—€1.4 trillion in primary resource costs, €3.0 trillion in other cash-out costs, and €1.9 trillion in externalities. On the current development path, negative externalities could remain unchanged, and some (e.g., congestion) could even increase.

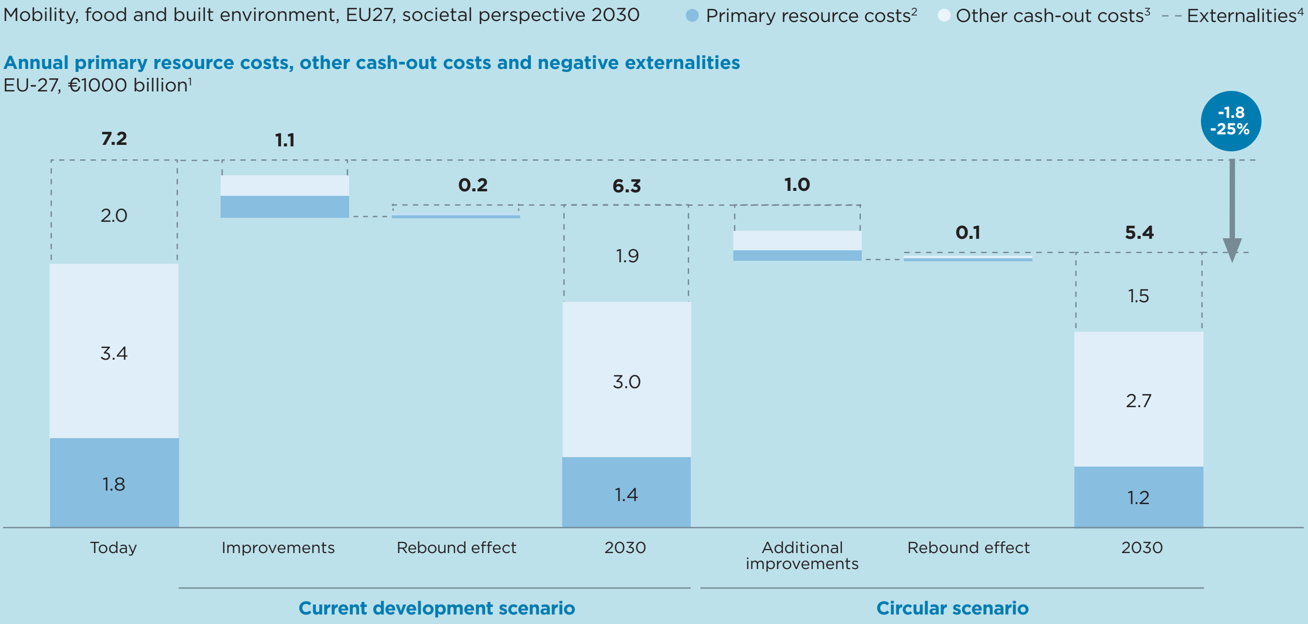
A circular development path could offer a better alternative. By 2030, TCO could drop €1.8 trillion, or about 25 percent less than today, and €0.9 trillion better than in the current development path. Annual primary resource cost could be €1.2 trillion, or 32 percent less than today and €0.2 trillion better than the current development path. This would translate into an annual resource productivity gain of 3 percent.The resource savings would likely improve quality of life for the average European household, as negative externalities could fall up to 26 percent, to €1.5 trillion, by 2030.

The ReSOLVE levers could be very profitable. The average economic multiplier is 2.0 excluding, or 4.5 including, externalities. A multiplier of 4.5 means that for €1 of resource saving, society would get €4.5 in non-resource and externality savings.[58] A multiplier of minus 1 represents the break-even point. A higher value means that, from a societal and lifetime perspective, the lever is profitable compared with the current development path. The analysis suggests that most levers would be more profitable than the incumbent technology, even excluding resource savings (i.e., multiplier above zero).

Three of the six levers could be particularly impactful. Sharing, exchanging (modal shifts, electric vehicles, and a substitute to a healthy food chain), and optimising (urban planning, energy efficiency, and digital supply chains) represent over 70 percent of the opportunity. By 2050, virtualisation looks to have huge impact, as autonomous driverless cars could control the market. The full and compounding value would materialise only if all the ReSOLVE levers were implemented at the same time.

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 18 **THE CIRCULAR ECONOMY OPPORTUNITY – 2030 SCENARIOS**
Mobility, food and built environment, EU27, societal perspective 2030



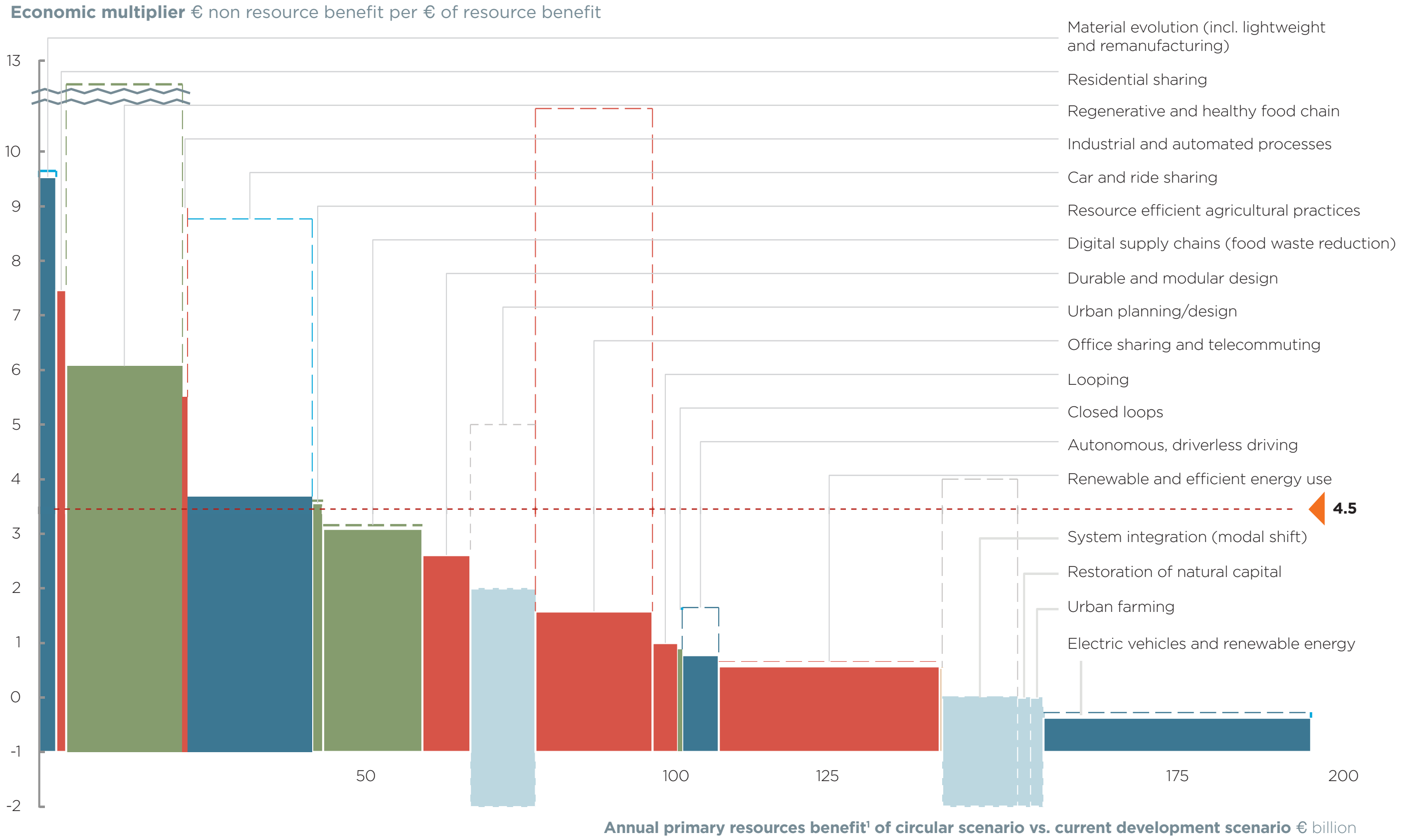
1 All numbers rounded to €100 billion 2 Primary resources include virgin automotive and construction material, virgin synthetic fertiliser (€535/tonne), pesticides, agriculture land and water use (€0.20/m³), fuel (€1.64/litre gasoline, €1.45/litre diesel, €0.91/litre of heating oil, €68/tonne of coal, €0.067/kWh of natural gas), land for residential and office buildings and non-renewable electricity (€0.20/kWh). 3 Other cash-out costs include all household and government expenditures on mobility, food, residential housing and office space, excluding the primary resource costs. 4 Externalities include CO_2 (€29/tonne), traffic congestion, non-cash health impacts of accidents, pollution and noise, land opportunity costs, opportunity costs related to obesity, adverse health effects due to indoor environment and transport time (related to urban planning) NOTE: Numbers may not sum up due to rounding.

Source: Company and expert interviews; Web search; Eurostat household expenditure data; ACEA, The Automobile Industry Pocket Guide, 2015; Todd Alexander Litman, Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications, Victoria Transport Policy Institute, 2009; Udo Jürgen Becker et al., The True Costs of Automobility: External Costs of Cars: Overview on existing estimates in EU-27, TU Dresden, 2012; ICCT, European Vehicle Market Statistics Pocketbook, 2013; ICE database of CO2 embedded in material; Frances Moore and Delavane Diaz, Temperature Impacts on Economic Growth Warrant Stringent Mitigation Policy, Nature Climate Change, 2015; MGI, Overcoming obesity: An initial economic analysis, 2014; FAO, Global food losses and food waste – Extent, Causes and Prevention, 2011; EEA, Towards efficient use of water resources in Europe, 2012; EU Commission, Official journal of the EU, Commission Agriculture and Rural Development, 2012 budget, 2012; FAOSTAT; Kimo van Dijk, Present and future phosphorus use in Europe: food system scenario analyses, Wageningen University, 2014; Josef Schmidhuber, The EU Diet – Evolution, Evaluation and Impacts of the CAP, FAO, 2008; Gregor Zupančič and Viktor Grilc, Anaerobic Treatment and Biogas Production from Organic Waste, 2012; Joint Research Centre (JRC) of the European Commission et al., Precision agriculture: an opportunity for EU farmers – potential support with the CAP 2014-2020, 2014; Laure Itard et al., Building Renovation and Modernisation in Europe: State of the art review, TU Delft, 2008; BPIE, Europe's buildings under the microscope: A country-by-country review of the energy performance of buildings, 2011; Per-Erik Josephson and Lasse Saukkoriipi, Waste in construction projects: call for a new approach, Chalmers University of Technology, 2007; Mark Hogan, The Real Costs of Building Housing, SPUR, 2014; Cushman & Wakefield Research Publication, Office space across the world, 2013; Ellen MacArthur Foundation, Delivering the circular economy toolkit for policymakers, 2015.

FIGURE 19 **THE RESOURCE BENEFIT CURVE**
Mobility, food and built environment, EU27

Cash-out[2] (excl. externalities) Mobility Food Built environment Illustrative[4]

Incl. externalities[3] Mobility Food Built environment



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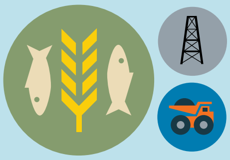
Source: Company and expert interviews; Web search; Eurostat household expenditure data; ACEA, The Automobile Industry Pocket Guide, 2015; Todd Alexander Litman, Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications, Victoria Transport Policy Institute, 2009; Udo Jürgen Becker et al., The True Costs of Automobility: External Costs of Cars: Overview on existing estimates in EU-27, TU Dresden, 2012; ICCT, European Vehicle Market Statistics Pocketbook, 2013; ICE database of CO2 embedded in material; Frances Moore and Delavane Diaz, Temperature Impacts on Economic Growth Warrant Stringent Mitigation Policy, Nature Climate Change, 2015; MGI, Overcoming obesity: An initial economic analysis, 2014; FAO, Global food losses and food waste – Extent, Causes and Prevention, 2011; EEA, Towards efficient use of water resources in Europe, 2012; EU Commission, Official journal of the EU, Commission Agriculture and Rural Development, 2012 budget, 2012; FAOSTAT; Kimo van Dijk, Present and future phosphorus use in Europe: food system scenario analyses, Wageningen University, 2014; Josef Schmidhuber, The EU Diet – Evolution, Evaluation and Impacts of the CAP, FAO, 2008; Gregor Zupančič and Viktor Grilc, Anaerobic Treatment and Biogas Production from Organic Waste, 2012; Joint Research Centre (JRC) of the European Commission et al., Precision agriculture: an opportunity for EU farmers – potential support with the CAP 2014-2020, 2014; Laure Itard et al., Building Renovation and Modernisation in Europe: State of the art review, TU Delft, 2008; BPIE, Europe's buildings under the microscope: A country-by-country review of the energy performance of buildings, 2011; Per-Erik Josephson and Lasse Saukkoriipi, Waste in construction projects: call for a new approach, Chalmers University of Technology, 2007; Mark Hogan, The Real Costs of Building Housing, SPUR, 2014; Cushman & Wakefield Research Publication, Office space across the world, 2013; Ellen MacArthur Foundation, Delivering the circular economy toolkit for policymakers, 2015.

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 20 **POSSIBLE CIRCULAR ECONOMY PILOTS**

RESOURCES



- Phosphorus recovery
- Rare earth metals/ toxic recovery
- High-value steel recovery
- Phasing out chlorines in packaging materials/ extract optimum value of plastics
- Introduction of new and superior packaging materials

GEOGRAPHIES

- Zero-waste cities
- Urban circular water system
- Urban circular material flows (urban mining/integration)
- Peri-urban nutrition for a city
- Shared mobility system in a city
- Roads to living space programme

VALUE CHAIN

- Waste-free agricultural chain
- Fully circular vehicles
- Performance models in appliances
- Material banks for buildings

5. SUCCESS WOULD REQUIRE SHIFTING FOCUS

Shifting to a more circular economy would mean systemic and pervasive change for Europe's companies, countries, and cities. It would change material flows, sector composition, employment, and value creation models. It would create many winners, but also some losing companies.

Perhaps most importantly, this shift would require changing how to think about the economy and define and measure economic success. The best European analogy might be the creation of the inner European market. Like this first major European economic policy project, a transition to a circular economy would likely take one or two decades, even with an ambitious timeline, and involve a myriad of changes at all levels of the economy.

Accelerating the transition to a circular economy would involve four efforts.

Europe-wide learning, research, and opportunity identification initiatives to clarify the near-and medium-term implications for industries and countries, creating a basis for more ambitious decision-making by policy-makers and business leaders. This effort might include:

Pilots (resource-, geography-, and value-chain-focused) to test aspects of the circular economy and demonstrate that circular principles work in practice (Figure 20).

Circular system change groups to identify improvement opportunities between materials suppliers, manufacturers, users, recycling companies, and policy-makers. Collaboration on mobility, food, and the built environment would already cover a large share of the opportunity. One way to start this transition could be to create a common language around how to manage stocks of products in a circular economy (Figure 21). Learning from the oil and gas sector, companies going circular could leverage language around reserves and publish reports on reserves similar to what extraction companies do today.

Academic research on circular economics, where many crucial topics remain at an early stage of study. A deeper view of the competitiveness implications and transition challenges of different sectors is one important topic, but not the only one (Figure 22).

FIGURE 21 **MANAGING PRODUCT STOCKS IN A CIRCULAR ECONOMY**

	Category	Oil industry	Potential circular economy application
1P / P1	Proved reserves	• Estimated with reasonable certainty to be commercially and economically recoverable given expected prices, operating techniques, and fiscal regimes • 90% probability of production	• Materials or products estimated with reasonable certainty to be commercially and economically recoverable after current lifetime • 90% probability of reuse, remanufacturing, or recycling • Fleet of 5-year-old cars for a leasing company
2P / P2	Probable reserves	• Unproven but likely to be recovered • 50% probability of total production at least equal to sum of proved + probable reserves (2P)	• Materials or products unproven but likely to be recovered after current lifetime 50% probability reuse, remanufacturing, or recycling • Example: Cars sold but company knows owners (e.g., guarantee contract)
3P / P3	Possible reserves	• Less likely to be recovered than P2 • At least 10% probability of total recovery exceeding sum of proved + probable + possible reserves (3P)	• Materials or products less likely to be recovered than P2 after current lifetime • 10% probability of reuse, remanufacturing, or recycling • Example: Cars sold but company has no link to owner (e.g. car sold several times)

Source: Society of Petroleum Engineers; Investmentpedia.

Development of a value-preserving material backbone—a core requirement for strengthening European industrial competitiveness. Such a system would enable the circulation of materials many more times than today, thanks to remanufacturing, better recycling systems, secondary resource markets, and better product design. For example, could banning toxic inks significantly increase the value of paper recovery? Could Europe make a step change in recovery of packaging plastics by promoting greater use of certain polymer types and design formats, multiplying the recovery yield and value? Could performance contracts receive tax treatment equal to purchase contracts?

The end state would require little virgin finite material, as recirculated supply would meet new demand. Achieving this end state could take decades and would require many company and market changes. A first step could be to develop a long-term, consistent plan for how to build such a circulatory system. Done right, this could bolster European competitiveness, just as paper recycling helps lower input costs for the paper industry in many countries.

Enabling initiatives for each area of the economy at the European, national, and city levels to help inherently profitable circular business opportunities materialise at scale. The circular economy has many similarities to energy efficiency, requiring a large number of small, non-financial interventions to remove barriers. Such enabling programs would likely need to proceed at the value-chain level to be specific enough but should ideally include the whole value chain to avoid fragmentation.[59] In addition, public procurement could role-model the transition towards the circular economy, while helping circular products and services reach scale.

Development of a new cockpit to steer the economy towards better resource productivity, employment, and competitiveness outcomes. A more balanced governance system might focus equally on improving the value derived from stocks and flows and regenerating natural capital. Today's linear economic model measures success almost exclusively in terms of a flow metric (GDP), and economic policies are designed to maximise flow. Most companies have linear business models.

FINDINGS AND CONCLUSIONS CONTINUED

FIGURE 22 **CIRCULAR ECONOMY RESEARCH QUESTIONS**

METRICS	1 Could one construct national-account metrics to measure key aspects of the circular economy?
	2 Could one construct company-level metrics to measure key aspects of the circular economy?
	3 Should formal accounting requirements at the company and national levels include these circular economy metrics? If so, how?
ECONOMICS AND LABOUR MARKETS	4 How can current economic modeling approaches, based largely on extrapolations of past correlations, be adapted to accurately model the impact of a circular economy?
	5 What impact would a shift to the circular economy have on European and global trade flows?
	6 What are the detailed labour demand implications of a shift to the circular economy, per sector and per qualification level?
	7 What are the key investments required to shift Europe towards a circular economy?
	8 What are the detailed international competitiveness effects of a shift to the circular economy?
	9 What economic implications would a gradual shift from labour to resource taxation have for Europe?
MATERIAL FLOWS	10 What should the future European material flow look like, per sector and in total?
	11 What should an ideal European recycling system look like?
	12 How could Europe avoid incineration of valuable materials and products?
	13 Should Europe stimulate a shift toward much more bio-based materials and, if so, how?
BUSINESS	14 What are the detailed industry structure implications of a shift to the circular economy? Are value-chains being integrated, are new or incumbent players better positioned to capture new markets?
	15 What would be the right financial solution to transition into a performance rather than sales model?
	16 How would organisational structures look like in a circular world, and how could companies manage the transition?

A balanced system would put much more emphasis on measuring the value of assets and developing principles and policies to preserve and increase their value. The system would define and manage the value of ecosystem assets, as well as technical assets. Such an upgraded economic governance system would allow:

A clear direction. Today, few CEOs know to what extent their future markets will be oriented towards circularity. As a result, many hesitate to invest in that future. Policy-makers at the European, national, regional, and city levels might clarify how they see circularity unfolding, including ambitions, targets, investments, and trade-offs. This might include developing a perspective and roadmaps for the development of the largest product value chains.

Metrics to measure and manage materials and manufactured asset stock. The importance of complementing the GDP metric is well-known but is underlined by the trends outlined in this report. Sharing and digitisation, for example, have major potential to increase consumer utility but are not well-captured in GDP. Europe might develop a more balanced set of metrics to measure the success of its economy, metrics more aligned with consumer utility and public expectations. Both the OECD and the World Bank have done extensive work in this area.

A long-term plan to rebalance factor costs and adequately price key externalities. Europe might consider longer-term fiscal changes (e.g., removing subsidies for fossil fuels and gradually rebalancing the tax base) in order to reap the full benefits of a circular economy.

FIGURE 23 **9 QUESTIONS FOR COMPANIES**

MARKETING AND SALES	1 What business opportunities does the ReSOLVE framework imply for your company ? 2 What value could you recover from products you have sold for the last 5 years? 3 Can you help your customers increase lifetime and utilisation of products?
PRODUCTS AND OPERATIONS	4 If your products were designed for take-back, how much value could you recapture from products sold? 5 If you had to take back all the products you sell, how would that affect design and production?
INDUSTRY/OVERALL	6 If new business models in the power sector turned incumbent growth negative, with dramatic implications, could something similar happen in your industry? 7 If your industry standardised and shared as much non-competitive material and infrastructure as possible, how much could you jointly save?
ENVIRONMENTAL FOOTPRINT	8 How much would your environmental footprint improve if you fully circulated products?
FINANCIALS AND RESILIENCE	9 If circularity substantially reduced your exposure to raw-material price fluctuations, what would happen to your cost of capital and resilience?

In parallel, companies might begin to evaluate how the circular economy transition could play out in their industries and assume accountability to their shareholders for how they design the business to reap the rewards of more resource independence and resilience. Investors might ask that question and fully price resource exposure. Companies would need a perspective on how to prosper in a circular market and what circular opportunities were available to them in the short term.

While major uncertainties about how a circular economy transition might happen remain, the economic, technological, and environmental arguments for it to happen are strong. Industrial history is full of companies that profited by acting early on such mega-trends and companies that acted too late. Companies might prepare by asking themselves some important questions today (Figure 23).

If Europe wanted to accelerate a transition to a circular economy, the timing is opportune. The technology revolution has only started and can be shaped, and transition investments could provide a much-needed stimulus to the European economy. Europe is experiencing a pervasive shift in consumer behaviour, with a new generation of customers seeming poised to prefer access over ownership. At least for now, easing of resource prices could pave the way for correcting regulatory failures and capitalising on low interest rates to finance transition costs. Not seizing the moment might prove an opportunity missed and vital time lost in a few years.

A circular economy seems to hold much promise for Europe but would require abandoning many beliefs formed under the old economic paradigm. The circular paradigm offers resource independence, innovation, employment, and growth. But navigating the transition remains a formidable leadership challenge at many levels of society. This report is intended to provide a fact base to anchor the debate on the trade-offs and potential ways forward.

THE TRANSITION TO A CIRCULAR ECONOMY – THE COST PERSPECTIVE

The strong economic rationale underlying the circular economy allows reframing the discussion into one of transition speed. That speed - in turn - defines the costs of the transition. These costs comprise asset investments or those in new digital infrastructure, R&D, retraining, support to promote market penetration of new products, or transitory support for affected industries. Accelerating the adoption of the circular economy to a rate higher than normal replacement cycles will increase these transition costs and create stranded assets.

In fact, the transition costs explain why a circular economy has not been implemented faster and at a larger scale yet. In the quest for an accelerated transition The transition cost story is however a bit more nuanced. Different from most other technology cycles the circular transition has elements that come at a low cost indeed. The transition costs for two of the main levers for a circular economy, sharing and virtualisation, are dropping sharply explaining the fast uptake and growth of new business models in these areas. Other levers still face large transition costs – a regenerate economy would require continued support for renewable energy and would result in stranded fossil power assets, optimise for example through energy efficiency programs come at a significant upfront cost, and looping would require significant infrastructure investments and could have a large impact on the extractive industries.

This project has reviewed a number of studies that have assessed the transition cost in relation to a more resource productive and circular economy. This review gives some triangulation points to calibrate the transition costs, which could be necessary to embrace the circular economy at a European scale:

- The British government has estimated that creating a fully efficient reuse and recycling system would cost around €14 billion, which would translate into €108 billion scaled to a Europe-wide level.

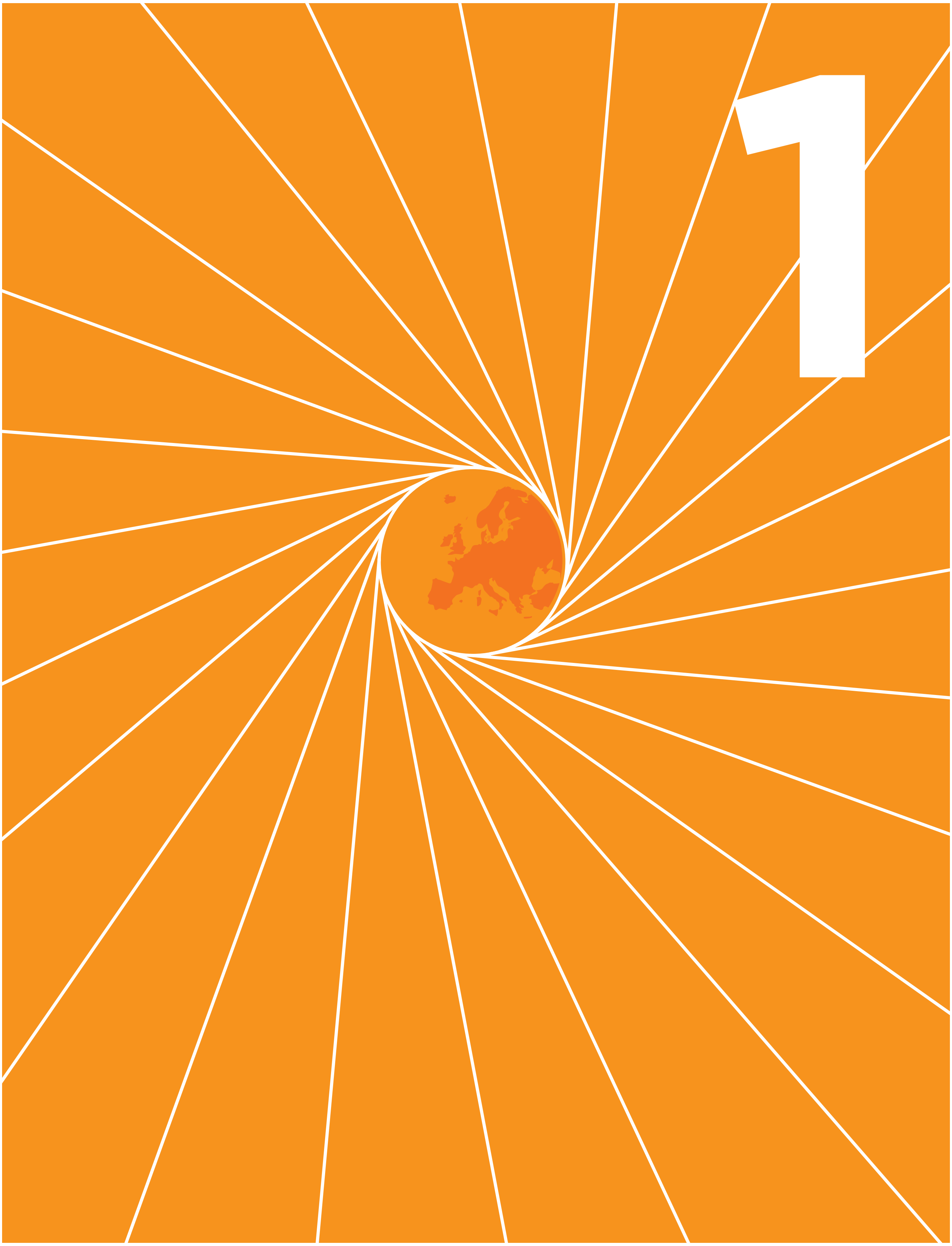
- The renewables transition in Germany cost €123 billion in feed-in tariffs to renewable plant operators from 2000 to 2013.

- The New Climate Economy estimated an additional global investment of $260 billion to $370 billion a year to reach a 450-ppm climate pathway over the coming 15 years.[60] The authors added, "these higher capital costs could potentially be fully offset by lower operating costs, for example from reduced expenditure on fuel". Scaled to a European level, this would mean an additional €30 billion to 50 billion annual investment.

- The International Energy Agency (IEA) has estimated that a €31 billion annual investment is required in Europe for each 1 percent reduction in energy consumption.[61] IEA also stated: "Europe needs to invest $2.2 trillion to 2035 to replace ageing infrastructure & meet decarbonisation goals".

It remains to be assessed to what extent these costs are additional relative to other development scenarios and to what extent they could act as a stimulus. For instance, the European Commission's agenda for establishing a digital single market and an energy union could create the core infrastructure for a regenerative and virtualised system.

RETHINKING VALUE CREATION: THE CIRCULAR PERSPECTIVE



1. RETHINKING VALUE CREATION: THE CIRCULAR PERSPECTIVE

THE CONCEPT OF A CIRCULAR ECONOMY

The notion of a 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. The concept distinguishes between technical and biological cycles.

The notion has deep historical and philosophical origins. The idea of feedback, of cycles in real-world systems, is ancient but enjoyed a revival with computer-based studies of non-linear systems after World War II.

Major schools of thought related to the circular economy emerged in the 1970s but gained prominence in the 1990s. Examples include the functional service economy (performance economy) of Walter Stahel;[62] the "cradle to cradle"® design philosophy of William McDonough and Michael Braungart;[63] biomimicry as articulated by Janine Benyus;[64] the industrial ecology of Reid Lifset and Thomas Graedel;[65] natural capitalism by Amory and Hunter Lovins and Paul Hawken;[66] and the blue economy systems approach described by Gunter Pauli.[67]

The term *circular economy* saw little use outside of China until 2010. While interpretations of the concept vary, most emphasise different approaches to efficiency and materials recovery. In general, the materials recovery approach has limitations:

- Materials recovery fails to challenge throughput-based business models (it usually creates an alternative source of raw materials to feed into the model).
- Overall increases in production and consumption increase harm to the environment, albeit at a decreasing rate, and therefore fail to create a virtuous or positive cycle, as described by Braungart and McDonough.
- Materials recovery loses the value add of retaining and maintaining product and component integrity, marginalising the business and economic case. For example, precious metals, the main source of recycling value, represent less than €5 on a cost of goods sold that amounts to over €200 for some smartphones. Recovering and retaining such value add implies providing goods as services or remanufacturing, refurbishing, and maintaining—the inner loops in the standard circular economy schematic.

As envisioned by the originators, a circular economy is 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. In a true circular economy, consumption happens only 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, with sufficient energy available, human intervention recovers materials and recreates order, on any timescale considered. Maintaining or increasing capital has different characteristics in the two cycles.

In a diverse, vibrant, multi-scale system, restoration increases long-term resilience and innovation.[68] The systems emphasis in the circular economy matters, as it can create business and economic opportunities that add value, while generating environmental and social benefits. The circular economy does not just reduce the systemic harm produced by a linear economy; it creates a positive reinforcing development cycle.

AN OUTLINE OF THE CIRCULAR ECONOMY

The circular economy rests on three principles (Figure 24). Each addresses several of the resource and system challenges that Europe faces.

This report uses GDP to measure the impact a circular economy would have on growth because this is the language best understood

OF STOCKS AND FLOWS

The circular economy explicitly acknowledges the importance of the relationship between various forms of natural capital and the flows that come from and return to them. The processes involved in the biological and technical cycles differ.

The technical cycle largely uses surplus energy to manipulate matter and to create and maintain infrastructure, tools, and products. This fight against entropy is part of the human aspiration to create, maintain, and restore order. In the circular economy, the dominant cue here is physics. Restoration of order by intention is the only way to increase order, albeit temporarily. This is why the debate over energy is so pertinent. Without sufficient surplus, the economy fails, bit by bit, as disorder grows.
The dominant force in the bio-cycle is life itself, biology. Soil as natural capital, for example, is far from "dirt plus NPK". Soil uses fungi, bacteria, and more to decompose, reorder, and regenerate and to harness energy from the sun, water, and minerals to restock plants and animals. At the same time, soil maintains or often increases its fertility and depth. All this suggests that regenerative best characterises the biosphere.

Before the first industrial revolution, society was limited by its reliance on bio-cycles and renewables. People recognised the need to close loops but also the hard physical work required.

The industrial world took its cue from physics so throughput and efficiency dominated (even in the biological realm), once energy became abundant and a stock of machine-made goods was created. The looming iteration of an industrial economy, a circular economy, strengthens synthesis. Applying the insights gained by understanding living systems and complex adaptive systems, the circular economy rebalances—for example, in the attention paid to stocks and flows. Effective flows achieve efficiency by optimising the system, not the part.

by business leaders and policy-makers today. The following discussion of each principle includes a potential metric to complement traditional metrics and monitor progress towards a circular economy.

Building a successful circular economy would require a balanced economic governance system focused equally on improving the value from stocks and flows. Such a system would put much more emphasis than seen today on measuring the value of assets and developing principles and policies to preserve and increase that value.

GDP alone could not sufficiently inform this paradigm shift. GDP measures do not capture several key dimensions of the circular economy and could not show the impact of the circular paradigm on consumer surplus, wealth distribution beyond averages, depletion of resources, unpaid activities like commuting, environmental costs, externalities, depreciation, and the value of leisure time.

GDP measures have other limitations. They use expenditures to value non-market activities. Imputed values are less reliable than measured values (e.g., imputed rents). Welfare is related more to consumption than to production. GDP includes products that are not a source of utility but are nevertheless necessary, such as commuting.[69]

Principle 1: Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows. This starts by dematerialising utility—delivering utility virtually, whenever possible. When resources are needed, the circular system selects them wisely and chooses technologies and processes that use renewable or better-performing resources, where possible. A circular economy also

1. RETHINKING VALUE CREATION: THE CIRCULAR PERSPECTIVE CONTINUED

FIGURE 24 **OUTLINE OF A CIRCULAR ECONOMY**

PRINCIPLE 1

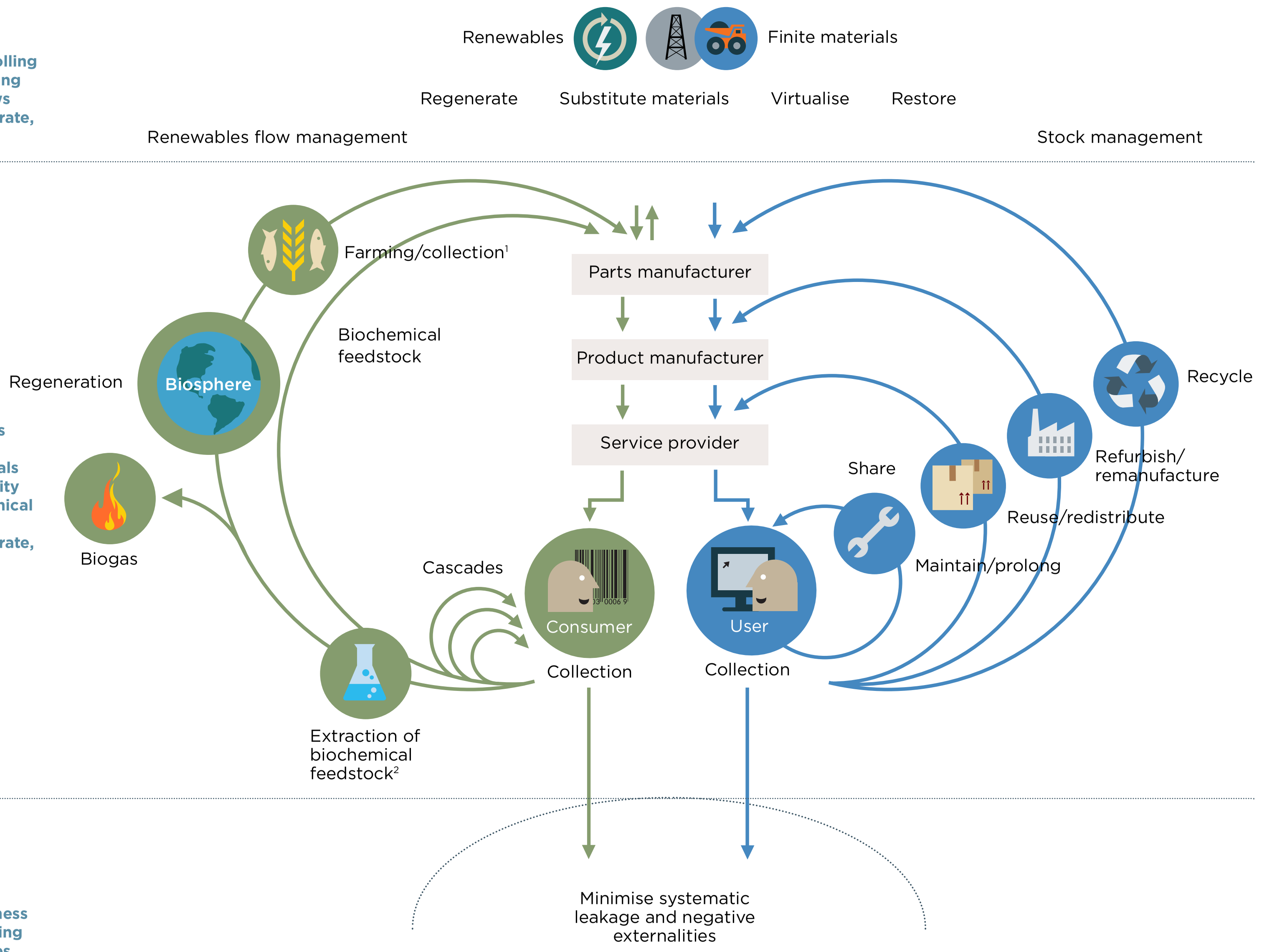
Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows
ReSOLVE levers: regenerate, virtualise, exchange

PRINCIPLE 2

Optimise resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles
ReSOLVE levers: regenerate, share, optimise, loop

PRINCIPLE 3

Foster system effectiveness by revealing and designing out negative externalities
All ReSOLVE levers



1. Hunting and fishing
2. Can take both post-harvest and post-consumer waste as an input

Source: Ellen MacArthur Foundation; McKinsey Center for Business and Environment; Stiftungsfonds für Umweltökonomie und Nachhaltigkeit (SUN); Drawing from Braungart & McDonough, Cradle to Cradle (C2C).

enhances natural capital by encouraging flows of nutrients within the system and creating the conditions for regeneration of, for example, soil.

The circular economy seeks to address several natural capital challenges.

Fresh water quality and depletion. Fifty-three percent of Europe's surface water bodies do not have good ecological status, as defined by the Water Framework Directive. On average, rivers and transitional waters are in worse condition than lakes and coastal waters; and more problems occur in central and northwestern Europe, especially where intensive agriculture is prevalent and population is dense.

In Europe, 13 percent of all renewable and accessible freshwater is extracted for human activity from natural bodies of water, including surface water and groundwater.[70] While water extraction for agriculture, industry, public-water supply, and tourism has declined since the 1990s, and the European Environment Agency (EEA) considers the current extraction rate relatively low by global standards, the EEA still lists over-extraction as a threat to Europe's freshwater resources. Local supply-demand imbalances do occur, especially in the summer. According to 2007 European Commission estimates, water scarcity affected at least 10 percent of EU territory and ~17 percent of the EU population.[71] Over the last 30 years, droughts in Europe have cost €100 billion.[72] Unsustainable sourcing approaches, such as dam construction, excess withdrawal from rivers, excess application, and groundwater overdraft, exacerbate permanent or semi-permanent depletion of aquifers.

Soil degradation. Steadily increasing crop production is depleting natural capital, threatening future productivity. Globally, 5-10 million hectares of arable land are lost each year.[73] In addition to climate change, sources of degradation include misuse of fertilisers, irrigation, and machinery. All create a direct link between resource consumption (flows) and long-term preservation of agricultural production assets (stocks).

Moreover, more than 25 percent of European territory suffers soil erosion by water, with negative effects on soil function and freshwater quality. Soil sealing and soil contamination are related issues.[73]

All of these issues have serious consequences for the productivity of agricultural supply chains. After the mid-century's so-called green revolution, productivity gains for major crops, such as cereals, oilseeds, and sugar, started to decline around the world. In Europe, productivity gains declined from 2.5 percent per decade in the 1970s to 1.3 percent in the 2000s.[75] The annual cost of soil degradation in Europe due to on-site effects (losses within the productive unit) and off-site effects (damage beyond the agricultural property) amounts to €38 billion.[76]

Bio-diversity loss. Sixty-six percent of species in Europe and 77 percent of European habitats remain in unfavourable condition. A major barrier to improvement is ongoing land take, as commercial, industrial, mining, and construction sites replace natural and semi-natural habitats.

Moreover, 30 percent of European territory is highly fragmented, affecting the connectivity and health of ecosystems and their ability to provide services like water purification and pollination and viable habitats for species. At a global scale, without any additional policy action, EU-funded research estimates that the value of ecosystem services due to bio-diversity declines will reach €14 trillion by 2050—7 percent of projected global GDP.[77] The EU-commissioned study, T*he Economics of Ecosystems and Bio-diversity*, puts the annual cost of forest loss at €1.8–4.6 trillion.[78]

Marine and coastal ecosystem quality. Meeting the EU's target of achieving good environmental status by 2020 is threatened by overfishing, sea floor damage, pollution by nutrient enrichment and contaminants (including marine litter and underwater noise), the introduction of invasive alien species, and the acidification of Europe's seas.[79]

This is a costly destruction of natural capital. The New Economics Foundation found that restoring the 43 European fish stocks studied to their maximum sustainable yield level would be worth €3.2 billion a year in additional landings—more than five times the annual fisheries subsidies paid to EU member states.[80]

Potential metric: degradation-adjusted net value add (NVA). The concept (and challenges) of adjusting economic measures for ecosystem degradation (and performance) is discussed extensively by the United Nations' Statistics Division in its collaboration on a System of Environmental-Economic Accounting (SEEA). SEEA's ecosystem accounting explicitly links ecosystems with economic and other human activity. These links are forged through the services provided by ecosystems and the impact that human activity may have on ecosystems and their future capacity.

SEEA applies an accounting structure similar to the System of National Accounts (SNA) and uses concepts, definitions, and classifications consistent with the SNA to facilitate the integration of environmental and economic statistics.

To calculate degradation-adjusted net savings, SEEA starts from GVA (gross value added) but includes more adjustments than usual to establish NVA and then net savings. The net savings number takes into account ecosystem transfers and degradation, both of which sit outside the system of national accounts.[81]

Principle 2: Optimise resource yields by circulating products, components, and materials at the highest utility at all times in both technical and biological cycles. This means designing for remanufacturing, refurbishing, and recycling to keep components and materials circulating in and contributing to the economy.

Circular systems use tighter, inner loops whenever they preserve more energy and other value. These systems also keep product loop speed low by extending product life and optimising reuse. Sharing in turn increases product utilisation. Circular systems also maximise use of end-of-use bio-based materials, extracting valuable bio-chemical feedstocks and cascading them into different, increasingly low-grade applications.

As in any linear system, pursuing yield gains across all these levers is useful and requires continued system improvements. But unlike a linear system, a circular system would not compromise effectiveness.

The circular economy seeks to address several resource challenges.

Material consumption. Between 1900 and 2009, industrialisation led to a ten-fold increase in global material use[82] and a seven-fold increase in domestic energy consumption in Europe.[83] While global extraction of materials has broadly remained at 2007 levels because of limited economic growth after the 2008 financial crisis, extraction growth is expected to return with economic recovery. The Wuppertal Institute's business-as-usual scenario projects that global extraction will grow from today's ~60 Gt per year to 100 Gt in 2030.[84]

There are signs of relative decoupling. From 1980 to 2008, OECD economies reduced material intensity 42 percent. Over the same period, their per capita consumption fell 1.5 percent, to 17.6 tonnes. In 2012, an average European used 16 tonnes of materials. Europe has shown clear leadership in such decoupling. Its resource productivity, expressed as GDP generated from each unit of oil equivalent, roughly doubled over the last 50 years. Some countries like Germany and Italy have even achieved absolute decoupling.

But considerable challenges remain. Europe remains the world's largest net importer of resources at €760 billion a year, 50 percent more than the US.[85] According to the EEA, the EU imported almost 60 percent of its fossil fuels and metal resources in 2011.[86] This is extremely important, as Europe generally has a cost disadvantage compared with other regions, driven mostly by raw materials and electricity.

Much of Europe's resource consumption has shifted from domestic production to trade flows. This effectively improves the resource footprint of the production base but not of consumption in Europe. For example, more than half of European fish supplies are imported.

Nutrient losses. While average levels of phosphate and nitrate in European rivers declined 57 percent and 20 percent, respectively, between 1992 and 2011, this drop principally reflects improvements in waste water treatment and lower levels of phosphorus in detergents.

Measures to reduce agricultural inputs of nitrate have been less effective.[87] Over the next decade, Fertilizers Europe expects EU27 fertiliser consumption to increase 1 percent for nitrogen, 6.7 percent for phosphate, and 11.6 percent for potash.[88] Beyond the cost of supplying such nutrients and the dependency on imports created, excessive nutrient application brings system risk and associated cost (see principle 3).

Waste of products and materials.Consider electrical and electronic waste. According to the UN University's latest report, nine of the ten largest producers of electrical and electronic waste per capita are in Europe. The region, including Russia, produced 11.6 Mt in 2014. This waste not only poses challenges in managing harmful substances like mercury, cadmium, and chromium. It also fails to exploit valuable embedded materials (300 tonnes of gold and 1,900 tonnes of copper on a global scale—a total estimated value of €44 billion) and associated value add.[89]

Potential metric: GDP generated per unit of net virgin finite material input. This would measure how much economic value finite inputs generated. Its starting point would be resource productivity—the ratio of GDP to domestic material consumption—as established in the EU's Resource Efficiency Scoreboard.[90] The metric would adapt this ratio to subtract recovered materials and include only finite materials.

Complementary measures might include product utilisation (average utilisation across all products), product depreciation/lifetime (average lifetime of products), and a material value retention ratio (value of recovered material, such as energy recovery, recycling, and remanufacturing/value of net virgin materials plus value of materials embedded in net product import [rolling net average over the last five years]).

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Principle 3: Foster system effectiveness by revealing and designing out negative externalities. This includes reducing damage to human utility, such as food, mobility, shelter, education, health, and entertainment, and managing externalities, such as land use, air, water and noise pollution, release of toxic substances, and climate change.

The circular economy seeks to address several system challenges.

Urbanisation. Urban areas have increased rates of congestion, soil sealing, and heat-absorbing surfaces—all likely contributors to more heat-related illnesses. The limited presence of green spaces also affects physical health, mental and social well-being, and quality of life and has negative effects on urban bio-diversity, air and noise pollution, and prevention of soil erosion and flooding.

These issues also have financial consequences. Analysis suggests the cost of time spent in congestion and the indirect societal opportunity cost at €3,500,[91] about one-third of the annual TOC for a European family's car. Across the European vehicle fleet,[91] the annual TOC, including opportunity costs, is around €2 trillion—equal to the GDP of Italy and Sweden.

Loss of health and quality of life due to noise pollution. At least 125 million Europeans were exposed to high levels of road traffic noise in 2011, and up to 20 million had similar exposure to rail, aircraft, and industrial noise. Such noise pollution has been linked to increased risk of disease, especially cardiovascular disease. For example, the European Environmental Burden of Disease due to noise pollution from road traffic alone in 2006 was estimated as an annual loss of at least one million life-years.[93]

System impact of emissions. Consider nitrogen. In 2000 emissions of nitrous oxide, nitrogen oxides, and ammonia into the air and nitrogen into the water caused estimated damage in the EU27 of €70–320 billion. This corresponds to a per capita welfare loss of €150–750, or 0.8–3.9 percent of average disposable income. About 60 percent of these damage costs are related to human health, 35 percent to ecosystem health, and 5 percent to effects on the greenhouse gas balance.[94]

Limited carbon-carrying capacity. European CO2 emissions per capita peaked in the early 1970s but have not declined sufficiently since then. European greenhouse gas emissions are 3-4 times higher than they should be to keep climate change below the 2°C threshold that the World Bank agrees would already have considerable consequences.[95] In Europe such consequences relate primarily to extreme weather events, such as cold spells and heat waves, changes in the distribution of climate-sensitive diseases, and changes in environmental and social conditions.

Potential metric: total cost of externalities and opportunity cost. Much has been written about the challenges of capturing the cost of externalities in monetary terms and even in other metrics. But the analyses for this report suggest that establishing such a metric is feasible. Acceptance of such metrics seems to be growing as more private-sector players are incorporating into their accounting practices shadow prices, such as for water or recycling.

INTEGRATING AN AUTOMATED, MULTI-MODAL, ON-DEMAND MOBILITY SYSTEM

2. INTEGRATING AN AUTOMATED, MULTI-MODAL, ON-DEMAND MOBILITY SYSTEM

According to the European Commission's Roadmap to a Single European Transport Area: "Transport is fundamental to our economy and society. Mobility is vital for the internal market and for the quality of life of citizens as they enjoy their freedom to travel. Transport enables economic growth and job creation: it must be sustainable in the light of the new challenges we face."[96]

But industry representatives agree that current trends do not favour a high-performing, low-cost system, as they continue to result in congestion, environmental depletion, and economic losses.

System-wide, people need more choices for how to be mobile. The speed and extent of this transformation will differ, depending on geographic location. This chapter describes a current development path scenario, where car technology would evolve rapidly, reducing cost and improving the customer experience. But the individual car would remain the dominant mode of transportation and would therefore not solve congestion and other negative externalities.

The chapter also outlines a potential system-level solution that taps four mobility levers—sharing, electrification, automation, and materials evolution—to create an automated, multi-modal, on-demand mobility system. The chapter explains why this is an optimistic, but realistic scenario and what Europe would need to do to start moving towards it.

This system would provide multiple mobility options and automated individual mobility as a flexible, but predominantly last-mile solution. Mobility service providers would offer the options that best fit user needs and preferences at any given time and would deliver just-in-time service. Highly utilised, autonomous vehicles would convoy and minimise congestion and enable cities to reclaim land used for roads and parking spaces. A multi-modal on-demand system would provide universal access and enhance user benefits by at least a factor three versus today. The system would also make better use of materials through design for durability and remanufacturing and decarbonise mobility, creating a more sustainable long-term platform.

STRUCTURAL WASTE IN THE MOBILITY SYSTEM

This sector has been vital to Europe's development, captivating customer imagination, spearheading economic growth and creating some of the most respected companies on the continent.

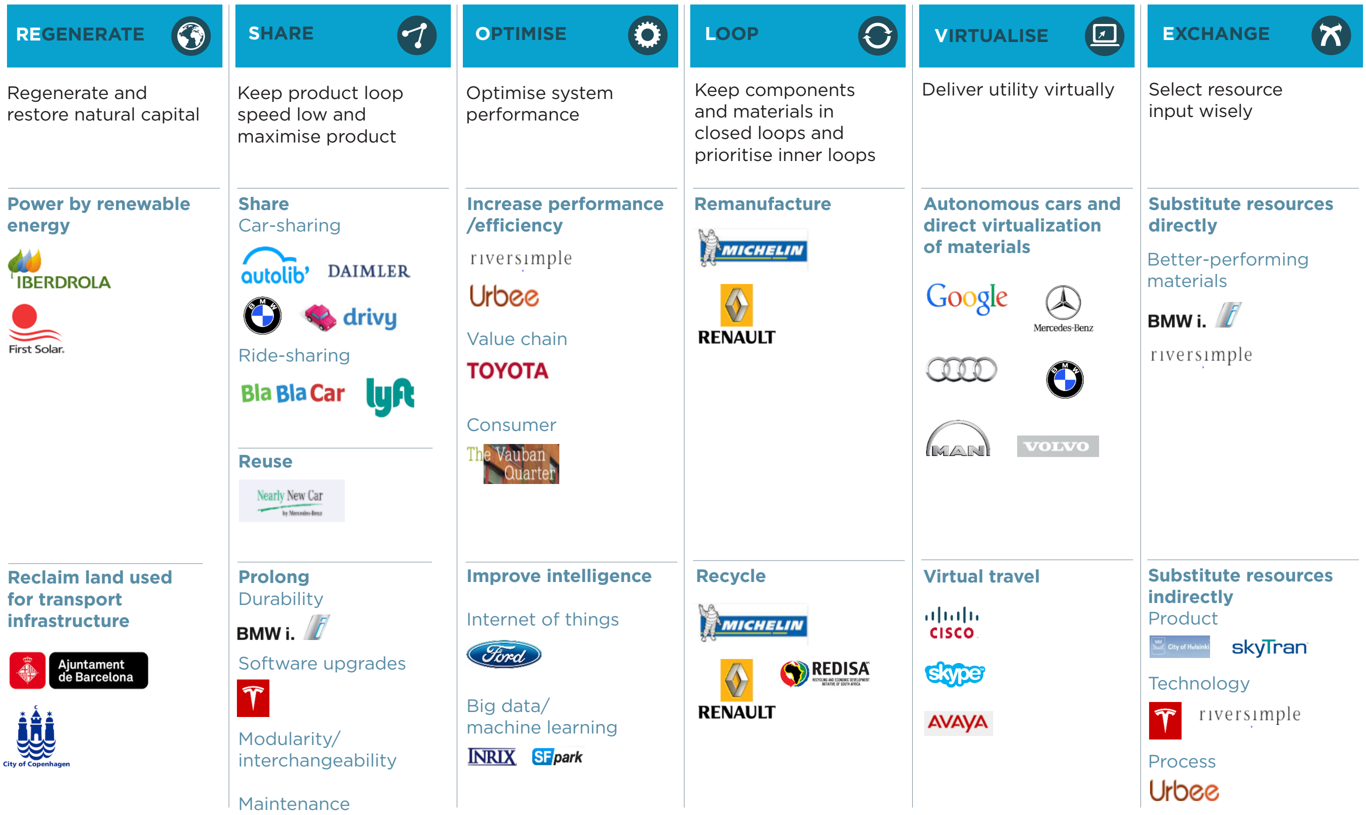
But the current transport system is costly and tied to a linear depletive model. Representing 83 percent of total motorised on-land passenger-kilometres in Europe, cars are the largest source of transport cost. The average European household spends €5,800 on car mobility each year, including taxes.[97] This represents almost 20 percent of the annual gross income of the average European worker, indicating the significant value that a more effective mobility system could create.[98] Adding the cost of time spent in congestion and the indirect societal opportunity cost of €3,500[99] brings annual TOC to almost €9,300. Across the European vehicle fleet,[100] the annual TOC, including opportunity costs, is almost €2 trillion—equal to the GDP of Italy and Sweden combined.

All these cars also expose 90 percent of city residents in Europe to air pollution at levels deemed harmful by the World Health Organisation (WHO).[101] According to the European Environment Agency (EEA), in 2012 the transportation sector (including low-grade fuels used in maritime transport, also known as bunker fuels) accounted for 24.3 percent of total European greenhouse gas emissions.[102]

The core challenge is the waste embedded in the transport system. The European car is parked (often on expensive inner-city land) 92 percent of the time. When the car is used, only 1.5 of its 5 seats are occupied. Although energy conversion cannot reach 100 percent due to the Carnot cycle, less than 20 percent of petrol propels the wheels. With a deadweight ratio[103] around 12:1, only 1-2 percent of the energy moves people.
As much as 50 percent of inner-city land is devoted to mobility (roads and parking); but, even at rush hour, cars occupy only 10 percent of the average European road. Congestion cost approaches 2 percent of GDP in cities like Stuttgart and Paris.[104]

Car-related waste also has a human dimension. Accidents claim 30,000 European lives

FIGURE 25 **6 LEVERS AT WORK IN MOBILITY**



Source: Company interviews; Web search. S. Heck and M. Rogers, *Resource revolution: How to capture the biggest business opportunity in a century*, 2014.

every year and cause four times as many permanently disabling injuries.[105]

These are surprisingly high numbers for a sector that is mature and optimised like few others. Product innovation alone cannot reduce the numbers. These problems require a systemic approach to rethinking mobility in Europe.

FIVE LEVERS THAT COULD TRANSFORM MOBILITY

The convergence of disruptive technologies, social trends, and new business models promises to disrupt mobility in Europe and around the world.[106] A broad group of stakeholders, ranging from traditional vehicle original equipment manufacturers (OEMs) to technology companies like Google and Apple, are all working to develop the car of the future.

In the coming decade, at least four major levers—sharing, electrification, automation, and a materials evolution—look likely to transform the personal car, which accounts for more than 80 percent of the average European's motorised transportation on land today (Figure 25). A fifth lever —the system-level integration of transport modes—has yet to achieve scale but could allow users to shift between personal and public transportation.

Each lever represents a major business opportunity, which is already or about to be profitable for the many global leaders that have built their success on innovation in just one area. Together, these levers amplify each other and look to shift the mobility paradigm faster than most expect.

Sharing. Mobility services and vehicle-sharing businesses are thriving, thanks to smartphones, big data, and the growing popularity of a sharing economy. In Europe car-sharing grew 40 percent a year between 2010 and 2013.[107] Car-sharing and ride-sharing are taking various forms:

2. INTEGRATING AN AUTOMATED, MULTI-MODAL, ON-DEMAND MOBILITY SYSTEM CONTINUED

- Uber, Lyft, Hailo, and Kabbee are promoting e-hailing or shared e-hailing—on-demand hiring of a private or shared-occupancy car via a service that matches passengers and driver. Shared e-hailing typically offers a 50-60 percent discount to reward higher utilisation and lower resource use per passenger.

- Car-sharing through a fleet operator offers on-demand, short-term rentals of cars owned and managed by the fleet operator. OEMs are entering this space rapidly. Well-known European examples are Autolib that is collaborating with Renault, DriveNow owned by BMW/Sixt, Quicar owned by Volkswagen, Car2Go owned by Mercedes-Benz, and Flinkster owned by Deutsche Bahn.

- Peer-to-peer car-sharing is a variation on the fleet model. Users share individually owned vehicles on an online platform. Drivy is the largest platform in Europe

- App-enabled car-pooling, such as BlaBlaCar, links a non-professional driver with passengers to fill empty seats.

- Sharing models are also popping up in transit transportation, with shuttle buses like Via, Chariot, RidePal, and Summon.

Investors recognise the business potential of such models. Between 2013 and 2014, annual global VC investments in start-ups increased ten-fold to about €5 billion.[108] As the industry matures, some consolidation, e.g., winning models of shared services, is likely.

Electrification. Electric vehicles (EVs) cost more up front today than cars with an internal combustion engine (ICE), but prices are falling rapidly towards parity. EVs cost less to operate since their fuel (electricity) is much cheaper than petrol (about 30 percent lower); their powertrains are at least three times more efficient, but suffers from conversion losses at the power plant. they have fewer moving parts and other maintenance requirements. Maintenance cost can drop at least 50-70 percent as EVs need no transmission fluid, engine tune-ups, or oil changes and experience dramatically less brake wear due to regenerative braking.[109] Their lower operating cost and therefore lower total lifetime costs make EVs likely to dominate the high-utilisation world of shared mobility, which would also create significant environmental benefits. To get the full environmental benefit Europe would need to supply the grid with more renewable energy. Hydrogen fuel cells might be another technology adopted widely.

Autonomous driving. Self-driving vehicles are becoming a reality. Google's self-driving car may be the most famous, having logged a million miles on public streets, but Google is not the only player in the game. Many other companies—from traditional OEMs and automotive incumbents like Audi, Mercedes-Benz, BMW, Volvo, and Tesla to technology companies like Apple and Uber—are all developing autonomous vehicles.

These early efforts have already revolutionised the transportation of goods. Rio Tinto, for example, has operated a fleet of over 50 autonomous trucks for years in Australia that, combined, have covered five moon return trips without accidents. The world's first autonomous 18-wheeler truck by Daimler recently went into operation, after logging more than 10,000 miles in testing.[110]

The cost of autonomous vehicles is dropping quickly. Today, a 70 percent autonomous Mercedes-Benz with active blind spot assistance, lane maintenance, and collision prevention commands a price premium of only €2,500.[111]

With sufficient penetration, autonomous vehicles could improve the mobility system. They have optimal acceleration and deceleration and can convoy with other autonomous vehicles, which could reduce congestion more than 50 percent by closing space between cars (1.5 meters versus 3-4 car lengths today) and improve energy efficiency significantly. Autonomous and self-driven vehicles can reduce weight by removing unnecessary human interface equipment like brake pedals and can cut accidents 90 percent - saving lives, and nearly eliminating damage repair costs. People could use their time productively in transit. In spite of these large benefits, the adoption of autonomous and driver-less vehicles may be slowed by regulatory barriers and consumer customs. Further, autonomous and self-driven cars are likely implemented first at highways, while urban penetration may take longer due to the level of complexity and unforeseeable events.

Materials evolution (light weight and remanufacturing). Investment in better materials management becomes more attractive in a high-utilisation world, where electric and self-driven vehicles have solved for CO2 emissions and safety standards. Two standards that today determine the lifetime of a vehicle.

Material evolution is already happening today as potential disrupters like Riversimple and incumbent OEMs like BMW (i3) are using carbon fibre to create light-weight vehicles with better aerodynamics and much longer life. Renault is planning to upgrade lifetime-dependent components to more durable and easy recyclable materials to get a longer life for the vehicle. Renault is investigating many types of materials for greater durability, such as high-quality and thinner steel, aluminium chassis and powertrain parts, magnesium body panels, in addition to serial production solutions like plastic fenders, that could reduce vehicle weight and the mechanical stresses at the same time.

Expensive and capital-intensive materials like aluminium, high-quality steel and carbon fibre[112] create strong incentives for remanufacturing vehicles. Renault's disassembly and remanufacturing plant at Choisy le Roi is the company's most profitable industrial site. It reuses 43 percent of carcasses, recycles 48 percent in foundries to produce new parts, and valorises the remaining 9 percent. Making remanufacturing and thereby upgradeability work at scale is likely to become a key driver of OEM performance, once more durable products are in the market.

System-level integration of transport modes. The technology and digital revolution could anchor the integration of transportation modes that would let people shift between personal, shared, and public transportation in an optimised mobility system. While the technology for developing efficient public transportation exists, city governments often have difficulty balancing stakeholder interests and implementing a modern public transport system. Progress is happening only in pockets of the mobility landscape. Further, many regulations and policies are not keeping pace with technology disruptions so they discourage, rather than encourage, system designs that leverage these advances.[113]

But some European cities are taking steps towards an optimised system solution. Helsinki has launched a programme to make personal cars irrelevant by 2025 by implementing a comprehensive mobility-on-demand system. Vienna is developing a prototype for an integrated mobility smartphone platform that integrates diverse mobility offerings into one option based on user needs.

Congestion-charging is enjoying success in London, Stockholm, and other cities. Zurich, Oslo, Munich, and other cities are testing other policies, such as imposing caps on car parking, giving preferred access to public transport/EVs, decreasing road space, and investing in better public systems. Car ownership in Zurich has declined from 400 cars per 1,000 inhabitants to 350 over the past 15 years. Even without a congestion-charging scheme, Lyon has seen the number of cars entering the city drop 20 percent over the last decade, encouraged by bike-sharing schemes and car clubs. Green spaces and parks have taken the place of car parks.[114]

Other technological disruptions promise to improve public systems. SkyTran, a NASA Space Act company, has developed an elevated personal rapid transportation (PRT) system of computer-controlled, two-people, "jet-like" vehicles. In some locations, this PRT system may require a new legal and regulatory framework. SkyTran is collaborating with cities and government authorities to adapt the regulatory framework for its operation.

SkyTran systems have been requested by several Israeli cities, including Tel Aviv (where construction of a demonstration system has started on the grounds of Israel Aerospace Industries), and in India, France, and the US. The system promises to make mobility 10-20 times cheaper than comparable light-rail transportation. It can transport almost 12,000 people an hour per guide-way—as much as a three-lane highway—by utilising 0.5-second space between vehicles, creating high-speed transportation in the urban environment (about 50 kilometres per hour within cities and 250 kilometres per hour between cities).

2. INTEGRATING AN AUTOMATED, MULTI-MODAL, ON-DEMAND MOBILITY SYSTEM CONTINUED

Smart traffic management systems are rolling out globally, thanks to the development of in-vehicle connectivity. Cars will be able to communicate with traffic lights for better fuel efficiency, and apps will identify open parking spots and the best routes for reducing the average car's fuel consumption more than 30 percent. Eventually, vehicle-to-vehicle and vehicle-to-infrastructure communication could reduce accidents, anticipate traffic, and adapt traffic-light synchronisation to demand.

POTENTIAL DEVELOPMENT PATHS

Depending on how the five levers play out, mobility in Europe could take very different development paths to 2050. Different regions will see very different development paths. In an upcoming paper, McKinsey will describe nine likely mobility development paths, two of which are especially relevant to Europe.[115] The following pages outline those two scenarios[116] and the assumptions underlying them and offer estimates of the potential order-of-magnitude impact of the scenarios (not to be confused with projections) on consumer utility, economic development, and the environment.

Scenario 1: The current development path scenario is a disruptive high-tech scenario, where autonomous and electric vehicles would penetrate the market rapidly, reducing cost and improving the customer experience. The individual car would remain the dominant mode of transportation. Adoption of remanufacturing and efficient materials would be low, due to lack of incentives for OEMs, and sharing would sustain strong growth rates in the short term that would flatten over time. System-level integration of transportation modes would remain available only in pockets of the economy. This scenario is likely for Europe's towns and for most mature cities.

Scenario 2: This development path predicated on circular principles and a system-based approach would create an automated, multi-modal, on-demand mobility system that took advantage of all five levers. Cities would make efforts to offer their inhabitants more mobility choices and to shift residents towards shared mobility, public transit, biking, or walking. The system would incorporate automated individual mobility as a flexible, interchangeable solution. Higher rates of utilisation would encourage vehicle design that took remanufacturing, durability, and easy maintenance into account. This scenario is likely for some of Europe's mature cities.

The current development path would likely produce a more cost- and resource-efficient single-mode system but little system optimisation

In a current development path scenario, Europe's towns, cities, and governments might have difficulty improving public transportation systems as quickly as private transportation advanced and so could not offer a competitive alternative. Some, but not most, users would embrace shared services. Consumers would still want their individual freedom and car ownership. Their cars would be autonomous and connected and more affordable, convenient, and resource-efficient.

But without broader system change, the rebound effect on car-kilometre volume would not solve and, in some cases, could even exacerbate congestion and other externalities.[117]

Sharing could continue to grow, accounting for as much as 30 percent of overall passenger-kilometres covered by cars by 2050, but would likely not penetrate towns and some urban areas. Vehicle-sharing would likely grow at varying rates in different European markets. Relatively supportive markets include Germany, where the number of people sharing cars has increased 50 percent a year since 2010 and reached one million at the end of 2014.[118]

Sharing companies would continue their strong growth in favourable markets but could face mounting legal and user challenges in other markets. Uber is already facing legal constraints and protests from organisations in Belgium, France, UK, Germany,[119] and other European countries.

Despite such challenges, sharing seems here to stay, as a more convenient, cost-efficient, and safe solution for users than privately owned cars. The current European-wide growth rate of 40 percent a year could drop to 30 percent by 2020 (sharing would then represent 0.5 percent of total passenger-kilometres by car), 20 percent by 2030 (5 percent of total passenger-kilometres by car), and 8 percent by 2050 (30 percent of total passenger-kilometres by car), as mature cities that are open to sharing became saturated, and towns and challenging markets did not embrace the system. By 2050 utilisation of the average car-kilometre could increase to 1.7 passengers per car from 1.5 today.[120]

Mass market production of extended-range EVs is expected to start by 2020, and EVs would likely represent a significant share of the fleet by 2030 and could be the dominant vehicle by 2050. In this scenario all major OEMs would offer EVs in the coming years, as they continued to descend the cost curve; but penetration by 2020 would likely remain limited, at about 1 percent, in terms of EV share of total car-kilometres in Europe.

European OEMs are introducing both battery electric vehicles like the Volkswagen Golf, Fiat, BMW, Mercedes-Benz, and Renault and plug-in hybrid electric vehicles like Audi, Volvo, and the Volkswagen Polo.

Tesla plans mass production of the Model 3 by 2020. At a starting price of about €28,000,[121] the Model 3 would be price-competitive with ICE cars (today's average price is €25,000) and more cost-competitive over its lifetime. The Tesla factory in Nevada aims to produce batteries at a cost of €75/kWh,[121] down from a best-in-class industry cost of €800/kWh in 2008.[123] Tesla's plans call for mass market production and penetration of the consumer market, if they deliver as scheduled, and address concerns on battery safety.

Since all (or almost all) shared vehicles would probably be electric,[124] EV penetration is likely to happen quickly. EV share of overall car-kilometres could grow from 0.02 percent today[125] to 1 percent by 2020, 14 percent by 2030, and 60 percent by 2050.

Fully autonomous vehicles[126] are expected to appear by 2020 in the urban environment, represent a significant share of the fleet by 2030, and dominate in driver-less mode by 2050.[127] Audi, Mercedes-Benz, BMW, and Volvo are likely to bring fully automated models to the market around 2020. Google aims to introduce autonomous vehicles by 2017.[128] Other mobility service providers and tech companies like Apple, Nokia, Sony, and several start-ups might try to do likewise.

This could result in faster uptake than most would anticipate, as consumers as well as policy- makers saw the potential safety improvements and other benefits. The introduction of the airbag offers a good analogy. Starting from a close to zero penetration in 1991, driver airbags in passenger vehicles needed only nine years to achieve 100 percent penetration of sales and about 20 years to reach 80 percent fleet penetration.[129]

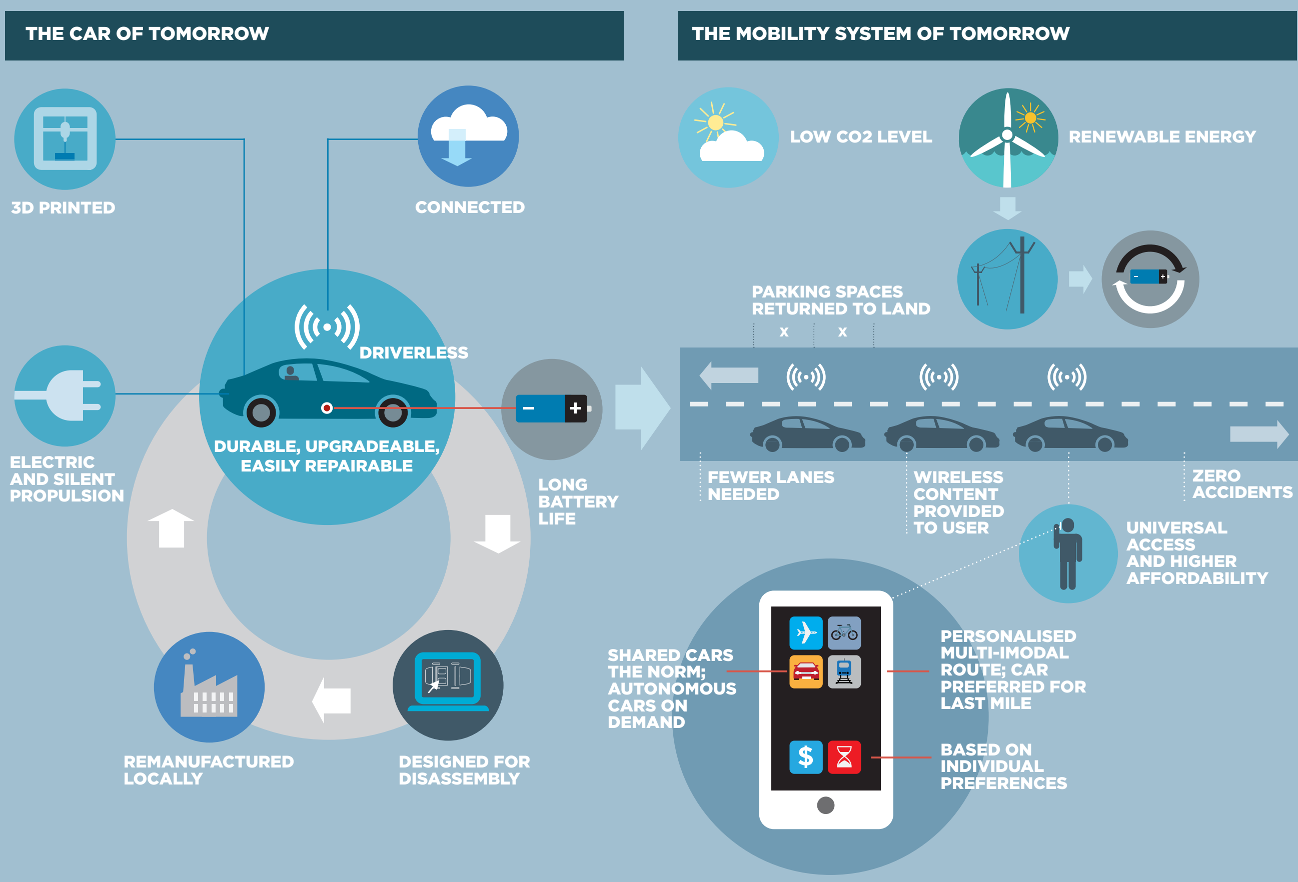
By 2020, shared vehicles could cover 0.5 percent of passenger-kilometres, increasing to 5 percent by 2030. If many shared vehicle providers pushed towards this more cost-efficient solution and if some owners of private vehicles took advantage of the technology, autonomous vehicles could capture significant share (25 percent of passenger-kilometres) by 2030, with greater share in mature cities. By 2050, all car owners might see the advantages of fully autonomous, driver-less vehicles, and very little transportation would happen without them.

Efficient materials are in higher demand in a world of higher utilisation. The introduction of shared, electric, and autonomous vehicles with higher utilisation designed for urban mobility would likely trigger changes in car design and production. Imagine a suite of shared urban cars that could serve different categories of users based on their mobility needs. Such specific cars designed for high utilisation and durability could reach a lifetime of one million kilometres if the batteries powering the electric engines could deliver over that lifetime.

These durable vehicles would likely be preferred in sharing schemes in mature cities but not by individual car owners. The lifetime of privately owned vehicles would gradually increase and could reach an average of 280,000 kilometres by 2030 and 340,000 kilometres by 2050. The penetration of shared vehicles into the fleet, combined

2. INTEGRATING AN AUTOMATED, MULTI-MODAL, ON-DEMAND MOBILITY SYSTEM CONTINUED

FIGURE 26 **A CIRCULAR MOBILITY SYSTEM**



with general technology improvements, could increase the average lifetime of the overall European fleet from today's 230,000 kilometres to 285,000 by 2030 and 400,000 by 2050.

These shifts would give OEMs further control over the fleet, allowing maintenance and take-back of components through service schemes. The share of remanufactured and recycled input could increase to 10-15 percent by 2030 and 40 percent by 2050, from today's 25 percent recycled input and negligible remanufacturing activities.[130]

A circular development path would see advances towards an automated, multi-modal, mobility-on-demand system

The circular scenario lays out an optimistic vision, in which European towns, cities and businesses would recognise the huge potential of circular mobility, invest to overcome today's barriers to its development, and see the quality of the mobility system improve dramatically.

The circular scenario would take advantage of the five levers that stand to transform mobility in Europe in an integrated way. This path would build an automated, multi- modal, on-demand system. The system would have multiple transportation options (like biking, public transit, ride- sharing, and car-sharing) at its core and would incorporate automated individual transport as a flexible, but predominantly last-mile solution.

The system would provide better service than a personal vehicle could, seamlessly connecting the interoperable mobility options. Mobility service providers would offer the options that best fit user needs and preferences at any given time and would deliver just-in-time service.

Users could pull out their smartphones, specify their destinations, and have the fastest, most inexpensive, and/or most socially enriching options available to them in seconds. The system might even suggest connecting to a virtual session to avoid excessive travel time needed to reach an in-person meeting (Figure 26).

Realising this scenario would require repositioning the car from today's preferred mode of transport to one of many options in the mobility system.

This scenario holds great promise for economic impact (lower mobility cost), environmental impact (land savings, less finite material consumption, and lower CO2 emissions), societal outcomes (enhanced liveability and improved health), and a vibrant service economy, but would require transition cost.

By 2020, car-sharing would be integrated into the urban mobility system. Mobile platforms, such as those in Vienna today, would roll out across Europe to integrate diverse mobility offerings into one system. These platforms would price all mobility options in real time, creating a more efficient and less congested system.

Cities and even towns would have to invest in non-motorised mobility and more agile public transportation. Governments would need to remove legal barriers to car/transit-sharing programmes and stimulate competition among mobility providers in all European economies. This would require implementing a suite of policies—congestion taxes, underutilisation taxes, preferred lanes for high-utilisation shared vehicles and public transport, and pricing of externalities.

In this scenario rapid growth of shared services would continue at about 40 percent a year, increasing the penetration of electric and material-efficient vehicles faster than in the current development scenario. Using mobility options rather than owning a car would make people more likely to choose public transportation.

But these changes would take time. By 2020, the portion of people using shared versus privately owned cars would remain low (about 0.8 percent), and the portion of people using mass rapid transportation would remain relatively unchanged from today. Adoption should speed up towards 2030.

By 2030, autonomous shared transportation and better public transportation would dominate the system. Some European cities could realise the prediction by the University of Texas at Austin that Austin could meet all of its mobility needs with a fleet of autonomous vehicles less than 10 percent the size of its existing car fleet.

New mobility providers (or the technology companies) would introduce driver-less autonomous vehicles faster than in the current development scenario. Eliminating the driver and making the car more responsive to user needs would significantly reduce the cost of mobility as a service. Combined with broad adoption of supporting policies, this would increase the number of sharing schemes and enable them to continue growing at the current annual rate of 40 percent so that shared mobility on demand would cover one-third of all car-kilometres by 2030. Higher utilisation of shared cars (2 passengers per car, rather than 1.5 today) would boost the utilisation of cars on the road to an average of 1.7 passengers per car.

Towns and cities investing in the quality and convenience of public transportation would also benefit. In the current development scenario, public transportation and non-motorised transport would lose market share. In the circular scenario, they would gain share—increasing from 19 percent of total motorised passenger-kilometres today to 20 percent. For the first time, system options (shared vehicles on demand and public/non-motorised transport) would provide more than half of all transportation.

The shared vehicles would be more material-efficient. To make these cars as cost-efficient as possible over their lifetime, mobility providers would push the limits of the vehicle used for shared transportation. Its lifetime could grow from today's 230,000 kilometres to 700,000 kilometres (some initial tests on EVs show a potential lifetime

2. INTEGRATING AN AUTOMATED, MULTI-MODAL, ON-DEMAND MOBILITY SYSTEM CONTINUED

A useful tool for prioritisation, communication, and decision-making, the benefit curve can help craft a strategy for resource-efficient development (Figure 27). The curve includes behavioural changes, for example sharing, as levers and introduces externalities unlike most other curves. The primary resource benefit of each improvement lever, shown on the horizontal axis, is calculated as the total annual savings of some key primary resources (for mobility, primary materials for vehicle production, fossil fuels, and non-renewable energy). The width of the entire curve represents the net total resource benefit potential of implementing all the levers, compared with the current development path. For example, the resource benefit of switching to an EV is calculated as the difference between the total primary resource cost of the forecasted fleet mix in the circular scenario (higher share of EVs) and in the current development scenario (lower share of EVs).

The economic multiplier of each lever is then calculated relative to the current development path and resource savings. This is a ratio expressing the amount of other cash-out benefits (i.e., total cash-out benefits minus primary resource benefits) and externality benefits per euro of primary resource benefits.[133] The analysis takes a societal perspective and looks at the annualised total benefits during the entire lifetime.[134 135] A multiplier of minus 1 represents the break-even point; a higher value means that, from a societal and lifetime perspective, the lever is profitable compared with the current development path.

For example, the multiplier of an EV is calculated as the annual non-resource savings (from lower maintenance cost, longer expected lifetime, etc.) minus the annualised additional upfront cost of purchasing the car compared with the average vehicle cost in the current development scenario, divided by the annualised total primary resource savings (reduced annualised material input due to the longer lifetime and lower consumption of non-renewable energy).

The benefit curve includes only levers that could generate primary resource savings and are overall profitable to society.

of more than one million kilometres). Average weight could drop 35 percent, to 900 kg, as vehicles would be designed specifically for city transport.

The more expensive materials used in these shared vehicles (that increase durability and decrease weight) make remanufacturing more attractive. Today 75 percent of material input for vehicles is virgin.[131] In a circular system, a vehicle would include 4 percent remanufactured components and 40 percent recycled materials. Designing vehicles with remanufacturing, durability, and easy maintenance in mind could encourage further sharing, and OEMs could see increased demand for vehicles designed this way in a high utilisation world.

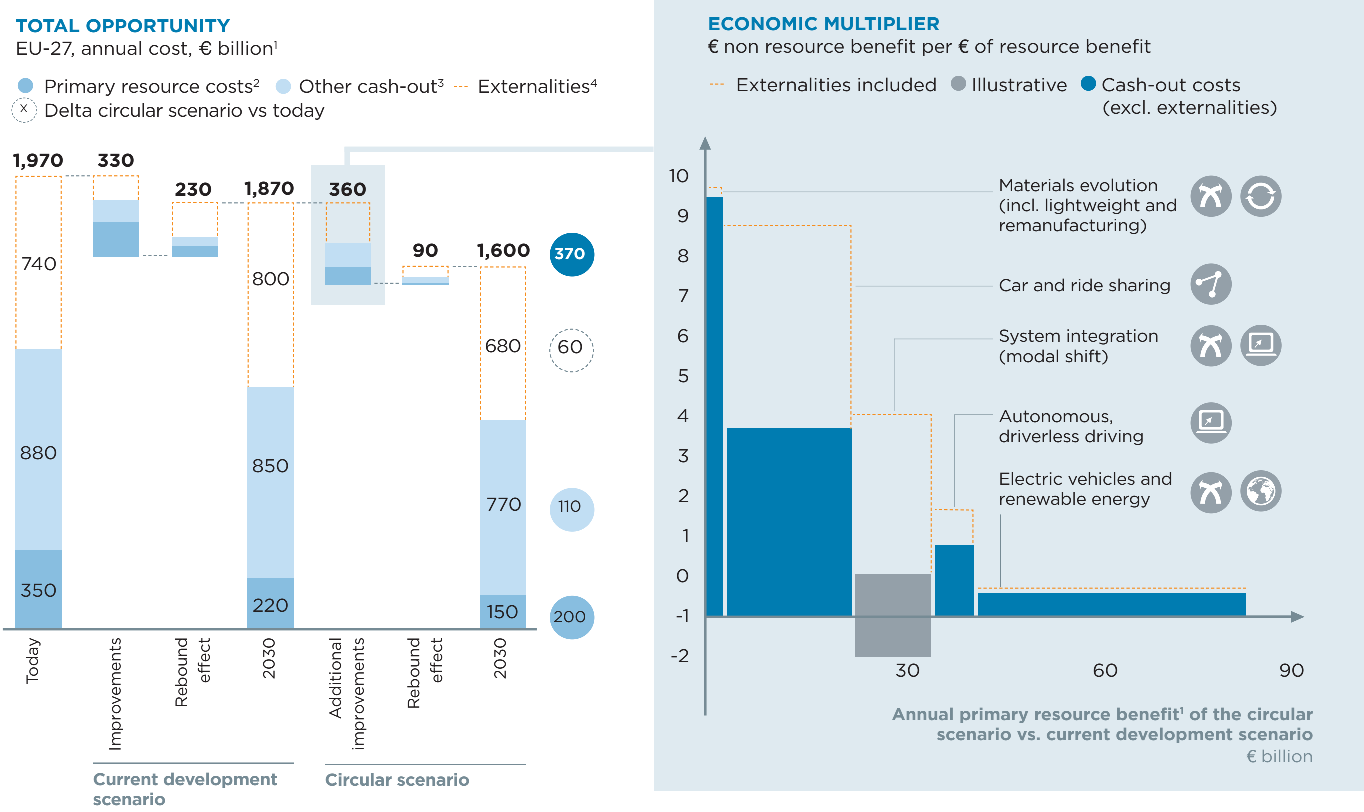
By 2050, almost all of Europe could have an automated, multi-modal, on-demand mobility system. In this scenario mobility on demand could cover about 95 percent of all passenger-kilometres. Shared vehicles would dominate the mobility market, carrying more passengers per car (2.5, up from 1.5 today). Public transit systems could cover up to a third of all passenger-kilometres. The two modes would be seamlessly integrated.

EVs would cover more than 90 percent of car-kilometres. The cost advantages of renewable energy and storage capacity could make almost the entire power grid renewable.

A shift away from vehicle ownership would mean that OEMs would further control the use and maintenance of components throughout their lifetime so OEMs would capture more value from remanufacturing. In this performance model, OEMs would have incentives to extract the maximum value from their stock of components and materials, providing customers with convenient access to mobility at low prices. An average vehicle could include 30 percent remanufactured components and 40 percent recycled materials, compared with much lower levels of remanufacturing in the current development scenario. The average car weight across the fleet would be 800 kg.

This system could completely change the planning of city development. Today, up to 50 percent of a European city is dedicated to roads, parking spaces, and other

FIGURE 27 **THE CIRCULAR MOBILITY OPPORTUNITY - 2030 SCENARIOS**
RESOURCE BENEFIT CURVE - mobility, EU27



1 All numbers rounded to €10 bln 2 Primary resources include virgin material (€1,200/tonne), fuel (€1.64/litre gasoline, €1.45/litre diesel) and non-renewable electricity (€0.20/kWh) 3 Other cash-out costs include all household expenditures on vehicle purchase, maintenance, insurance, fuel and parking, as well as government expenses on infrastructure and governance and cash-out costs related to accidents, pollution and noise, but exclude the primary resource costs 4 Externalities include CO2 (€29/tonne), traffic congestion, non-cash health impacts of accidents, pollution and noise, land opportunity costs

Source: Company and expert interviews; Web search; Eurostat household expenditure data; ACEA, The Automobile Industry Pocket Guide, 2015; Todd Alexander Litman, Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications, Victoria Transport Policy Institute, 2009; Udo Jürgen Becker et al., The True Costs of Automobility: External Costs of Cars: Overview on existing estimates in EU-27, TU Dresden, 2012; ICCT, European Vehicle Market Statistics Pocketbook, 2013; ICE database of CO2 embedded in material; Frances Moore and Delavane Diaz, Temperature Impacts on Economic Growth Warrant Stringent Mitigation Policy, Nature Climate Change, 2015

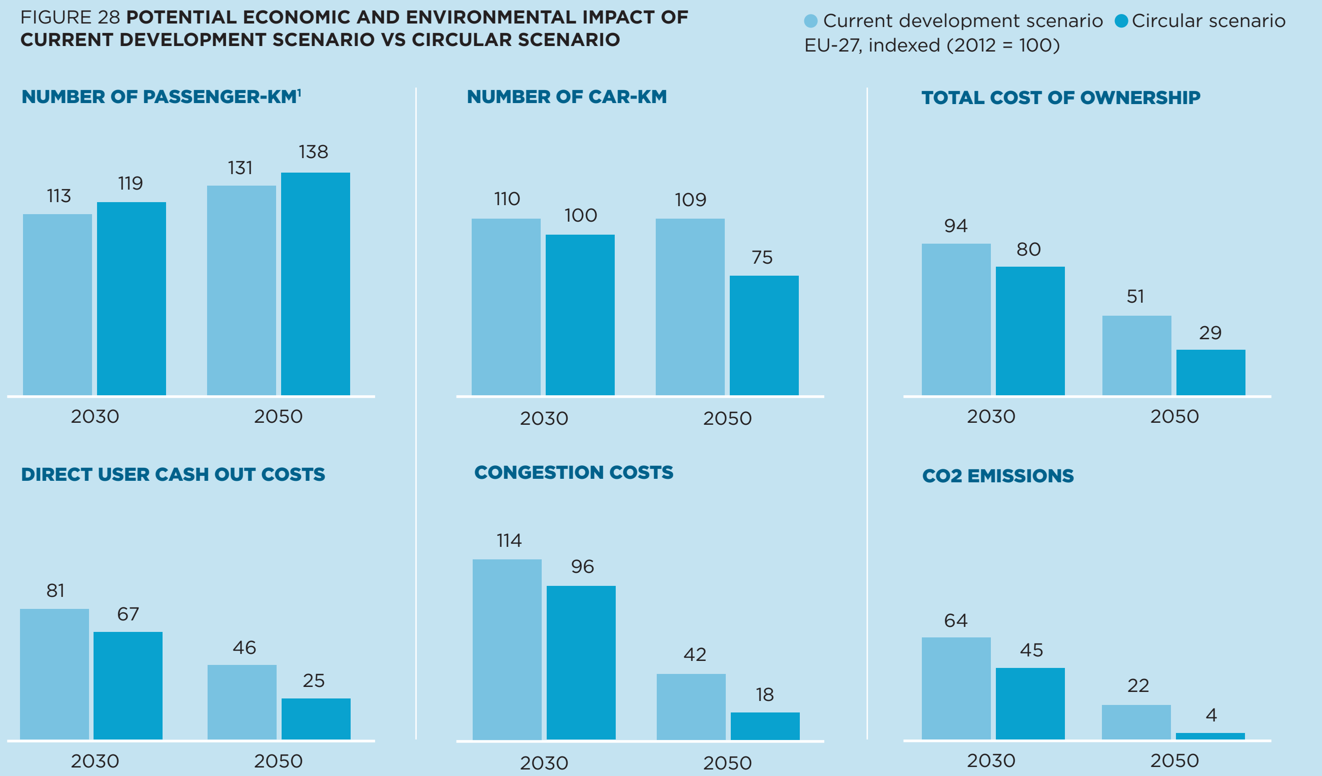
transportation infrastructure. A city with a circular mobility system could replace excess infrastructure with housing and businesses, public spaces, green areas, and shopping facilities. Barcelona, for example, is aiming to reclaim land now used for roads in order to expand pedestrian areas, reintroduce nature into the city, open up covered rivers, and create open spaces for children to play and people to meet.[132] Such changes would make cities more compact and productive, less congested and polluted, and more liveable. These benefits would attract people to the city centre and reduce urban sprawl and demand for individual, motorised transport—creating a virtuous cycle.

Implementation by 2030 of all the levers that would produce resource savings could generate total benefits of approximately €270 billion versus the current development path,[136] or €370 billion versus today. This includes €200 billion in primary resource benefits, €110 billion in other cash-out benefits, and €60 billion in externality benefits.

The benefit curve suggests that all levers are cost-effective versus the technology mix in the current development path so the savings could materialise. The most resource-efficient lever, EVs (due primarily to fuel substitution), is less cost-efficient today but could be a cost-optimising solution for users by 2030. Many other, less mature levers could assume considerable importance by then.

2. INTEGRATING AN AUTOMATED, MULTI-MODAL, ON-DEMAND MOBILITY SYSTEM CONTINUED

FIGURE 28 **POTENTIAL ECONOMIC AND ENVIRONMENTAL IMPACT OF CURRENT DEVELOPMENT SCENARIO VS CIRCULAR SCENARIO**



1 Including public transport, virtualised mobility, and share of car-km replaced by walking/cycling.
Source: Company and expert interviews; Eurostat household expenditure data; ACEA, The Automobile Industry Pocket Guide, 2015; Todd Alexander Litman, Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications, Victoria Transport Policy Institute, 2009; Udo Becker et al., The True Costs of Automobility: External Costs of Cars: Overview on existing estimates in EU27, TU Dresden, 2012; ICCT, European Vehicle Market Statistics Pocketbook, 2013; ICE database of CO2 embedded in material.

The circular path could boost consumer benefits by a factor of at least three, put Europe on a sustainable environmental path, and increase GDP growth

A circular path could decouple the rebound effect, increasing consumer utility, GDP, and jobs by adding passenger-kilometres, while reducing car-kilometres, congestion, climate change, and resource consumption. The current development path would probably not achieve all of these benefits.

In the circular scenario, user benefits could increase at least by a factor of three by 2050 (Figure 28).

Direct user cash-out cost[137] per passenger-kilometre would likely be almost five times lower than today, dropping from 19 eurocents to 4[138] (7 in the current development scenario). This lower cost would probably encourage more consumption of passenger-kilometres (given today's income elasticity of -0.5,[139] passenger-kilometres could rise almost 40 percent), increasing user utility. A household that pays €4,300 for car mobility today could pay €1,075 (€2,000 in the current development scenario) and get 15 percent more passenger-kilometres by car. The circular scenario would deliver superior user benefits in 2020 (7 percent cost reduction) and 2030 (35 percent cost reduction).

In the circular scenario, this increase in passenger-kilometres would not increase congestion or time cost for households. In fact, this opportunity cost through transport standards would decrease by a factor of five, from €2,600 per household to €475 (to €1,100 in the current development scenario), as total car-kilometres (not passenger-kilometres) in Europe would drop 25 percent, thanks to greater use of public transportation and non-motorised transport and more passengers per car as shared services became more popular. At the same time, autonomous cars would make better use of roads by driving in convoys and would enable productive use of travel time.

Besides congestion cost, other indirect cash-out costs and opportunity costs include infrastructure and governance costs, the societal cost of CO2, and costs related to pollution, noise, and accidents.[140] These costs could drop from €3,350 to €1,330 in the circular scenario (€2,000 in the current development scenario), thanks to the overall decrease in car-kilometres, the shift to silent, non-polluting, renewable-powered EVs, and almost accident-free autonomous cars. In the circular scenario, the total average household cost of mobility could decrease 70 percent or by more than a factor of three, from €9,300 today to €2,675 by 2050 (50 percent, to €4,750 in the current development scenario).[141]

The circular scenario would create better environmental results. By 2030, with roughly half of passenger-kilometres delivered in a system-optimised way, emissions could be expected to fall 55 percent. By 2050, the sector could be almost entirely decarbonised (95 percent) as the vehicle and public transport fleet would be electrified and powered by renewable energy. Some minor emissions would likely remain in production but would be reduced by extending the average car's lifetime and looping the materials, decreasing the extraction of virgin materials (95 percent) to achieve an almost fully circular system.

The calculations outlined in the scenarios take a simplistic partial equilibrium perspective that calculates the exogenous cost impact of the scenarios on mobility expenditure as a fraction of base-year consumption expenditure. Since mobility represents about 15 percent of household expenditure, analysis must include the impact of cost savings on the rest of household spending and the overall economy.

In a general equilibrium world, where technology and business model innovations in mobility were implemented at the 2030 levels described above, the disposable income of European households could be 11 percent higher than today on a circular development path, compared with 5 percent on the current development path. This translates into a GDP increase of 7 percent, compared with 3 percent in the current development path, driven by increased consumption.

The computable general equilibrium (CGE) analysis offers a state-of-the-art method for economy-wide assessment of the impact of technology shifts and regulatory policies. The value added by the CGE model is the inclusion of comprehensive substitution and income effects in the assessment of potential cost savings so the analysis can trace how these exogenous technology assumptions or policy measures affect the input/output structure of the economy, factor remuneration, GDP, and CO2 emissions.[142]

The CGE model requires rich information on the current structure of the economy. Applying the model to the future is challenging because it requires a similarly detailed description of that future.

The analysis treated the future development paths as a shock to the current economy, without regard to time. Thus, technology shifts are unconditional, i.e., the model does not explain the causes of the transition from the benchmark technology to the future technology. This analysis sought simply to understand whether the circular scenario could outperform the current development scenario.

The general equilibrium model also shows the rebound effects on CO2 emissions much more accurately than the partial equilibrium model. At the 2030 implementation level, mobility emissions could drop as much as 40 percent versus today's level, compared with 30 percent in the current development scenario. Emissions from oil could decrease more than 50 percent. Rebound effects in increased energy consumption in other sectors would swallow 12 percent of the CO2 emission savings, if other sectors did not decarbonise during the same period. By 2050 mobility emissions could drop as much as 77 percent in the circular scenario.

2. INTEGRATING AN AUTOMATED, MULTI-MODAL, ON-DEMAND MOBILITY SYSTEM CONTINUED

The modelling also tested one of many potential policy shocks that would promote efficiency gains. The modelling applied a congestion tax to remedy pre-existing inefficiencies in the transportation system that could free up unused labour time across Europe. Recycling additional congestion charges against reductions in distortionary labour taxes could reinforce these efficiency gains in a time of high unemployment (reduce unemployment rate 0.2 percentage points) and increase the average disposable income of households 2.3 percent, leading to increased consumption and a GDP increase of 1.4 percent, delivering a triple dividend.

A POTENTIAL WAY FORWARD

Moving towards a circular mobility system would require society to address the market imperfections that create today's wasteful use of resources. Innovative business models and technologies alone cannot correct for these market imperfections. They would require action by consumers, policy-makers, and businesses.

The principal market imperfections are the social cost of resource consumption, information barriers, congestion and other unproductive transportation time, and health effects. A circular mobility system would mean addressing these challenges, especially by:

- **Investigating the true cost of resource consumption.** Today, the social cost of resource consumption is best estimated in the current and potential economic losses of climate change. Research on the social cost of resource consumption could eventually develop uniform cost estimates for factors like noise impact or the negative health impact of air pollution. Neither cost is known fully today.

- **Promoting better public mobility systems.** The public mobility system needs more complete rethinking to accommodate more agile solutions (recognising the need for investments to make change happen). People would also need to embrace better public systems and change their mobility behaviour. Congestion charging to address congestion and other unproductive travel time could make a positive first step.

- **Creating a level playing field and legislative support for innovative business models and platforms.** Information failures make it costly for users to share and better utilise cars. Traditional car-pooling systems have not succeeded due to the high transaction costs caused by these information failures. The mobile internet, apps, and other digital breakthroughs are enabling innovative business models and need support, rather than roadblocks to their entering cities. This would include the development of supporting standards, such as legislation on autonomous vehicles.

- **Emphasising the opportunities for consumers.** Cars are often seen as a statement to fulfil a consumer's desire for mobility and freedom. In order to counter the car ownership fed by those desires, policy-makers and businesses would need to highlight the improved mobility services and higher utility that consumers would experience in a circular mobility system. Consumers must choose to become users, which may seem like a small shift on paper but is a large shift in reality.

- **Balancing the redistributive effects of the changes** that the realisation of this circular vision might produce for consumers, businesses, and nations. National governments, for example, would have to investigate replacements for lost income from fossil fuel taxes, materials, and other environmental taxes. The incumbent industry may also face potential downsides and significant transition cost, if not managed well. See sidebar "How to adapt to an industry disruption".

A circular mobility system could create significant opportunities for diverse players.

- **Incumbent OEMs could play a central role and be mobility providers,** rather than car producers, but would have to rethink a century of optimised business processes, organisational structure, supply chains, and customer relations to realise the vision. First movers could capture the value presented by this opportunity.

- **A circular path centred on platforms would create new service markets.** Going towards a circular business model would result in

HOW TO ADAPT TO AN INDUSTRY DISRUPTION

Research has shown that the average company's tenure on the S&P 500 dropped to about 18 years in 2012, down from 61 years in the 1960s. At the current rate of churn, thanks to mergers and acquisitions, start-ups, and the decline of incumbent firms, 75 percent of the S&P 500 could change by 2027.[143]

Building on this observation, the McKinsey Global Institute[144] outlined five ways that businesses can adapt to industry disruption, which may be helpful for the European mobility sector:

- **Understand and *monitor* the new ecosystem. To keep pace with rapid innovation, successful companies have deployed solutions to reduce as much as possible the blind spots posed by technology start-ups. General Electric has created the GE Garage, which incubates start-ups and provides them with high-tech equipment. Start-ups get access to the expertise of GE staff, and GE benefits from a first mover's advantage when hosted technologies reach maturity. Many other established players have adopted the same strategy. Samsung runs accelerators in Silicon Valley and Tel Aviv, and BMW's i Ventures incubator houses companies like Life360 and ParkatmyHouse.com.**

- **Tap the power within.** When threatened by a new competitive landscape, traditional players can take revisit the assets at their disposal and try to maximise their value. This value may take the form of brand reputation, accelerated materials innovation, superior quality, etc. For example, traditional German OEMs have made considerable efforts to enhance their cars by adding connectivity features (e.g., "stop & go", apps to find a car in the parking lot, and multi-media screens), improving safety, and developing new materials like carbon fibre.

- **Form alliances.** Recent research points out the major role played by extensive partnerships in achieving company outperformance.[145] Creating a strong network of partners is crucial when competition is shifting rapidly, and traditional business models may quickly become uprooted. For example, as sensors in cars allowed OEM to monitor driving habits like distance travelled, speed, and braking behaviour,[146] car manufacturers could become major insurance players. To mitigate the threat, insurers, such as Allianz, have already entered into partnerships.

- **Engage the world's talent.** As new competitors emerge at a global scale, traditional players will have to manage to attract talent from all over the world. According to one survey of senior executives, 76 percent believe their organisations need to develop global leadership capabilities, but only 7 percent think they are currently doing so very effectively.[147] To do better, some companies (for example, General Electric and Caterpillar Group) have split their corporate centres into two or more locations that share decision-making, production, and service leadership.

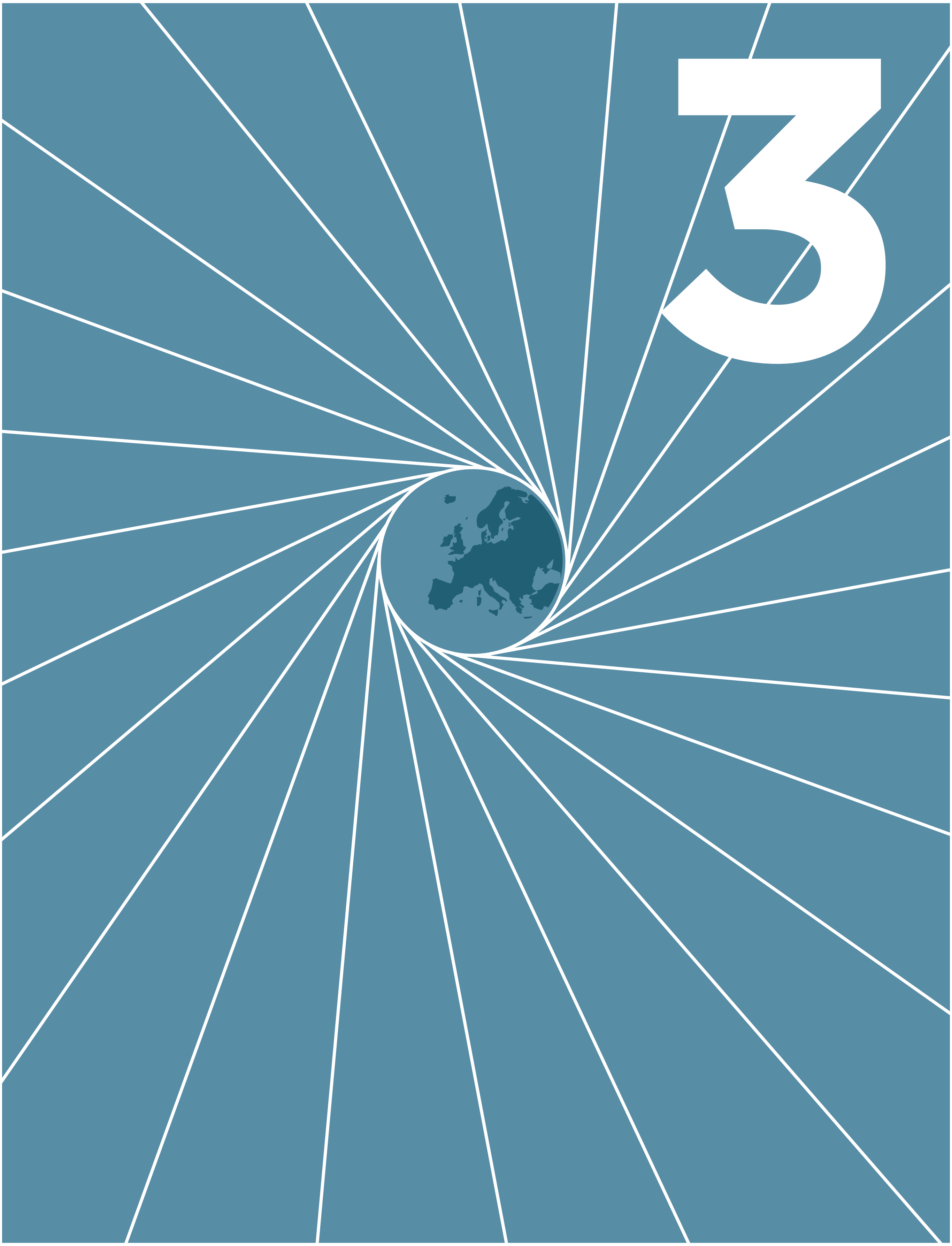
- **Avoid inertia.** In a changing environment, maintaining the status quo is risky, and building agility should be a top priority for companies that have to handle disruptions. Based on data from more than 1,600 companies, McKinsey found that total return to shareholders of the top one-third most agile companies— those with the highest capital reallocation year over year— was 30 percent higher than that of the least agile companies that maintain fixed capital allocation year after year.[148]

2. INTEGRATING AN AUTOMATED, MULTI-MODAL, ON-DEMAND MOBILITY SYSTEM CONTINUED

many more interaction points between the user and the mobility provider in comparison to today's system. European innovators could capture this opportunity and provide the services that users would demand during transit. Both incumbent industry leaders and emerging SME companies could capture new business opportunities, from better conference meeting facilities, to entertainment, creative commercials, and environmental services like better air quality and less noise during travel.

The convergence of disruptive technologies, social trends, and new business models promises to disrupt mobility in Europe and create a huge opportunity to transform the mobility system for better economic, social, and environmental outcomes.

REINVENTING A REGENERATIVE FOOD SYSTEM



3. REINVENTING A REGENERATIVE FOOD SYSTEM

The food system occupies 40 percent of European land, meets such vital societal needs as nutrition, and provides such ecosystem services as pollination and energy.[149] The sector remains a key pillar of rural economies and, since the 1950s, has experienced a great productivity boost driven by industrialisation, specifically intensification and specialisation.

But most observers agree that industrialisation has not curbed, or has even caused, three major problems. The food system is wasteful. It causes environmental externalities and does not produce healthy outcomes for the entire population.

The impact of industrialisation is flattening, as European productivity gains have been declining from 2.5 percent annual growth in the 1970s to 1.3 percent in the 2000s.[150] On the current development path, the challenges will likely intensify as the demand for food is increasing with less arable land and farmers to produce it.

Europe could address these challenges in the coming decades and advance towards a food system that is regenerative, resilient, non-wasteful, and healthier. This system would build on the technological progress of industrialisation and the traditional farm system. The new system would restore and rehabilitate land and fish stocks and would reconnect nutrient and material loops to provide the needed input. The system would leverage digital solutions and greater proximity to consumers to avoid waste along the value chain. The distributed food would be non-toxic and healthy.

Most of these levers are not new but have been forgotten or suppressed in a time of misaligned incentives, lack of pricing and knowledge of environmental and health externalities, and low resource costs. Setting the true price of resources and natural capital, pricing externalities, shifting taxes away from labour, and removing environmentally harmful subsidies could make this vision a reality.

THREE PROBLEMS IN THE FOOD SYSTEM

The food industry is essential to Europe. It represents the second-biggest spending item for the average European household—€6,600 a year, or 19 percent of total spend, including food, and catering (e.g., restaurants).[151]

The industry also looms large on the agenda of the European Commission. The Commission devotes 45 percent of its budget to agriculture and rural development through the EU Common Agricultural Programme (€56 billion or €265 per household).[152]

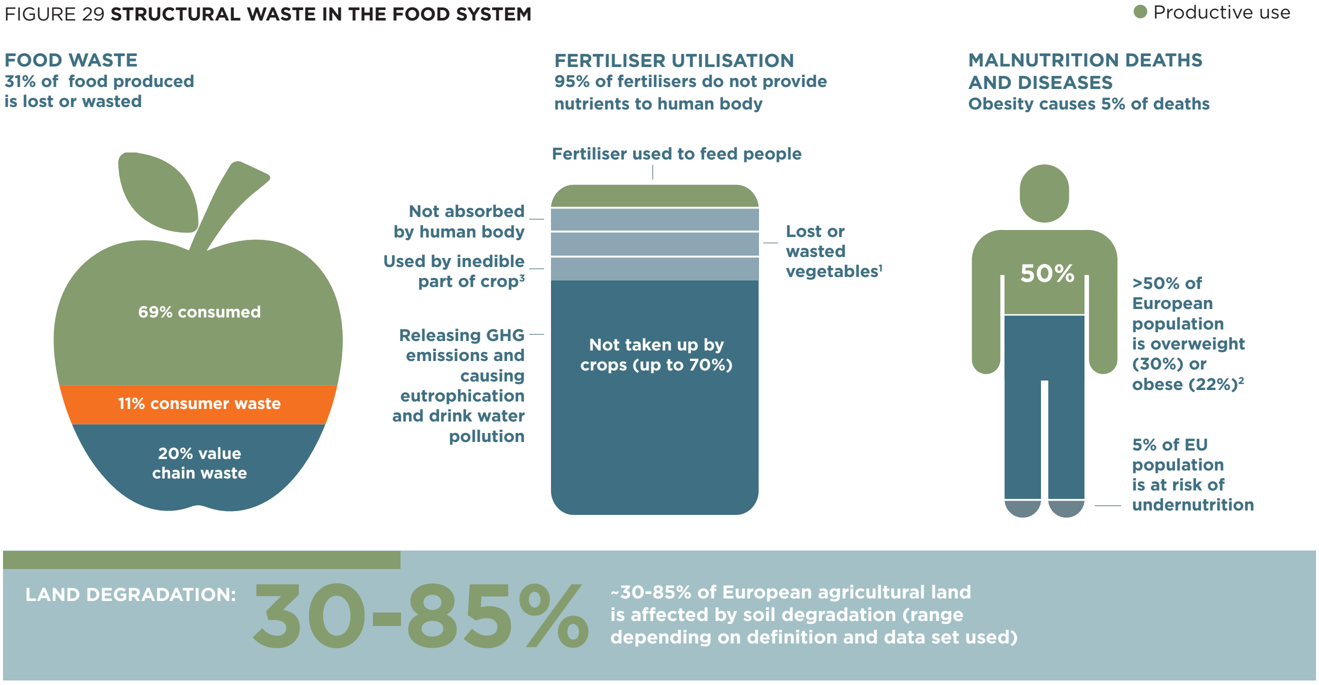
But Europe's food system has three major problems (Figure 29).

The system is wasteful. About one-third of all food produced in Europe for human consumption is lost or wasted before people consume it. For fruits and vegetables, this number may reach 46 percent.[153] In general, 20 percent of food produced is wasted along the supply chain, from agricultural production (9 percent) to post-harvest handling and storage (4 percent), processing and packaging (5 percent), and distribution (3 percent). The consumer throws away another 11 percent.

Agricultural production uses water and fertiliser in wasteful ways. Agricultural activities account for almost a quarter of Europe's water withdrawals[154] (70 percent on a global scale), and 25 percent of this amount is lost in conveyance.[155] Crops absorb less than 35 percent of the water applied to the field. Part of the water creates non-edible parts of crops which, while necessary for resilient natural systems, are not returned to closed nutrient loops. Finally, a significant part of the food produced is wasted. The compounded effect is that people consume only 20 percent of all water withdrawn. Meanwhile, 23 percent of the European surface area is water-scarce during the summer (11 percent year-round), and that number is expected to increase to 45 percent (30 percent year-round) by 2030.[156]

The same pattern holds for fertilisers. Crops absorb only 30-50 percent of applied fertiliser[156] and use almost 25 percent of that amount to create the non-edible parts of crops, which in today's model is discarded as waste. Taking into account food waste and the fact that the human body does not absorb all the nutrients consumed, this means that 95 percent of the fertiliser applied to land does not provide nutrients to the human body.

FIGURE 29 **STRUCTURAL WASTE IN THE FOOD SYSTEM**



1 In Europe ~46% of edible mass of fruit and vegetables is lost or wasted (FAO, Global food losses and food waste, 2011). 2 BMI >25 (overweight) or >30 (obese).
3 On average 23% of vegetable crops is not edible (peels, leaves, ...).
Source: FAO, *Global food losses and food waste – Extent, Causes and Prevention,* 2011; MGI, *Overcoming obesity: An initial economic analysis,* 2014; WHO website obesity data; EEA, *Towards efficient use of water resources in Europe,* 2012; IFDC; Olle Ljungqvist and Frank de Man, *Under-nutrition - a major health problem in Europe,* 2009; Holly Gibbs and Meghan Salmon, *Mapping the world's degraded lands,* 2015.

The agricultural system is predominantly linear, as nutrient flows are not closed loops. Most nutrients in food waste, sewage, and waste water are not recovered. They are incinerated or landfilled, or they leak into the biosphere. In the EU27, 70 percent of the phosphorus in sewage sludge and biodegradable solid waste is not recovered.[158]

The system is responsible for significant environmental externalities.[159] The unprecedented successes of the agricultural revolution and industrialisation arose largely from intensification of inputs (nitrogen, phosphorus and potassium fertiliser, pesticides, and fuel) and specialisation. But significant environmental externalities also arose.

Today, more nitrogen is fixed synthetically in fertilisers than fixed naturally in all terrestrial ecosystems combined,[160] and phosphorus flows have tripled compared with pre-industrial levels, despite the fact that phosphorus is on Europe's critical raw materials list.[161] Nitrogen fixation and phosphorus flows into the ocean have exceeded the safe operating limits of the planet by a factor two.[162]

The run-off of fertiliser into rivers, lakes, and oceans creates a breeding ground for algae that cause eutrophication, depleting stocks of fish and other species. This has created more than 400 dead zones or low-oxygen zones in oceans and lakes around the world, many of them along European coasts.[163]

Overfishing, another form of intensification, has had similar negative impact on natural capital. Tuna, once abundant even in northern Europe, have largely disappeared from European waters. In the last decade, blue fin tuna collapsed in the Mediterranean, and regeneration is uncertain, even with the current fishing ban.

Specialisation of agriculture has destroyed bio-diversity and top soil. Several studies estimate that soil degradation affects 60-160 million hectares in Europe[164] —very high numbers compared with the total agricultural area of 185 million hectares in the EU in 2012.[165] On a global scale, continuing current rates of degradation would mean losing all of the world's top soil within 60 years.[166]

As a result of soil degradation, soils do not retain as much carbon, so changing land use and restoring degraded land could be a key lever to keep atmospheric CO2 levels below the 2°C threshold.[167] Higher intensification and specialisation are principally responsible for the 10 percent of European GHG emissions that come from agriculture.[168]

The system does not produce healthy outcomes. Food quality should improve over time. But, during the second half of the 20th century, the nutritional content of several vegetables studied fell significantly. Compared with the 1950s, tomatoes provide 55 percent less potassium, cucumbers 78 percent less iron, and salad 63 percent less vitamin B2.

Today's food often contains traces of toxic chemicals or plastics. Fish, for example, accumulate plastics and toxic pollutants by eating small fragments of debris floating in the ocean and by absorbing heavy metal contamination and other pollutants.[169]

The availability of more affordable food created by an industrialised agriculture sector has been great for people. But the resulting increase in consumer demand has led to increased prevalence of overweight and obesity, one of the top social burdens according to the McKinsey Global Institute, with a societal cost of 3.3 percent of European GDP,[170] or €2,100 per household a year.

While 5 percent of the European population is at risk of under-nutrition,[170] over 50 percent is overweight or obese.[171] In fact, the average daily calorie intake in the EU has been growing steadily and exceeds 3,500 kcal today,[172] which is 40 percent above the recommended daily intake of 2,500 kcal.[174]

And the European diet has become too fat, too salty, and too sweet over the past 40 years.[175]

While these issues are concerning, they offer major opportunities for improvement and growth. With the population expected to reach 9.6 billion by 2050 and increasing wealth encouraging more consumption of protein, the food system will need to produce 70 percent more food calories in 2050 than at the beginning of the century[176] and enhance nutritional quality. This growth must happen while dealing with a scarcity of natural resources, climate change, and a system that faces declining productivity gains. It could be time to take a new path.

SIX LEVERS THAT COULD RESHAPE THE FOOD SYSTEM

A new path could tap a broad range of levers structured along the ReSOLVE framework (Figure 30), but six major levers seem especially promising. Some are already scaling and are likely to materialise in the short term; others are nascent and will require decisions by companies, policy-makers, consumers, and other stakeholders to reach implementation at scale.

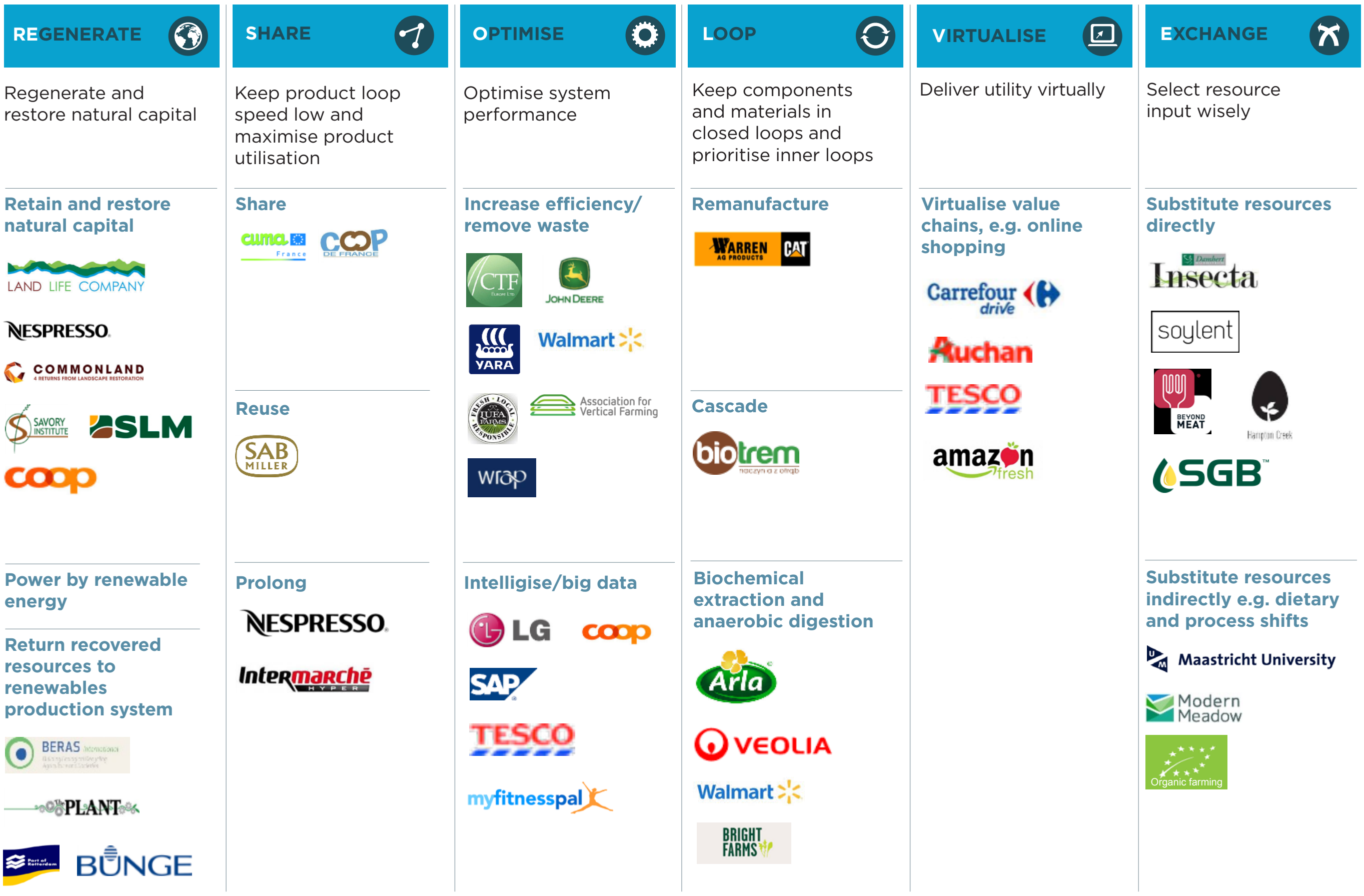
More resource-efficient agricultural practices. IT and automation are positively disrupting farming practices by enabling precision agriculture—a whole-farm management approach that leverages IT, big data, remote sensing, and satellite positioning data. These technologies optimise returns on inputs while reducing environmental impact.[177]

Precision agriculture is already profitable in many cases,[178] and the technologies have great potential to improve resource efficiency. Farmers report 20-30 percent improvement in irrigation efficiency, 10-20 percent reduction in fertiliser and pesticide use, and as much as 75 percent reduction in machinery and input costs by combining precision agriculture with no-tillage farming.[179] Today, 70-80 percent of new farm equipment sold includes some precision agriculture component.[180]

New technological solutions promise to further increase resource efficiency. For example, vapour-transfer irrigation systems enable saltwater irrigation by using low-cost plastic tubes so water vapour, but not water or solutes, can pass.[181]

Regenerative farming practices. Various sustainable and regenerative agricultural practices to preserve natural capital and optimise long-term yields are seeing growth. Organically cultivated land area in Europe is expanding 6 percent a year.[182] No-till farming techniques are growing 1.5 percent a year in the US as growers seek new ways to protect and conserve their soil and save time and money.[183]

FIGURE 30 **RESHAPING THE FOOD SYSTEM**



Source: Company interviews; Web search. S. Heck and M. Rogers, *Resource revolution: How to capture the biggest business opportunity in a century*, 2014.

The Baltic Ecological Recycling Agriculture Society (BERAS) promotes ecological recycling agriculture that integrates organic crop production with cultivation of leguminous grassland and animal husbandry. This recirculates animal manure as fertiliser and achieves high self-sufficiency in fodder and fertilisers.[184]

Other examples of sustainable and regenerative agricultural practices are agroforestry, holistic-planned grazing, silvopastoral systems,[185] and pasture-based dairy systems with no/minimal fertiliser use.

Closed loops of nutrients and other materials. The potential to extract valuable bio-chemicals or recover energy and nutrients from various waste streams is significant. For example, phosphorus recovered from sewage sludge, meat and bone meal, and biodegradable solid waste in the EU27 amounts to almost 30 percent of today's use of synthetic phosphorus fertiliser.[186] This is important, since more than 95 percent of the consumed phosphorus in Europe is imported as fertiliser, livestock feed, food, and other organic products.[187]

Closing nutrient loops is happening today in pockets of the European economy. In Sweden, two municipalities have mandated that all new toilets must be urine-diverting,[188] separating urine from faeces, because urine makes up only 1 percent of the domestic waste water volume but contains most of the nutrients.[189] Local farmers can collect the urine once a year for use as liquid fertiliser.

Recovery of energy and nutrients through digestion and composting is happening at larger scale. In Italy, more than 4,000 municipalities conduct intensive source-separation of food and garden bio-waste.

3. REINVENTING A REGENERATIVE FOOD SYSTEM CONTINUED

Each year these efforts affect about 40 million inhabitants and collect 4.8 million tonnes of bio-waste for treatment in composting or anaerobic digestion plants.[190] In the UK, 66 percent of sewage sludge is treated in 146 anaerobic digestion plants, and another 175 plants produce bio-energy from solid waste, a number that is growing rapidly.[191]

Of course, not producing waste is an even better solution. Several companies have developed closed-loop systems that use by-products or the waste from one process as input for other processes. Bunge, one of the world's largest agribusiness and food companies, found synergies between their soybean and sugarcane bio-processing value chains. The Plant in Chicago uses carefully selected tilapia, vegetables, beer, and kombucha tea production to balance waste and feed stock needs. Combined with a commercial kitchen and an anaerobic digestion chamber to convert remaining waste into power and steam, this is a fully closed-loop, zero-waste system.[192]

Scaling such a closed-loop system requires identifying synergies between existing input and output flows. This, in turn, requires more transparent resource flows and cross-company and cross-sector collaboration.

Restoration and preservation of natural capital. Restoration of large, damaged ecosystems is commercially viable. The most famous example is probably the Loess plateau in China, where 1.5 million hectares of degraded land have been restored. This project lifted more than 2.5 million people out of poverty, almost tripling their income, by replacing low-value agricultural commodities with high-value products. This shift increased per capita grain output 60 percent, doubled the perennial vegetation cover from 17 to 34 percent, increased employment from 70 percent to 87 percent, reduced flooding risk, and increased the availability of water, bio-diversity, and carbon absorption.[193]

Some institutions have already proven the commercial potential of restoration. The Savory Institute has influenced the regeneration of more than 2.5 million hectares of land by promoting holistic land management. SLM Partners acquires and manages rural land on behalf of institutional investors and delivers financial returns and environmental benefits by scaling up regenerative, ecological farming systems. The Land Life Company provides low-cost, biodegradable products to improve the ecological and aesthetic value of land as part of large restoration and landscaping projects in dry climates like Spain.

Peri-urban and urban farming. Interest in peri-urban and urban farming to meet the increasing demand for local, fresh, relatively unprocessed food is growing. Organising short supply chains between local farms and retailers or consumers in nearby cities reduces so-called food miles and related food transport waste. This is also a way to create local jobs and strengthen rural/urban links by bringing farmers and consumers closer, as consumers buy, order, or maybe even harvest fresh food at local farms.

Barcelona, for example, has developed a vision of increasing its self-sufficiency that includes the target of producing half of the city's food in the city and the surrounding region.[194] Walmart has built greenhouses near or attached to their stores to shorten the supply chain of some fresh vegetables.

On a smaller scale, urban farming is also emerging. To address the scarcity of arable land in cities, people started developing vertical, hydroponic, and aquaponic farms. Vertical farms grow produce inside or on top of buildings; hydroponic agriculture grows plants without soil, with their roots in a watery solution of mineral nutrients; and aquaponic farms leverage the symbiosis between hydroponic agriculture and aquaculture (plants absorb fish excretions as nutrients, and clean water returns to the fish basins). All three forms of urban farming typically happen in a controlled environment that enables faster crop cycles, more crop rotations per year, and 70-90 percent less water and fertiliser consumption by keeping unabsorbed water and nutrients in the system.[195]

Despite the emergence of commercial urban, soil-less, vertical farms in cities around the world, some challenges exist in the scaling of these solutions. Not all crops can grow in a controlled environment, and soil-less farming is limited mainly to vegetables and herbs. Understanding the full value and contribution of this sector of industrial food systems requires further analysis.

Digital supply chains could reduce food waste. The European Parliament designated 2014 "the year against food waste", and the European Commission set the target of reducing food waste in the manufacturing, retail/distribution, and food service/ hospitality sectors and households at least 30 percent by 2025 in the Circular Economy package of 2014.

Such pronouncements have raised awareness and prompted action. To address the 20 percent of food wasted from farm to retail, players are leveraging big data and IT to take inventory management to the next level. Tesco's weather team better forecasts local sales and required stock levels using local weather forecasts. SAP's dynamic consumer pricing system changes item prices in real time, based on availability and expiration date of the product. COOP has automated their replenishment system for fresh food.[196]

Consumers account for about one-third of all food waste in Europe. Organisations like WRAP in the UK have invested a lot of effort in reducing consumer food waste. While evaluating the impact of specific initiatives is difficult, WRAP estimates that their various local campaigns and other interventions have reduced food waste 15-80 percent.[197] Digital solutions, such as smart refrigerators, on-demand e-commerce delivery, and wearable monitors, also address the food waste caused by consumers.

POTENTIAL DEVELOPMENT PATHS

Depending on how these levers play out, Europe's food system could take very different development paths to 2050.

The following pages outline two of the many potential development scenarios and the assumptions underlying them and then offer estimates of the potential order-of-magnitude impact of the scenarios (not to be confused with projections) on consumer utility, economic development, and the environment.

Scenario 1: On the current development path, the European food value chain would become more efficient, thanks primarily to resource-efficient agricultural practices and waste reduction in the supply chain, but would not capitalise on the opportunities represented by rehabilitation of degraded land, closed-loop farming, organic agriculture, and peri-urban farming. Due to this lack of a systemic shift, changes in diet and health outcomes would be limited.

Scenario 2: A development path predicated on circular principles and a system-based approach would create a regenerative, resilient, non-wasteful, and healthy food system. Consumers would have ready access to fresh, high-quality food that would encourage healthier dietary choices. This system would close the nutrient loops and preserve natural capital by applying regenerative agricultural practices, minimising the need for synthetic fertiliser and pesticides. This system would create a market for rehabilitating degraded land and fish stocks. Peri-urban farming and digital solutions would match supply and demand in an on-demand and less-wasteful supply chain. Consumers would have ready access to fresh, high-quality food that would encourage healthier dietary choices.

The current development path would likely see a more resource-efficient food system but little system-level resilience

In this scenario the current development path of industrial agriculture would make the food value chain more efficient. Technological innovation in bio-science and precision farming would enhance agricultural efficiency, while businesses would leverage IT and better planning to reduce waste. Together, these advances would gradually improve economic outcomes and resource productivity within the existing system of intensification and specialisation. But these advances would develop little system-level resilience and therefore would not fully address the waste and environmental and health externalities in the system.

The current development scenario could increase the efficiency of agricultural resources significantly, resulting in a cost reduction of as much as 10 percent in agricultural primary resource input and a reduction in food waste of as much as 45 percent by 2050. Technological advancements in IT and agricultural and farming equipment would enhance resource productivity. As the cost of these technologies dropped, they would further penetrate the market as they became profitable investments for smaller farmers. By 2050 fertiliser, pesticide, and water use could be 45-50 percent lower than today and GHG emissions, land, fuel and electricity use 15-20 percent lower.

Businesses along the entire supply chain would be more aware of waste and the related economic losses and would intensify waste-reduction efforts accordingly. They would leverage new technologies, big data, and IT to better coordinate product flows along the value chain. Retailers would also harness these technologies, simplifying and harmonising product labels to eliminate confusion.

These efforts would reduce food waste along the supply chain (excluding consumer food waste) as much as 50 percent by 2050. Consumer food waste reduction would be limited to 35-40 percent by 2050. Technological developments like improved packaging, e-commerce, and smart refrigerators would drive this improvement. But the current development scenario would likely not address the issues of degraded lands. Closed and local loops would probably remain niche practices. Obesity rates would likely continue to rise.

The lack of pricing of resources and externalities would result in continued undervaluation of natural capital and would slow the penetration of organic farming. Converting bio-waste to energy and similar outer-loop activities would continue, but the prevention and recovery of nitrogen, phosphorus, and potassium from waste water and sewage streams would not reach large scale. Urban farm projects would appear sporadically in some European cities.

In this scenario average daily calorie intake would remain at today's high level, or 40 percent above recommended intake levels. The related social costs of obesity would stay constant as well.

A circular development path could advance towards a regenerative food system

The circular scenario lays out an optimistic vision. In this scenario European cities and businesses would recognise the huge potential of a circular food system, invest to overcome today's barriers to its development, and see the quality of the food system improve dramatically.

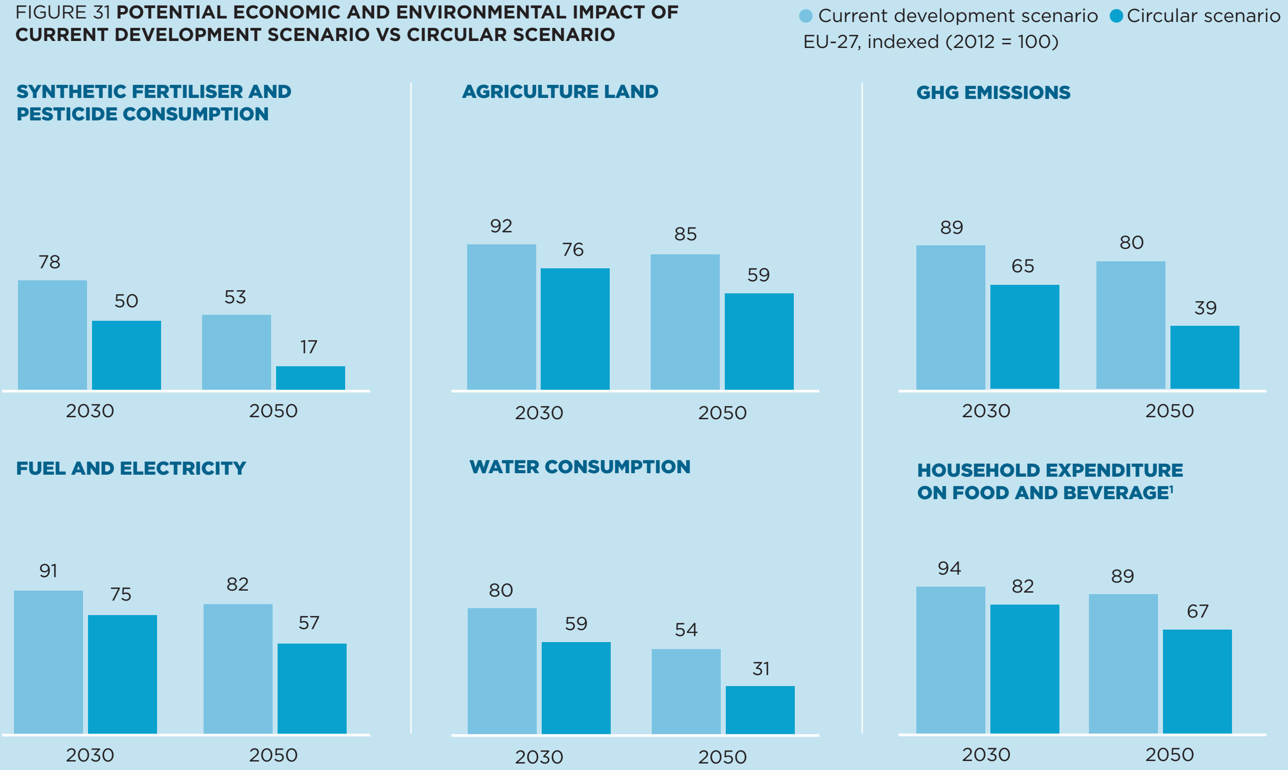
Systemic change would reap the benefits of the traditional farm system and learn from industrialisation to build a regenerative food system that would produce better environmental and health outcomes. This system would be regenerative, closing nutrient loops with minimal leakage and maximum long-term value extraction from each loop in short, local supply chains with almost zero waste. The system would offer accessible, fresh, and healthy food that would encourage consumers to embrace a healthier and/or less resource-intensive diet. Realising this scenario would require enacting new policies and restoring and reclaiming local farm land.

A regenerative agricultural system would require a concentrated policy effort to set the price of resources and natural capital, price externalities, and shift fiscal incentives towards labour. Policies would shift support to restoring degraded lands and reclaiming infrastructure land that a circular mobility system would free for other uses.

Europe would have redesigned processes for collecting, separating, and processing bio-waste, waste water, sewage, and human excreta to maximise the recovery and reuse of nutrients. This would free organic agricultural practices from dependence on synthetic fertilisers and help cities realise new visions for local, fresh, and organic food. More integrated and local supply chains would foster collaboration among stakeholders to reduce food waste, achieving a reduction of as much as 80 percent by 2050. Interventions to address consumer food waste would include clear date labelling, and better packaging. Related efforts would explore new business models to change how people consume food, such as broader use of subscriptions for daily or weekly delivery of recipes that specify the right quantity of the necessary ingredients.

The large retail chains would offer a broad range of local food. Greater availability of healthy produce would improve people's diets. The emergence of healthy supply

FIGURE 31 **POTENTIAL ECONOMIC AND ENVIRONMENTAL IMPACT OF CURRENT DEVELOPMENT SCENARIO VS CIRCULAR SCENARIO**



1 Including food and catering services (e.g., restaurants).

Source: Expert interviews; Eurostat household expenditure data; MGI, Overcoming obesity: An initial economic analysis, 2014; FAO, Global food losses and food waste – Extent, Causes and Prevention, 2011; EEA, Towards efficient use of water resources in Europe, 2012; EU Commission, Official journal of the EU, Commission Agriculture and Rural Development, 2012 budget, 2012; FAOSTAT; Kimo van Dijk, Present and future phosphorus use in Europe: food system scenario analyses, Wageningen University, 2014; Josef Schmidhuber, The EU Diet – Evolution, Evaluation and Impacts of the CAP, 2008; Gregor Zupančič and Viktor Grilc, Anaerobic Treatment and Biogas Production from Organic Waste, 2012; Joint Research Centre (JRC) of the European Commission et al., Precision agriculture: an opportunity for EU farmers – potential support with the CAP 2014-2020, 2014; Ellen MacArthur Foundation, Delivering the circular economy toolkit for policy makers, 2015.

chains, combined with public and private initiatives and IT-based delivery of dietary information like health and diet trackers, could reverse the upward trend in daily calorie intake. Public interventions could address portion control, labelling, nutritional education, and healthy, balanced diets in schools and public institutions.[198] These efforts could help to reduce the average EU calorie intake almost 10 percent by 2030 and 20 percent by 2050, still about 10 percent above the recommended intake level.

A circular development path could lead to better societal outcomes

A food system based on circular design principles would likely produce better consumer utility and environmental outcomes than the current development path could achieve.

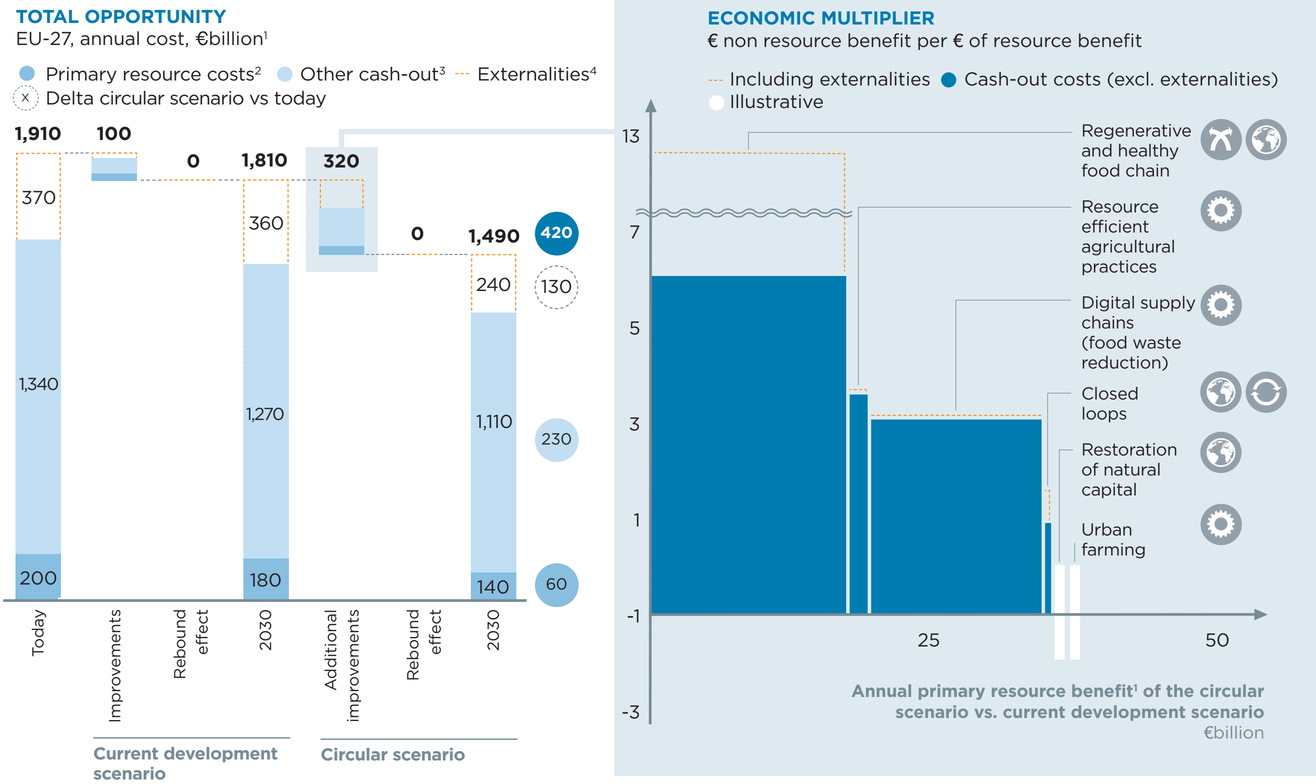
Combining lower calorie intake with an 80 percent reduction in food waste would mean that providing a healthy diet for the European population would require up to 40 percent fewer calories in 2050 than today. This could lower average annual household spending on food almost 25 percent by 2030 and 40 percent by 2050, driven totally by volume rather than efficiency or the quality or price of the goods.

Environmental outcomes would likely also be better in the circular scenario, with significant reductions in the consumption of synthetic fertiliser, pesticides, energy, land, and water and GHG emissions (Figure 31).

Today, 16 million tonnes of synthetic fertiliser go into the agricultural system. The circular development path could reduce that number as much as 80 percent by 2050 by

3. REINVENTING A REGENERATIVE FOOD SYSTEM CONTINUED

FIGURE 32 **THE CIRCULAR FOOD OPPORTUNITY - 2030 SCENARIOS**
Resource benefit curve - food, EU27



1 All numbers rounded to € 10 bln.
2 Primary resources include virgin synthetic fertiliser (€535/tonne), pesticides, agriculture land, fuel, electricity, and water (€0.20/m^3).
3 Other cash-out costs include all household expenditures on food and catering services, as well as EU CAP spend and the cash-out costs (e.g., health costs) related to obesity, but exclude the primary resource costs. 4 Externalities include CO2 (€29/tonne) and opportunity costs (e.g., productivity loss and loss of lives) related to obesity. Other externalities such as eutrophication, biodiversity loss, deforestation are not quantifies in this analysis, but are likely to be significant as well.

Source: Company and expert interviews; Web search; Eurostat household expenditure data; MGI, *Overcoming obesity: An initial economic analysis,* 2014; FAO, *Global food losses and food waste – Extent, Causes and Prevention,* 2011; EEA, *Towards efficient use of water resources in Europe,* 2012; EU Commission, Official journal of the EU, Commission Agriculture and Rural Development, 2012 budget, 2012; FAOSTAT; Kimo van Dijk, *Present and future phosphorus use in Europe: food system scenario analyses,* Wageningen University, 2014; Josef Schmidhuber, The EU Diet – *Evolution, Evaluation and Impacts of the CAP,* FAO, 2008; Gregor Zupančič and Viktor Grilc, *Anaerobic Treatment and Biogas Production from Organic Waste,* 2012; Joint Research Centre (JRC) of the European Commission et al., *Precision agriculture: an opportunity for EU farmers – potential support with the CAP 2014-2020,* 2014; Laure Itard et al., Ellen MacArthur Foundation, *Delivering the circular economy toolkit for policymakers,* 2015.

cutting waste and average food intake and realising the potential of closing the loop and recovering nutrients. For example, the EU27 could meet as much as 30 percent of today's demand for phosphorus use in synthetic phosphorus fertiliser by closing the loop. This would significantly reduce eutrophication and other environmental externalities. The current development path could reduce consumption of synthetic fertiliser up to 50 percent through more resource-efficient agricultural practices like precision farming and through reduction in food waste.

Reducing fertiliser consumption 80 percent, combined with reducing fuel and electricity needs, storing more carbon in restored lands, and reducing demand due to less waste, could reduce GHG emissions as much as 60 percent. On the current development path, the limited reduction in fertiliser use and less restoration of land would reduce GHG emissions only about 20 percent.

Today, European agriculture withdraws 73 cubic kilometres of water each year. Stemming the 25 percent conveyance loss and applying precision irrigation techniques could achieve water savings of as much as 45 percent in the circular scenario by 2050. Savings in the current development scenario would be around 35 percent. In the circular scenario, combining these improvements in water consumption with the reduction in food waste and in average calorie intake could lead to as much as 70 percent less water consumption by 2050. In the current development scenario, this number would not exceed 45 percent.

These social outcomes in the circular scenario could have major impact on consumers' health and related healthcare costs and other societal costs, capturing a significant share of the more than 3 percent of GDP lost today to obesity by 2050. The circular scenario would also likely create more jobs in Europe as organic farming practices and waste management are relatively labour-intensive activities.

The following resource benefit curve compares the impact of the two scenarios (Figure 32).

Implementation by 2030 of all the levers that could produce resource savings could generate total benefits of approximately €320 billion versus the current development path, or €420 billion versus today. On the cash-out side, this includes €60 billion in primary resource benefits and €230 billion in other cash-out benefits compared with today. In the circular scenario, negative externalities could decline as much as €130 billion versus today, compared with about €10 billion in the current development scenario. The benefit curve shows shifting towards regenerative and healthy food chains and significantly reducing food waste would deliver a large share of the benefits.

A POTENTIAL WAY FORWARD

Moving towards a circular food system would require society to address the market imperfections that lead to today's wasteful use of resources, environmental externalities, and unhealthy outcomes. Innovative technologies and food waste reduction alone cannot correct for these market imperfections. They would require policy interventions to improve the economic efficiency of using resources and natural capital use and improve health outcomes.

The principal market imperfections are the social cost of resource consumption and natural capital losses, information barriers, health effects, and related costs. Moving towards a better food system would mean addressing these challenges, especially by:

- **Emphasising the importance of local, healthy food supply chains with less waste.** Mainstreaming regenerative agricultural practices through large-scale retailing would be essential but would require a new supply chain. Governments might find ways to promote such local supply chains—for example, through public procurement or stimulation of demand.

Policy options to stimulate healthier supply chains have begun to emerge. Possibilities include tax incentives (e.g., on sugar, salt, fat, and bio-waste disposal), standards or limits on ingredients (e.g., fat, sugar, and salt in certain products), clear labels (indicating high content of certain nutritional elements), and inclusion of topics in the school curriculum (e.g., importance of avoiding food waste, healthy nutrition and diets).[200]

- **Closing nutrient loops.** Significantly reducing agriculture's dependence on continuous inputs of synthetic fertilisers would require recovering and reusing nutrients at scale, as well as rethinking source separation, promoting advanced soil research, and investing in better collection, treatment, and recovery of solid waste, human excreta, animal manure, and waste water.

Potential solutions include mandating urine-diverting toilets in new buildings and creating or scaling a marketplace for recovered nutrients (such as eMarket[199]). While several projects and companies are already investing in phosphorus recovery, nitrogen and potassium recovery requires similar research and pilots. One option might be to lower taxes on secondary materials (e.g., recovered nutrients), which might stimulate the scaling up of recovery techniques and markets.

- **Pricing the true cost of resource consumption and losses in natural capital.** The latest EU Common Agricultural Programme Called for rewarding farmers for their services to the public, even though these services do not have a market value.

Pricing externalities could help level the playing field for resource-intensive and resource-efficient practices. Organic farming, for example, could compete more fairly with industrial practices, if the costs of eutrophication were taken into account. Peri-urban farming would be more competitive, if pricing accounted for the social cost of transportation emissions. Valuing natural capital could create a profitable market for land restoration and ecosystem rehabilitation, a market that is already emerging.

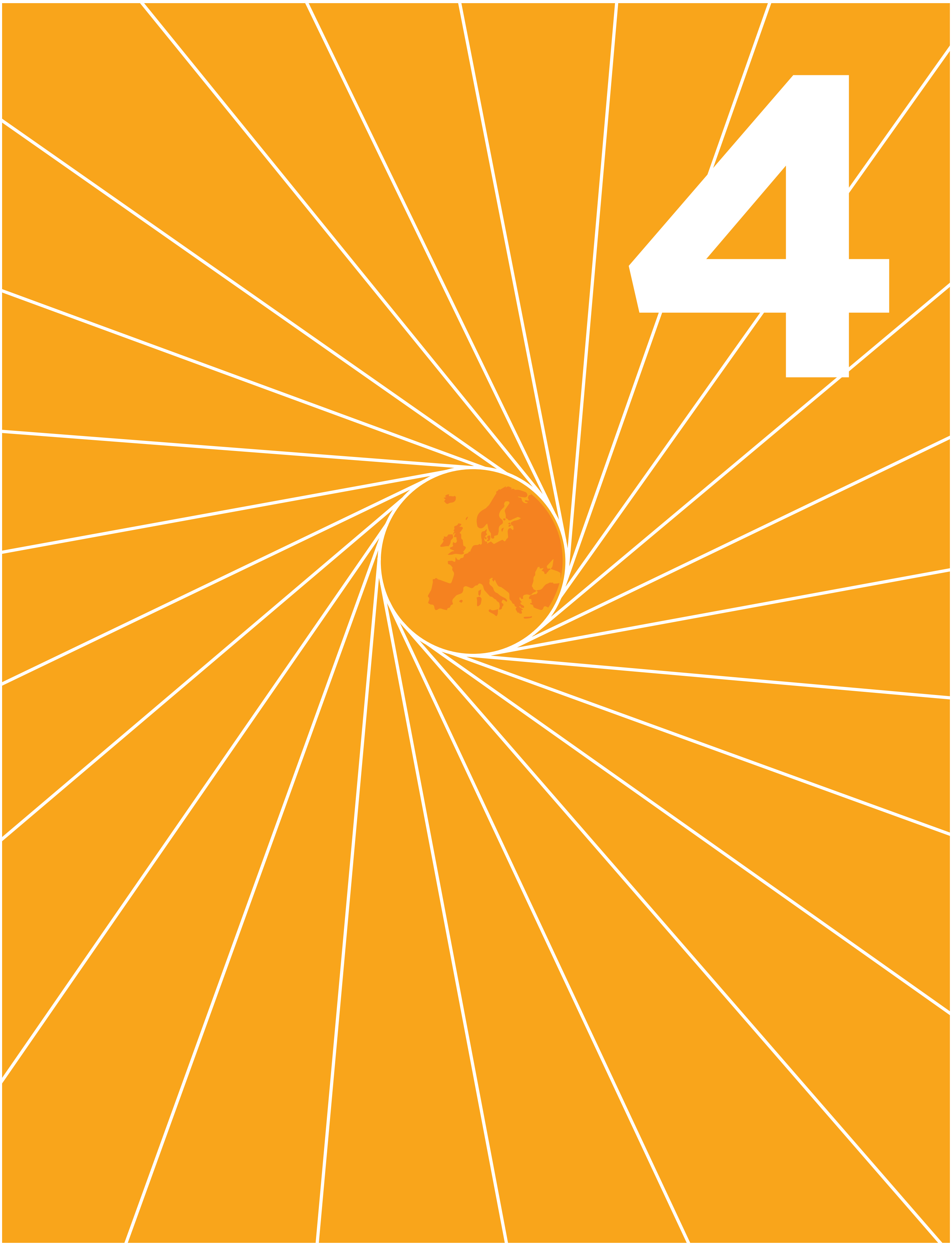
Valuing natural capital could create a profitable market for land restoration and ecosystem rehabilitation, a market that is already emerging.

- **Shifting taxes away from labour and recovered materials.** Shifting taxes from labour to finite resources could level the playing field for more labour-intensive, but less resource-intensive practices. This creates jobs, while saving resources.

Lowering taxes on secondary materials (e.g., recovered nutrients) could stimulate the scaling up of recovery techniques and markets, which would help to reduce the continuous input of synthetic fertilisers and build a value-preserving materials backbone for Europe.

Despite significant barriers, the time may be right to build a new food system. Multiple trends—increasing attention to healthy diets, growing awareness of food waste, and mounting concern about natural capital conservation and rehabilitation—create a firm foundation for moving towards a regenerative food system that provides better societal outcomes.

BUILDING SMART, MODULAR AND PRODUCTIVE HOMES IN A LIVEABLE URBAN SYSTEM



4. BUILDING SMART, MODULAR AND PRODUCTIVE HOMES IN A LIVEABLE URBAN SYSTEM

The future of the built environment is a crucial topic for Europe. Housing is the largest direct expense for European households, with an average annual cost per household of €9,600, or 27 percent of direct annual spend (€15,500, including societal and opportunity costs).[201] Construction is one of the largest economic sectors of the European economy, representing 8.8 percent of GDP and almost 14 million jobs.

Most (72 percent) of the population lives in cities, towns, and suburbs (80 percent by 2020) so cities will play a crucial role in the European economy, at the heart of innovation and growth. The largest consumption of energy and material resources in the economy will happen in cities.

Although recent decades have seen tremendous progress in improving the energy efficiency of buildings and the liveability of cities, the built environment sector remains wasteful. Construction productivity is stagnating in many countries. Supply and demand are not well matched. Buildings consume 40 percent of Europe's energy demand and emit 36 percent of total CO_2.[202] Urban sprawl is growing.

Europe might be at a turning point. A number of new building technologies and business models are emerging and reaching scale, and consumer behaviours are changing. Urban planners could embrace the circular forces at work in the mobility and food systems and reclaim unlocked, valuable inner-city land to create high-quality spaces where people would live, work, and play.

Such a development path could create smart and modular homes that would produce rather than consumer energy and water in liveable urban systems, where circulation and regeneration of resources were the norm. This vision holds promises for the economy (lower housing cost) and for the environment (land savings, less finite material consumption, and lower CO_2 emissions). Societal outcomes would also improve if Europe reinvented the built environment guided by circular economy principles.

STRUCTURAL WASTE IN THE BUILT ENVIRONMENT

For all its achievements, the built environment still contains structural waste. Numbers are

FIGURE 33 **STRUCTURAL WASTE IN THE BUILT ENVIRONMENT**

CONSTRUCTION | UTILISATION | USAGE | END OF LIFE

CONSTRUCTION

- **10-15%** of building material wasted during construction
- **0-0.5%** productivity increase per year in most European countries 1990-2015, whereas 2% per year achieved in some countries

UTILISATION

- **60%** of European offices are not used even in working hours
- **50%** of residential dwellers report living in too much space

USAGE

- **20-40%** of energy in existing buildings can be profitably conserved
- Passive building standards at or near profitability for most new-build segments, but still only constitute a minority of buildings

END OF LIFE

- **54%** of demolition materials landfilled, while some countries only landfill 6%
- Most materials unsuitable for reuse as they contain toxic elements

URBAN PLANNING:

- **50% of most city land dedicated to infrastructure**
- **11 million households experience severe housing deprivation**
- **Congestion cost 2% of GDP in many cities**

Source: 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; IEA Statistics © OECD/IEA (http://www.iea.org/stats/index.asp) Energy Statistics and Balances of Non-OECD Countries, Energy Statistics of OECD Countries, and United Nations, Energy Statistics Yearbook; European Commission, *Service contract on management of construction and demolition waste,* 2011.

surprisingly high for a sector that many consider mature and optimised. Four factors account for most of this waste (Figure 33).

Low productivity in construction. Over the last 25 years, the US and Germany, two of the world's largest economies, have seen labour productivity in the construction sector stagnate, while productivity in the rest of the economy increased 50 percent. Most European countries face similar productivity stagnation.

The sector tends to be conservative and cautious about new technologies, perhaps because of builders' long-term legal responsibility in many countries (for example, garantie décénale in France, seguro decenal in Spain, and Merloni laws in Italy). This lack of willingness to embrace new technologies affects how builders use resources. Often 10 percent of materials are wasted on-site during construction.[203]

The construction sector is highly fragmented and relies heavily on local (and sometimes informal) markets. This may result in talent mismatches (complex knowledge skills required in small enterprises) or limited sharing of international best practices. These barriers are not impossible to surmount, as the examples of Belgium and Austria show. Both have seen productivity increases of about 2 percent a year over the last 15 years.

Efficient technical solutions do exist. If construction used them to achieve 50-100 percent of the productivity growth realised by other manufacturing industries, construction costs could fall 50 percent, in relative terms, in 20-40 years.

Under- or over-utilisation. Utilisation of some buildings is very low, while demand is increasing. EU27 has 25 billion square metres of floor space, but much of it remains empty or underutilised. Even during working hours, only 35-40 percent of European offices are used,[204] despite high prices for space on expensive inner-city land.

Forty-nine percent of owner-occupied homes in the UK are "under-occupied" (at least two bedrooms more than stated need, according to a recent *English Housing Survey*[205]). Significant floor space constitutes real quality of life and must not be subject to limitations. Yet, In the UK about 33 percent of people over 60 would like a smaller residence, but only 10 percent actually downsize.[206] Better optimised utilisation would reduce costs for households.

On the other hand, 11 million EU households, or 5 percent, experience severe housing deprivation—defined as living in overcrowded or substandard conditions.[207] That rate jumps to 12 percent for the poorest 20 percent in the EU.

Energy consumption. Buildings continue to use enormous amounts of energy, despite the availability of many improvements. Energy management programs often reduce energy consumption in existing buildings 20-40 percent. Passive and zero-net-energy houses are available in many segments of the market but still constitute only a minority of new buildings.

Policy-makers have partially addressed this issue, especially through the European Energy Performance of Buildings Directive. But major obstacles remain, including consumer lack of information about the costs and benefits of such installations, agency issues regarding required investments, and local workforce inability to do energy-efficient retrofitting.[208]

End-of-life waste and toxic materials. Construction and demolition account for 25-30 percent of all waste generated in the EU, and recovery of demolition waste is unattractive because the waste is often contaminated with "paints, fasteners, adhesives, wall-covering materials, insulation, and dirt."[209] Current demolition waste comes from old buildings torn down yesterday and today, but buildings erected now may well cause the same issues in 30 years.

Much of this waste is hard to separate and contains toxic elements. Many PVC formulations include plasticisers and toxic heavy metals, such as cadmium and lead. PVC is common in windows, doors, siding, flooring, wall coverings, interior surfaces, and insulation. Equally common are volatile organic compounds, some of them suspected carcinogens and immune system disruptors, such as particleboard, paint, textiles, adhesives, and carpet off-gas.[210]

4. BUILDING SMART, MODULAR AND PRODUCTIVE HOMES IN A LIVEABLE URBAN SYSTEM CONTINUED

FIGURE 34 **6 ACTIONS TO TRANSFORM THE BUILT ENVIRONMENT**

REGENERATE	SHARE	OPTIMISE	LOOP	VIRTUALISE	EXCHANGE
Regenerate and restore natural capital	Maximise product utilisation	Optimise system performance	Keep components and materials in closed loops and prioritise inner loops	Deliver utility virtually	Select resource input wisely
Renewable energy IBERDROLA First Solar.	**Residential sharing** airbnb	**Industrial processes** BSB DIRTT Build better.	**Durability and modularity** DIRTT Build better.	**Tele-working** CISCO skype Microsoft	**Better-performing, materials** Zeobond GLASS APPS K-BLOCK
Land restoration Ajuntament de Barcelona	**Parking sharing** JustPark	**Smart urban design** The Vauban Quartet City of Copenhagen Ajuntament de Barcelona	**Remanufacturing** Piece-by-piece demolition TAISEI Material banks and stock management DELTA DEVELOPMENT GROUP	**Virtualisation of products or processes** iCloud	**Better-performing, technologies** PHILIPS Lighting
	Appliances/ tools sharing peerby Zilok	**Energy efficiency** Whirlpool			
Resources recovery and renewables production system P-REX	**Co-housing**	**Passive design**	**Recycle** WINSUN DESSO The Floor is Yours	**Smart homes, big data, and connected appliances** energieID nest RWE SFpark hue	**3D-printing** WINSUN CONTOUR CRAFTING
	Office-sharing and flexible seating Microsoft				

Source: Company interviews; Web search. S. Heck and M. Rogers, *Resource revolution: How to capture the biggest business opportunity in a century,* 2014.

SIX LEVERS THAT COULD TRANSFORM THE BUILT ENVIRONMENT

Six levers could advance the built environment towards a more attractive and less wasteful model (Figure 34). Some are moving quickly and are already reshaping many markets—sharing of residential space, office virtualisation and sharing, and energy-efficient buildings powered by renewable energy. Others are not new but are not moving as fast as expected—modularity and durability and smart urban planning. Still others are just emerging but show great promise, like 3D-printed building envelopes. Finally, some might not happen at all or remain marginal.

Industrial production and 3D-printing. Moving construction towards factory-based industrial processes is already helping companies cut costs as much as 30 percent and shorten delivery time 50 percent or more.[211] While not a new idea, industrialisation has much untapped potential.

Consider the Broad Group. Off-site production of modules in a factory (up to 93 percent of construction hours off-site) enabled this Chinese company to erect a 30-story hotel in 15 days, after only six months of industrial activity. The cost was low—€900-1,100 per square metre, or 10-30 percent less than conventional construction, with no sacrifice in quality (resistance to a magnitude-9 earthquake and five times more energy efficiency than average buildings).[212]

A Canadian company, Do It Right This Time (DIRTT), also builds modules in a clean, precise, focused factory setting at a cost that is 50 percent below on-site construction (the more complex the design, the greater the savings).

New technologies like 3D-printing are also revolutionising construction. Chinese construction company WinSun demonstrated how far 3D-printing has advanced by building full-sized houses and apartments.[213] In 2014 WinSun printed and assembled ten houses, each about 195 square metres, in 24 hours, at a cost of €5,000 per house, and used 30-60 percent less material than traditional construction. The "ink" they use for their 3D-printers is a mixture of dry cement and construction waste, and WinSun plans to open 100 recycling factories in China to transform waste into cost-efficient ink.

Energy generation and use. Europe has lots of room to improve energy consumption in buildings. Two levers will likely drive that improvement—better energy efficiency and distributed production of renewable energy. Today's alternative construction methods like passive houses[214] show that building design can achieve heating and cooling energy savings of up to 90 percent, with an average upfront investment of only 10 percent more than traditional construction.

Retrofitting an existing building into a passive one is difficult, but other solutions to reduce energy consumption 20-30 percent in existing houses, such as better insulation and smart homes, are becoming more prevalent.[215] Energy management tools (smart metres and connected devices, lighting controls, and smart thermostats) are growing at an annual rate of 20 percent.

Buildings go from being consumers to producers of energy with distributed renewable energy mainly in the form of solar PV. This technology has already reached residential grid parity in some European countries, and solar PV is becoming increasingly popular as costs drop.

Water consumption is moving in a similar direction. Green roofs filter and capture rainwater. More and more projects are reducing consumption and promoting water reuse and recirculation (e.g., use shower water to flush the toilet or clean water through natural filters).

Shared residential space. Europe has a major opportunity to increase utilisation of buildings, including residential space. Smartphones, online verification, and the rise of communities have made sharing more convenient and trusted.

Common spaces are popping up in new development projects across Europe. Many new buildings offer guest rooms, lounge areas for working and socialising, terraces with outdoor kitchens, drying rooms for laundry—all shared by the owners of the flats.[216] Such shared facilities could increase utility for households at an affordable cost and encourage a more community-based lifestyle.

Sharing is also becoming a game changer in the leisure market. Increased desire for low-cost travel and the opportunity to earn additional revenue have encouraged peer-to-peer sharing and revolutionised the way people secure accommodations when they visit a city.

Consider Airbnb. It has more than one million spaces listed in more than 34,000 cities across more than 190 countries. Its valuation at over €9 billion makes Airbnb worth more than legacy players like hotel chain giants Wyndham and Hyatt. On New Year's Eve 2014, more than 0.5 million people stayed in Airbnb spaces—4 percent of total global hotel capacity. The list of Airbnb spaces grew 90 percent a year between July 2011 and the end of 2014. At that rate, Airbnb listings would overtake the total number of hotel rooms worldwide in four or five years. This success could spell trouble for hotels, as sharing platforms could soon be an important part of the European hospitality industry.[217]

Shared and virtual office space. Europe underutilises office space. Offices occupy some 1.4 billion square metres. These offices stand empty more than half of the time, even during business hours. But this picture is changing rapidly. Flexible seating, desk-sharing, office hoteling, tele-working, and audio and video conferencing are major trends in the real estate marketplace that are winning acceptance among European workers who appreciate the flexibility and adaptability.

New business models are emerging to capture this opportunity. For example, 39 percent of IBM's 300,000 staff members worldwide work in a remote environment, and the staff-to-desk ratio has increased to an average of 12:1, providing global real estate savings of around €1 billion over the last 10 years. Cisco has likewise realised significant savings from tele-working—€260 million a year.[218]

This trend is developing rapidly and could accelerate in the coming years. In a 2012 survey of 500 construction and building management CEOs, they predicted a 55 percent reduction

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in average office space per employee within five years, thanks to tele-working and office-sharing.

Modularity and durability. A key barrier to better use of floor space is the lack of flexibility in building and room configurations. But new concepts and techniques are bringing much more flexibility into the housing market, as it copes with elderly people who want to downsize but cannot and homeowners who invest in retrofitting to change the organisation of their homes.

DIRTT has capitalised on the modularity trend. It builds interior components that are modular and standardised and offer maximum inter-changeability to existing as well as new buildings. Modularity employs easy-to-use software to design an interior in a few hours, calculate the price during design, and press "print" to deliver exact specifications for components.

Modularity and durability often go hand-in-hand. Modular design typically reuses and refurbishes some 80 percent of the components in the envelope of a building that can stand for 100 years or more, infusing life into unattractive buildings and avoiding demolition.

This is particularly relevant since some 80 percent of Europeans live in buildings that are at least 30 years old, and the possible obsolescence of this housing stock is a major issue.[219] Better modularity and durability could help address traditional factors in housing obsolescence, such as changing lifestyles, shifting demographics, an aging population, and poor construction quality.

Urban planning. Changes like shifting land use patterns, taking advantage of inner-city vacant land, and promoting compact urban growth can reduce land use as much as 75 percent, compared with a sprawl scenario.[220]

Barcelona offers an example. Its compact growth shaped by smart urban planning makes its CO2 emissions 10 times lower and its land consumption 26 times lower than the city of Atlanta, which has a similar population of five million people.[221]

Europe starts in a favourable position. Partly due to their medieval walled history, European cities have a culture of relatively dense areas. The scale and density of these cities create high-quality urban environments, while using far fewer resources.[222] And Europe has promoted more sustainable urban planning for years. A report published in 2013 listed 50 European projects on integrated, sustainable, and participative urban development.[223]

On the other hand, the European Environment Agency (EEA) estimates that Europe is still creating urban sprawl, rather than density. Between 1990 and 2000, urban areas grew 5.7 percent across Europe, and this trend accelerated between 2000 and 2006 (to 6.1 percent).[224]

An EEA report in 2006 documented the negative impact of sprawl on the European economy, society, and the environment.[225] The combined effects of sprawl (including increased congestion, social segregation, and soil sealing) lead to higher resource use and keep the economy from growing.

POTENTIAL DEVELOPMENT PATHS

Depending on how the levers play out, the built environment could take very different development paths to 2050. The following pages outline two of the many potential scenarios and the assumptions underlying them and then offer estimates of the potential order-of-magnitude impact of the scenarios (not to be confused with projections) on consumer utility, economic development, and the environment.[226]

Scenario 1: On the current development path, the levers would likely play out independently and at different paces. Sharing, tele-working, and energy efficiency would advance rapidly, supported by the digital revolution, while modularity and industrial processes would progress more slowly. The European built environment would probably see lower construction costs and operating expenses but increased sprawl and relatively little system optimisation (urban planning). Urban sprawl would have negative impact on the economy, society, and the environment.

Scenario 2: A development path predicated on circular principles and a system-based approach with urban planning at the centre would create an enjoyable and smart built environment that took advantage of high-value unlocked land in urban areas to create more durable, modular, and shareable buildings. This circular scenario would lower household costs; protect land from degradation, fragmentation, and unsustainable use; reduce negative environmental impact; and make cities more liveable and convenient.

The current development path is likely to reduce costs in the built environment but unlikely to solve the problems of sprawl and suboptimal urban planning

In the current development scenario, the European built environment would likely see lower construction costs and operating expenses but increased sprawl and little system optimisation, as lower costs would trigger a rebound effect.

Residential sharing would likely continue expanding, but its current strong growth could slow, due to regulatory issues increasingly raised by legislators.[227] Despite the strong growth of sharing platforms, peer-to-peer sharing models today have only a small share of the hospitality industry in terms of occupied rooms per night, an estimated 2-3 percent. Regulatory challenges to the legality of the offerings, unpaid taxes, and health and safety issues could slow the growth rate so that the average EU household would use peer-to-peer sharing models to cover 5 percent of its need for accommodation services by 2020, 10 percent by 2030, and 30 percent by 2050.

Tele-working and office-sharing, enabled by digitalisation, would likely continue to grow but would not fully solve the underutilisation issue. This trend seems likely to continue, as predicted by industry insiders. Average office space could drop as much as 55 percent by 2020, 70 percent by 2030, and 80 percent by 2050. Hence, a rebound effect would be unlikely in this segment.

Durability and modularity would likely remain prevalent in only pockets of the economy. The penetration of modular building techniques would likely be around 5 percent of new buildings by 2030 and 20 percent by 2050, and the average lifetime of new buildings could be 5 percent longer in 2030 and 20 percent in 2050.

Industrial production, increasingly coupled with 3D-printing and modular assembly on site, could improve construction productivity significantly. Major European construction companies or holdings have the scale for success and might make further investments in these technologies. If so, up to 30 percent of new buildings could use industrial approaches by 2020 (versus 20 percent today), 50 percent by 2030, and 80 percent by 2050.

Renewable and efficient energy (distributed energy, smart-home systems, and better home technologies for appliances, lights, etc.) would make resource management more efficient. The EU has called for all new buildings to be nearly zero-energy by 2020.[228] Full costs for best-in-class residential solar PV systems are expected to drop more than 50 percent by 2020, becoming fully cost-competitive with fossil fuels.

Penetration of renewables could reach 40 percent by 2020, 50 percent by 2030, and 80 percent by 2050. New buildings would probably be almost zero-energy by 2020, and the overall residential building stock could improve energy consumption almost 50 percent by 2050.

Urban planning would probably not improve significantly. The European built environment would likely see lower construction costs and operating expenses, but lower costs could trigger an undesired volume rebound effect—continued urban sprawl. Household cost for housing could fall as much as 30-35 percent by 2050, and research suggests that demand for floor space could increase as much as 30 percent.

Land-take offers a way to quantify the expansion of urban sprawl. Land-take is the area of land taken by infrastructure and facilities that necessarily accompanies infrastructure, such as filling stations on roads and railway stations.[229]

In the current development scenario, annual land-take in the EU would probably remain stable at 1,000 square kilometres, an area about the size of Berlin. This figure is consistent with the European Environment prediction in 2015 that, over the next 20 years, “land use management and the associated environmental and socio-economic drivers are not expected

4. BUILDING SMART, MODULAR AND PRODUCTIVE HOMES IN A LIVEABLE URBAN SYSTEM CONTINUED

to change favourably."[230] This sprawl could exacerbate congestion and commuting time; have negative impact on CO2 emissions, noise, and air quality; accelerate soil erosion, fragmentation of natural habitats, and loss of arable land; and worsen economic and social inequalities.

The circular development path would see advances towards a smart and enjoyable built environment

The circular scenario is optimistic. European cities and businesses would recognise the huge potential of urban planning, invest to overcome today's barriers to such development, and see the quality of the urban environment improve dramatically.

In the circular scenario, urban planners would integrate the new technologies and business models for maximum impact. At the same time, the rapidly changing mobility system would free up roads and parking places for development.

Urban planners would seize this opportunity to address congestion, pollution, and lack of real estate in big cities. They would reclaim unlocked, valuable inner-city land to create high-quality spaces where people would live, work, and play. Roads and parking spots freed up by circular mobility systems would turn into green infrastructure—parks surrounding durable buildings designed in a modular way, built of looped and non-toxic materials. These buildings would generate, rather than consume, power and food, using closed water, nutrition, material, and energy loops.

Buildings would have high utilisation, with shared and flexible office spaces available on demand in one building, flexible and smart homes in another, or perhaps some of both in a single building. Modular homes would include multi-purpose rooms to use space as efficiently as possible.

In this scenario construction would employ low-waste processes like prefabrication and 3D-printing. Materials would include no toxic components and would be tracked to enable repair, reuse, and remanufacturing.
This scenario holds tremendous promise for economic impact (lower housing cost and improved workforce productivity[231]), environmental impact (land savings, less primary material consumption, and lower CO2 emissions), and societal outcomes (enhanced liveability, improved health, and more sense of community).

By 2020 decision-makers would fully embrace the concept of smart urban planning. Cities and regions would commit to smart urban planning, with better coordination between levels of government. Government leaders could implement ambitious urban planning strategies like integrated city development planning, regional cooperation, transit-oriented development, and stakeholder involvement in city planning. They could coordinate planning of the built environment with mobility system planning to accelerate change.

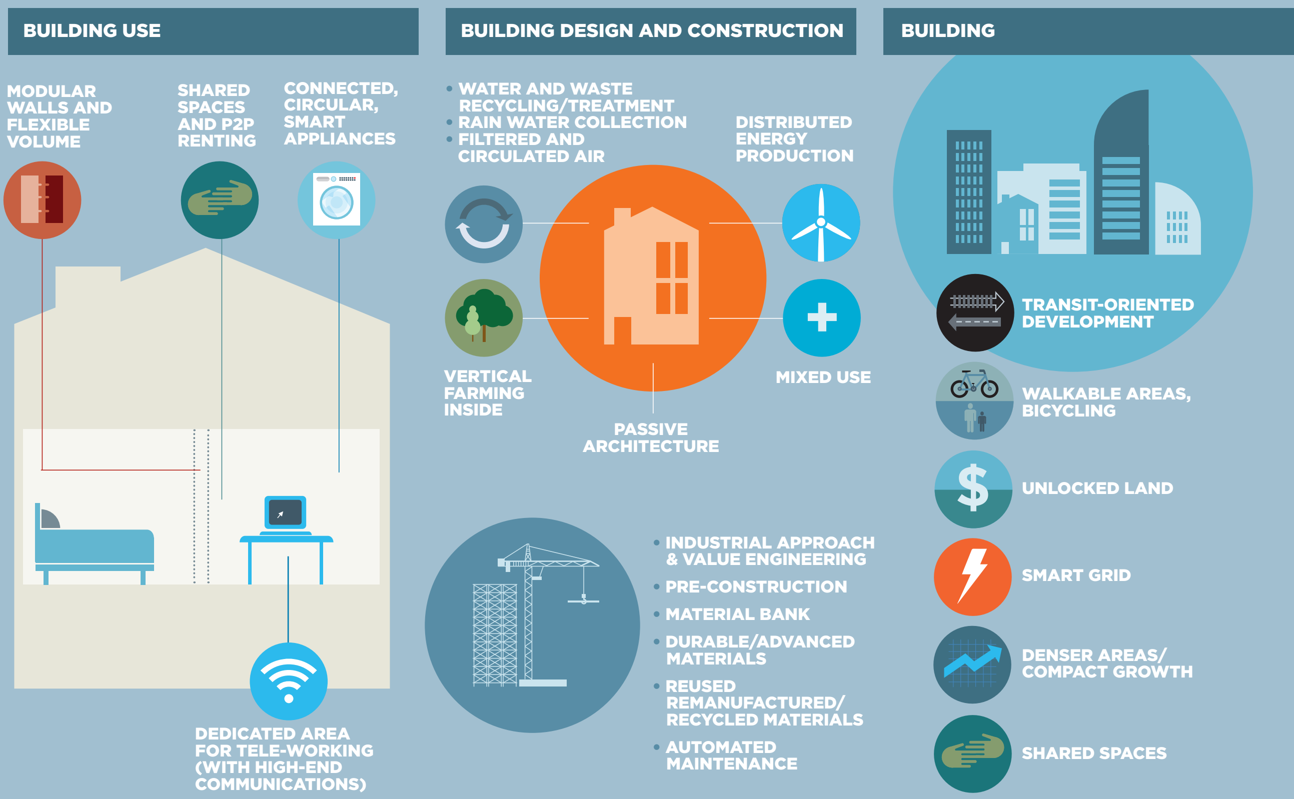
More dense and mixed-used urban areas could create incentives for better circulation of materials within the city. Applying the principles of prolong, repair, and remanufacture, the city could circulate technical materials in closed loops. The city could also cascade or regenerate 10-20 percent of biological waste (energy and nutrients recovered from anaerobic digestion) and filter waste water to capture nutrients and cascade grey water.

Better city planning could help new technologies and business models gain traction faster than in the current development scenario. Governments could remove barriers and promote strategies to increase utilisation of buildings. Peer-to-peer rentals would cover as much as 10 percent of households' need for accommodation services. Office-sharing and tele-working could decrease office floor space as much as 60 percent.

Energy would be demonstrably more efficient, with complete enforcement of the European Energy Performance of Buildings Directive. All new construction would produce zero-net-energy buildings.

By 2030, urban sprawl could be stopped and cities made more liveable.
In a circular scenario, urban redesign strategies would start to show promising results, with visibly less urban sprawl. With better transportation provided by a circular mobility system, inner-city land once occupied by infrastructure and parking would hold new housing projects and shared green areas for recreation.

FIGURE 35 **A CIRCULAR BUILT ENVIRONMENT**[1]



New and renovated buildings would follow new norms that would make them shareable, durable, and modular. Construction would meet passive standards and would use industrial processes and looping, non-toxic materials. As much as 70 percent of new building projects would use new processes that would reduce construction waste and track materials and interior components for future reuse. Some 10-20 percent of new buildings would start to be energy- positive, delivering renewable energy surplus to the grid.

Offices would occupy up to 80 percent less space, as tele-working would be the norm for at least half of the work week, and employees of all companies would share flexible spaces.

The city would regenerate as much as 90 percent of organic waste (e.g., compost and bio-gas production). Urban and peri-urban farming would provide a reasonable share of the city food supply.

By 2050, the average European could live in a circular city with mixed-use buildings

Urban sprawl could be reversed before meeting the goal of "no net land-take by 2050" set by the Resource Efficiency Roadmap. Buildings and flats would be modular and support diverse uses, with very little consumption of resources. Increased modularity and shared spaces would make buildings more flexible and enable society to get more utility from the same spaces and surfaces.

Many buildings would contribute to regeneration—purifying water and sending it into the landscape, producing rather than consuming energy, and providing food for people and habitat for animals.[232]

The city would have a multi-modal mobility system dominated by public and shared transportation. The city would supply much of its own food, reusing food waste and sewage in closed and local loops to produce vegetables,

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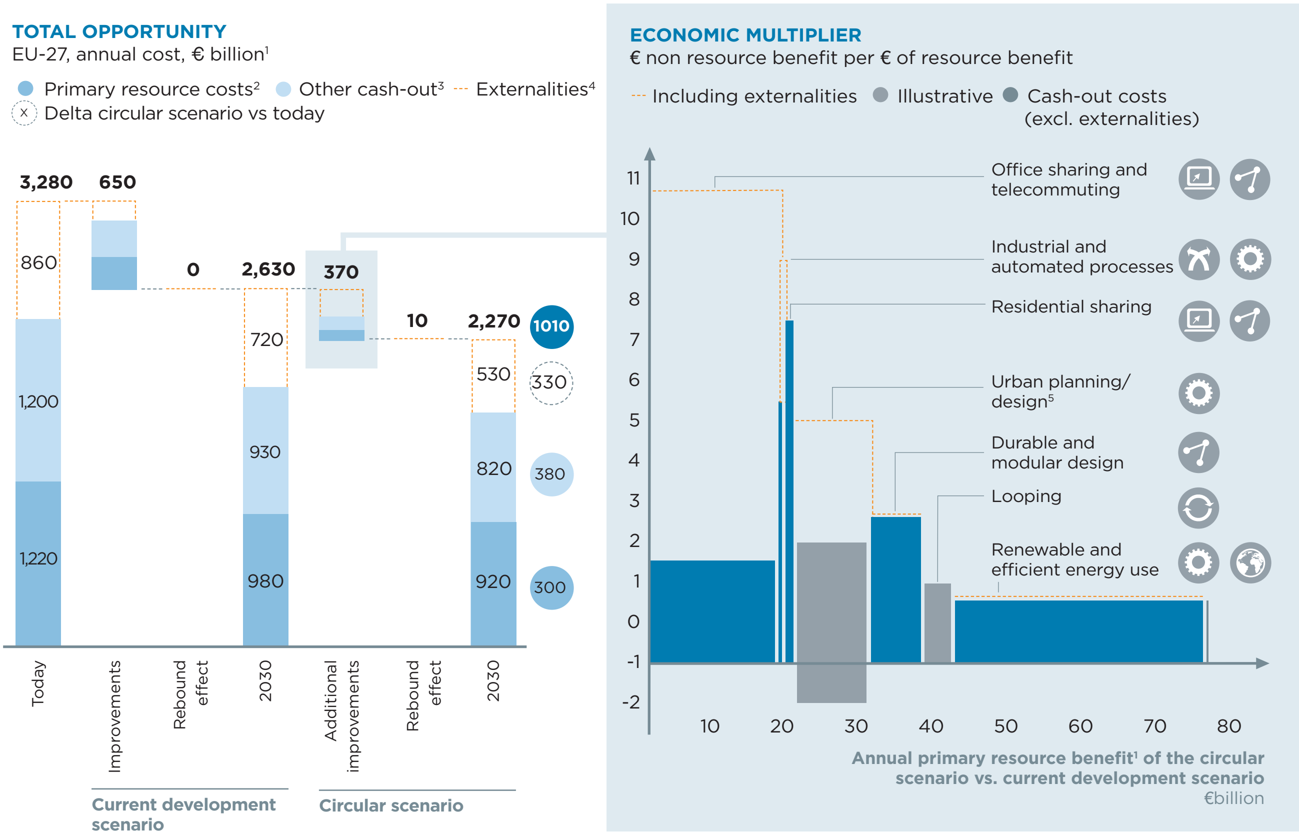
FIGURE 36 **THE CIRCULAR BUILT ENVIRONMENT OPPORTUNITY - 2030 SCENARIOS**
RESOURCE BENEFIT CURVE - BUILT ENVIRONMENT, EU27



1 All numbers rounded to €10 bln
2 Primary resources include virgin construction materials, direct use of fossil fuels for heating (€0.91/litre of heating oil, €68/tonne of coal, €0.067/kWh of natural gas) , residential and office land use and non-renewable electricity(€0.20/kWh)
3 Other cash-out costs include all household expenditures on (imputed) rent, maintenance, utilities, appliances, insurance and accommodation services (e.g. , hotels) as well as related government expenses (e.g., social housing, waste management, street lighting) and the cost of office space, but exclude the primary resource costs
4 Externalities include CO_2 (€29/tonne), adverse health effects due to indoor environment and transport time (related to urban planning)
5 Urban planning impact not fully quantified. Potential impact on mobility, on urban sprawl and additional land-take is enormous (30 thousand km² land-take difference by 2050), but required investments and economic returns are hard to quantify.

Source: Company and expert interviews; Web search; Eurostat household expenditure data; Laure Itard et al., Building Renovation and Modernisation in Europe: State of the art review, TU Delft, 2008; BPIE, Europe's buildings under the microscope: A country-by-country review of the energy performance of buildings, 2011; Per-Erik Josephson and Lasse Saukkoriipi, Waste in construction projects: call for a new approach, Chalmers University of Technology, 2007; Mark Hogan, The Real Costs of Building Housing, SPUR, 2014; Cushman & Wakefield Research Publication, Office space across the world, 2013;

fruit, and fish in urban and peri-urban farms. The city's buildings would be modular, smart, shareable, and regenerative, and urban planners would reclaim unlocked, valuable inner-city land to create high-quality spaces where people would live, work, and play (Figure 35).

Of course, one size does not fit all. Making a successful circular future would require rooting planning and development in deep understanding of the unique local context—the city's demographics, topology and geography, culture, historical architecture, housing stock, local economic issues, and regulations.

The release of inner-city land that is fundamental to this vision would require careful management by local or regional authorities to avoid speculative investments in land and buildings that became available.

A circular scenario could reduce the TCO of housing as much as 50 percent, stimulate economic growth, increase people's well-being, and put Europe on a positive environmental path

The circular scenario would increase utility at lower cost for households. By 2050 housing expenditures per household could be as much as 50 percent lower than today, including societal and opportunity costs, and 15 percent lower than in the current development scenario:

- Direct housing cash-out cost per household could be 30-35 percent lower than today, thanks largely to reduced utility costs driven by increased energy efficiency, distributed production, and water recirculation.

- Societal costs, including government spend and office space costs, could be up to 70 percent lower than today, due mainly to less need for office space triggered by tele-working and shared, flexible work areas.

The circular scenario would reduce total urban sprawl up to 30,000 square kilometres between 2015 and 2050, compared with the current development scenario. Repurposing infrastructure space for mixed-used housing and green areas would make cities more attractive and liveable. Such improvements could reduce income-based segregation of residential development, improve air quality and noise, and reduce transport time between home and office. By 2050, these costs could drop 60-70 percent, compared with today—a more-than-factor-of-three improvement.

By 2050, neutral- or positive-energy buildings could reduce CO2 emissions as much as 85 percent, versus 70 percent on the current development path.

The benefit curve compares the impact of the two scenarios (Figure 36).

Implementation by 2030 of all the levers that would produce resource savings could generate total benefits of approximately €360 billion, versus the current development path, or €1,010 billion versus today. This includes €300 billion in primary resource benefits, €380 billion in other cash-out benefits, and €330 billion in externality benefits.

Realising the large potential resource and externality benefits of urban planning would likely require considerable upfront investment and decision-maker commitment by municipalities, regions, and states. That investment could contribute substantially to relieving pressure on primary resource use.

A POTENTIAL WAY FORWARD

Moving towards a circular built environment would require society to address the market imperfections that produce today's wasteful use of resources. Innovative business models and technologies alone cannot correct for these market imperfections. They would require policy interventions to improve the economic efficiency of resource use.

The principal market challenges are infusing new business models and technologies into the fragmented and traditional construction sector and reinventing European city planning. Moving towards a circular built environment system would require addressing these challenges, especially by:

- **Recognising the enormous potential of smart urban planning and investing accordingly.** All levels of decision-makers, from city mayors, to heads of regions or states, to the European Commission, would make urban planning a top agenda priority. One way to do so would be to find a common language around urbanism, currently fragmented across multiple disciplines, including architecture, engineering, economics, technology, and sociology.[233]

Designing a master plan for a city is a hugely complex task, and decision-makers would have to address multiple fronts simultaneously to encourage more compact urban planning. potential actions include unlocking inner-city land and making it affordable, promoting transport-oriented development (TOD), and encouraging mixed-use buildings and more walkable cities. The high price of housing in inner cities continues to encourage sprawl as developers seek lower prices in more peripheral areas.[234] Finding land in an appropriate location is the most critical step in providing affordable housing.[235]

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Solutions exist to promote rehabilitation of inner-city land. In Singapore, for example, every new real estate project has to prove that the project cannot be implemented on a brown field area in order to get a construction permit for virgin land. Taking different mobility options into consideration when designing urban plans is also critical. Cities like Boston show that, even in developed cities, increasing the density of the transit network or the number of stations can revitalise urban areas and create economic growth, as well as jobs.

- **Encouraging new technologies, business models, and innovative practices in the built environment.** Policy-makers could help to foster innovation and the sharing of best practices. Many more efficient technologies are already on the market but do not reach scale because highly fragmented local companies do not know about them or how to use them. Policy-makers could plan now for building the capabilities required for future use.

Urban planning is similarly uninformed about current land use and could benefit from tools like satellite imagery and big data. For example, the new European settlement map released in February 2015 by the Joint Research Centre uses vast amounts of satellite images and data to provide the first comprehensive overview of all the built-up areas in Europe.[236]

- **Improving liquidity and flexibility in the housing supply.** Various strategies could address the mismatch between housing supply and demand. Policy-makers could develop financial mechanisms to improve market liquidity, such as incentives to encourage elderly people to move into more suitable residences and subsidies for retrofitting derelict empty buildings or offices to increase the supply of new housing in cities.

Despite significant obstacles, a built environment founded on circular principles offers many important benefits—higher quality of life for the average European, positive impact on the environment, and economic growth.

FOOTNOTES

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