Economics of the health implications of waste management in the context of a circular economy
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Abstract
The world is at a crossroads. For decades, economies have relied on the linear model to “take, make, and dispose”; a circular economy is slowly emerging, which looks to “renew, remake, and share” instead. Moving toward a circular economy requires a fundamental rethinking of waste management practices and how they can affect health and well-being. This report analyzes assessment of economic benefits of the health outcomes from better waste management, and discusses approaches for assessing health impacts and their economic consequences in decision-making for a zero-pollution future based on the principles of a circular economy and sustainable waste management. Transformation to more sustainable waste management with low health risks entails substantial economic costs: in remediation of historic waste deposit sites, investment in purchasing and maintaining modern technologies for waste burning, and promoting job switching to avoid lost livelihoods. Economic assessment methods have evolved and include selected topics in the social dimension of sustainability, such as equity. This trend in economic assessment has substantially facilitated the evaluation of health and well-being in the context of the circular economy and waste management in both the short and long term.

Keywords
WASTE MANAGEMENT
HEALTH IMPACT ASSESSMENT
ENVIRONMENT
SUSTAINABLE DEVELOPMENT
ECONOMICS

Document number: WHO/EURO:2023-5536-45301-64839

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Design: Veranika Ardytskaya
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This report was written by Julie Mokrá, Technical University of Liberec, Czechia. Conceptual development and technical guidance were provided by Sinaia Netanyahu, WHO Regional Office for Europe.

WHO thanks Jana Loosová, Regional Public Health Authority Liberec, Czechia, for frequent consultations, support, supplementary materials and valuable comments.

Liz Green, Policy and International Health, Public Health Wales, United Kingdom, and Nir Becker, Tel-Hai College, Israel, are acknowledged for providing elaborate suggestions and comments on the draft report.

This report was produced with the financial support of the German Federal Ministry of Health and the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection.
## Acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AoP</td>
<td>area of protection</td>
</tr>
<tr>
<td>CBA</td>
<td>cost–benefit analysis</td>
</tr>
<tr>
<td>CE</td>
<td>circular economy</td>
</tr>
<tr>
<td>CEA</td>
<td>cost–effectiveness analysis</td>
</tr>
<tr>
<td>COI</td>
<td>cost of illness</td>
</tr>
<tr>
<td>DALY</td>
<td>disability-adjusted life year</td>
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<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EPS</td>
<td>Environmental Priority Strategies</td>
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<tr>
<td>EPR</td>
<td>Eco-cost/Value Ratio</td>
</tr>
<tr>
<td>GBD</td>
<td>Global Burden of Disease</td>
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<tr>
<td>HIA</td>
<td>health impact assessment</td>
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<tr>
<td>HiAP</td>
<td>health in all policies</td>
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<tr>
<td>HTA</td>
<td>health technology assessment</td>
</tr>
<tr>
<td>IHME</td>
<td>Institute for Health Metrics and Evaluation</td>
</tr>
<tr>
<td>LCA</td>
<td>life-cycle analysis</td>
</tr>
<tr>
<td>LCIA</td>
<td>life-cycle impact analysis</td>
</tr>
<tr>
<td>MMG</td>
<td>Milieugerelateerde Materiaalprestatie van Gebouw [environmental performance of buildings and building elements]</td>
</tr>
<tr>
<td>NIMBY</td>
<td>not in my back yard</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
</tr>
<tr>
<td>PM</td>
<td>particulate matter</td>
</tr>
<tr>
<td>QALY</td>
<td>quality-adjusted life year</td>
</tr>
<tr>
<td>VOLY</td>
<td>value of life year</td>
</tr>
<tr>
<td>VSL</td>
<td>value of statistical life</td>
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<tr>
<td>WHO</td>
<td>World Health Organization</td>
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<tr>
<td>WHO CHOICE</td>
<td>WHO project on CHOosing Interventions that are Cost–Effective</td>
</tr>
<tr>
<td>WTP</td>
<td>willingness to pay</td>
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</table>
This glossary was compiled to accommodate the multidisciplinary, interdisciplinary nature of the topic. The impact of waste on human health and general sustainability requires a systematic, long-term, integrated assessment, with approximation of concepts that were initially used in separate disciplines, such as the project on harmonization of selected terms in the field of environment and health (1), because terminology not only unifies and leads to understanding but also, if not clarified, can divide or lead to misinterpretation.

Economic quantification of health impacts is important for communicating effective allocation of resources to protect and promote the health and well-being of society and individuals. For more details on the role of economic evaluation in health and well-being topics, see reference 1.

Methods in health and health-care economics evolved with methods for environmental economics and began to complement each other. Harmonization of terminology and the principles underlying value extraction also evolved to ensure a basic level of comparison, such as in the Cochrane Collaboration, an important source of evidence for health care (2).

The aim of monetizing impact evaluations is to assess the distribution of positive and negative impacts among stakeholders and to optimize decision-making for the overall well-being of society and individuals (3), described in economic terminology as “welfare and utility”. The intertwining of terminology for economics and health evaluation was thus driven by a desire to communicate with stakeholders beyond the purely financial categories captured by markets. Economic evaluation offers means to monetize the impacts of waste on health and well-being, representing all three pillars of sustainability in decision-making (4), although only partially. Such decisions cannot be made without communication, through which key concepts are understood consistently.

For this glossary, definitions of key terms used in the report were derived from publications by international expert groups in relevant fields, taking into account the disciplinary and thematic context. The selected terms are linked to the definitions of an umbrella organization (5) or initiative (6). The term “triple bottom line” (7) is used in a broad context for economic evaluations.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td><strong>Burden of disease</strong></td>
<td>A measure of the gap between a population’s current health and the optimal state in which all people attain full life expectancy without suffering major ill-health (4).</td>
</tr>
<tr>
<td><strong>Cost–benefit analysis</strong></td>
<td>A form of economic evaluation in which both the costs and the benefits of an intervention are measured in commensurate, usually monetary, units to assess whether an intervention is worthwhile. A full or an ideal cost–benefit analysis (in which all the benefits can be valued in monetary units and all alternative uses and opportunity costs are incorporated) can be used to address the question of allocative efficiency. The benefits in such an analysis are valued in monetary units (2).</td>
</tr>
<tr>
<td><strong>Cost–effectiveness analysis</strong></td>
<td>For estimating the costs and health gains of alternative interventions; a method for prioritizing allocation of resources to environmental and health interventions by identifying the projects that could yield the greatest improvement in health for the fewest resources (8).</td>
</tr>
<tr>
<td><strong>Cost of illness</strong></td>
<td>Measure of the total costs attributable to a particular disease. The evaluation is not an economic one, as it is not used to assess the costs and benefits of alternative courses of action. It may provide useful information that can be used in the context of an economic evaluation of interventions related to the disease category; however, not all costs included in a cost-of-illness study represent resource costs (2).</td>
</tr>
<tr>
<td><strong>Determinant of health</strong></td>
<td>Personal, social, economic or environmental factor that determines the healthy life expectancy of individuals and populations (4).</td>
</tr>
<tr>
<td><strong>Disability-adjusted life year</strong></td>
<td>A non-monetary measure of life lost and years lived with disability. One disability-adjusted life year equals one year of life lost that would otherwise be lived in good health; time spent living in less than full health is measured with weights that indicate the degree of disability (9).</td>
</tr>
<tr>
<td><strong>Economic evaluation</strong></td>
<td>Application of analytical methods to identify, measure and value both the costs and benefits of alternative interventions in order to provide evidence of technical or allocative efficiency and aid decision-making for resource allocation (2).</td>
</tr>
<tr>
<td><strong>Environmental determinant</strong></td>
<td>One of the physical conditions in which people live and work that has an impact on health (4).</td>
</tr>
<tr>
<td><strong>Environmental health</strong></td>
<td>Those aspects of human health and disease that are determined by factors in the environment. Also refers to the theory and practice of assessing and controlling factors in the environment that could affect health. Includes both the direct pathological effects of chemicals, radiation and some biological agents and the effects (often indirect) on health and well-being of the broad physical, psychological, social and aesthetic environment, which includes housing, urban development, land use and transport (4).</td>
</tr>
<tr>
<td><strong>Externality</strong></td>
<td>Third-party effects (positive or negative) that usually arise as a result of the consumption and production of goods and services. In health care, “externality” refers to any effect of an intervention on individuals or groups that do not receive or provide the intervention (2).</td>
</tr>
<tr>
<td><strong>Health impact assessment</strong></td>
<td>A combination of procedures, methods and tools for judging a policy, programme, product or service with regard to its effects on the health of the population and the distribution of those effects within the population (4).</td>
</tr>
<tr>
<td><strong>Health in all policies</strong></td>
<td>An approach to public policy development among sectors that systematically takes into account the health implications of decisions, seeks synergies and avoids harmful health impacts in order to improve population health and health equity (4).</td>
</tr>
<tr>
<td><strong>Impact assessment</strong></td>
<td>The process of identifying the future consequences of a current or proposed action. The “impact” is the difference between what would happen with and without the action. Impact assessment has a dual nature, each with its own methodological approaches. First, as a technical tool for analysis of the consequences of a planned intervention (policy, plan, programme, project), providing information to stakeholders and decision-makers; or unplanned events, such as natural disasters, war and conflicts. Secondly, as a legal and institutional procedure linked to decision-making in a planned intervention. Methods mentioned in the report are: health impact assessment, environmental impact assessment, strategic environmental assessment and environmental and social impact assessment.</td>
</tr>
</tbody>
</table>
**Incremental cost–effectiveness ratio**  
The ratio of the difference in costs between an intervention and a specified comparator and the difference in effectiveness between that intervention and the specified comparator. From the results of a cost–effectiveness analysis, an incremental cost–effectiveness ratio can be calculated that gives the extra cost per unit of outcome obtained when comparing one treatment option with another. In this case, a value judgement will be required to assess whether the extra unit of outcome is worthwhile (see Cost–benefit analysis) (2).

**Intervention**  
Any treatment (drug), device, therapy or policy that is used to improve health or a health outcome (2).

**Investment for health**  
Resources that are explicitly dedicated to improve health and well-being. They may be invested by public or private agencies or by individuals or groups. Strategies are based on knowledge about the determinants of health and are designed to gain political commitment to health in all policies (4).

**Life-cycle assessment**  
An internationally standardized method (ISO 14040) for quantifying the environmental pressure of goods and services (products), the environmental benefits, the trade-offs and areas for improvement, taking into account the full life-cycle of the product. A life-cycle inventory and a life-cycle impact assessment are consecutive parts of a life-cycle assessment.

**Life-cycle impact assessment**  
Estimation of indicators of environmental pressures such as climate change, summer smog, resource depletion, acidification and human health effects associated with environmental interventions attributable to the life-cycle of a product. A phase of life-cycle is assessed to understand and evaluate the magnitude and significance of potential environmental impacts for a product system throughout the life-cycle of the product (ISO 2006) (6).

**Multi-criteria decision analysis**  
A method used with economic evaluations to help decision-makers evaluate “alternative courses of action” that require consideration of multiple criteria, e.g., to incorporate the benefits or outcomes of interventions beyond quality-adjusted life years in an explicit, transparent, consistent manner. A set of methods and approaches to aid decision-making when decisions are based on more than one criterion, which make
explicit the impact on the decision of all the criteria applied and the relative importance attached to each \((2, 10)\).

### Opportunity cost

A concept central to economics and health economics, which rests on two principles, scarcity of resources and choice. When resources are scarce, society must make choices about what health programmes to fund and which to forgo. The benefits of the next best alternative health programme that is foregone because the funds are not spent on that programme constitute the opportunity cost \((2)\).

### Public health

An organized activity of society to promote, protect, improve and — when necessary — restore the health of individuals, specific groups or the entire population. It requires a combination of sciences, skills and values applied through collective societal activities and involves programmes, services and institutions for protecting and improving the health of the population \((1)\).

### Quality-adjusted life year

A measure of health outcome that captures both length and quality of life. Calculated by multiplying the total time (years) in a specific health state (or the number of life-years remaining) by the “utility” of those years, measured from 0, representing the worst imaginable health; values less than 0 represent health states worse than death, to 1, representing perfect health. May be calculated with generic health measures such as EQ-5D or condition-specific measures such as the Glaucoma utility index and King’s health questionnaire for incontinence \((2)\).

### Risk communication

Real-time exchange of information, advice and opinions between experts or officials and people who face risks to their survival, health or economic or social well-being \((1)\).

### Sensitivity analysis

A technique used in economic evaluation or decision analysis to determine how and/or whether plausible changes in uncertain clinical or costing variables affect the main results of the analysis \((2)\).

### Social determinants of health

The social, cultural, political, economic and environmental conditions in which people are born, grow up, live, work and age and their access to power, decision-making, money and resources that give rise to those conditions of daily life \((1)\).
Social return on investment

Based on the concept of return on investment. In measuring outcomes (“financial value”), the economic, social and environmental impacts of interventions are taken into account. As in cost–benefit analysis, the outcome is measured in monetary units. The outcomes cover a broader range, with stakeholder involvement as a key component (2).

Stated preferences method

Valuation of health-care interventions and health benefits by asking individuals directly about their preferences in a hypothetical or virtual market (9).

Threshold

Cost–effectiveness thresholds help a decision-maker to judge the opportunity costs of an intervention. If an intervention has an incremental cost–effectiveness ratio below a given threshold, it is assumed that resources can be reallocated from interventions that have an incremental cost–effectiveness ratio above that threshold (2).

Triple bottom line

Originally an accounting approach for reporting on the three pillars of sustainability — social, economic and environmental — that define the well-being of individuals and societies.

Uncertainty

Uncertainty exists when the expected costs and effects of an intervention on a particular population of patients are unknown, even if all patients in the population appear to have the same characteristics. It may consist of either the value of a parameter or the relations between parameters (structural uncertainty). Additional evidence can reduce uncertainty and provide a more precise estimate of expected outcomes for a whole population or subgroups (9).

Value of life year

An individual’s marginal rate of substitution between money and life years remaining; often estimated by dividing the value of statistical life by remaining life expectancy (9).

Value of statistical life

An individual’s marginal rate of substitution between money and mortality risk in a defined period; often estimated by dividing an individual’s willingness to pay for a small change in risk by the change in risk (9).

Well-being

A positive state experienced by individuals and societies. Similar to health, it is a resource for daily life and is determined by social, economic and environmental conditions (4).
**Willingness to accept**

For an improvement, the minimum amount of money an individual would accept to forgo the improvement, such that his or her well-being is as good with the money and without the improvement as with the improvement; for harm, the minimum amount of money he or she would require to accept the harm (9).

**Willingness to pay**

For an improvement, the maximum amount of money an individual would exchange to obtain the improvement, given his or her budget, such that his or her well-being is as good with the improvement and having made the payment as without. For harm, the maximum an individual would pay to avoid the harm (9).
Executive summary

The current broad area of sustainability links the topic of health to a number of areas in which significant changes can be expected after transition to a circular economy (CE) under conditions of climate sustainability. In such a context, there is pressure to transform the waste sector as well as the material flows of resource use throughout supply chains. In evaluating such actions, emphasis is naturally placed on techno-economic parameters that take into account environmental impacts. The topic of health and waste is thus dispersed in the CE into a number of sub-agendas, such as environmental health, water reuse, food safety and sustainable transport.

Each of these areas impacts several determinants of health and well-being simultaneously. In a number of cases, the impacts of individual determinants oppose each other; e.g., inadequately regulated water reuse for irrigation in agriculture leads to more hazardous substances in food. If a CE solution is to be sustainable, however, the negative impacts must not outweigh the positive ones, from not only a techno-economic but also an environmental and social perspective.

Measurement of social well-being falls within the area of health metrics. The most widely used metrics for decision support in health and health care include quality-adjusted life year (QALY) and disability-adjusted life year (DALY), which cover a certain proportion of social well-being, partly depending on the method of expressing their monetary value. The dominant approach in recent decades has been based on non-market-based valuation methods in stated preference studies, resulting in a willingness to pay (WTP) for a change in the risk of health damage. The value thus obtained is subject to a number of biases that economists are still addressing systematically, and the method overall requires a careful approach and a high level of expertise. Nevertheless, its use is widespread because it can theoretically provide a robust estimate of financially unreported values related to societal views of health and well-being. The values are used to prepare the results for further communication of the outputs of health assessment methods with stakeholders or are further elaborated in the form of cost–benefit analysis (CBA) or cost–effectiveness analysis (CEA) to support sound decision-making. For the global health and development agenda, these analyses are extended to include the distribution of impacts, such as equity issues, and to deal with uncertainties due to unquantifiable impacts as part of recommended practices.

There is methodological overlap between the magnitude of uncertainty of economically unquantifiable effects and estimates of the magnitude of health impact or risk, as in both
cases the aim is to provide a sound basis for decisions and subsequent communication with stakeholders.

The framework for economic evaluation of the health implications of waste in the CE is based on an analysis of relevant methods and definition of three levels of evaluation management in relation to the time horizon of a plan, programme, policy or project. A portfolio of methods from the static perspective, which balances the effects of health determinants in all three pillars of sustainability, the “triple bottom line”, provides the most accurate, detailed basis for decision-making. The disadvantage is relatively rapid outdating of such assessments. For the single-cycle perspective, the methods have a degree of uncertainty. The economic viewpoint is used to evaluate system capacity in terms of resource efficiency or society-wide preferences derived from WTP. Linked to this are thresholds for the level of acceptability of proposed medium-term activities. The last circular perspective has a long-term sustainability strategy, in the sense of investment in health and systematic balancing and enhancing of the positive effects of health determinants on overall health and well-being. This occurs not only during one material, product or resource recovery facility cycle but also takes into account and monitors impacts in subsequent cycles. This perspective has a high level of uncertainty, which is reflected in the portfolio of proposed methods.

From an economic viewpoint, the circular perspective incorporates the principles of investment appraisal with an impact on the social rate of return on investment. Waste prevention combined with successful transformation of the waste sector into a sustainable resource recovery sector under climate-neutral conditions has a realistic prospect of achieving a very high social return on investment. In order to prove this assumption, the right direction of health impacts for all sub-topics in the public and private sectors must be carefully managed when deciding on plans, programmes, policies or projects in the waste sector in a CE. From a strategic circular perspective, a coordinated HiAP approach meets those assumptions.
The economics of the health implications of waste in the context of a transition to a circular economy (CE) are not sufficiently covered in the literature. The main topic in assessing system performance in a CE is the material cycle and the resulting focus on techno-economic and environmental solutions. The social issues of the topic, like health and waste prevention, are under-represented in the literature.

Economic tools for evaluating health and well-being can be used in the context of the CE, as these now include selected topics in the social dimension of sustainability, including equity. Despite a number of shortcomings, non-market valuation methods with a willingness-to-pay (WTP) approach dominate economic valuation of health implications because they include the social component of health and well-being.

The theme of health is reflected in its determinants in all pillars of sustainability when assessing system sustainability. The portfolio of methods and approaches analysed in the static perspective of the proposed framework for economic evaluation of the health implications of waste in the context of a CE provide the most accurate evidence for decision-making. The disadvantage is rapid outdating of the evidence base.

The proposed circular perspective covers the longest time horizon for long-term sustainability strategies and provides a platform for coordinating health issues in the public sector and the private sphere through investments for health in the framework of the health-in-all-policies (HiAP) approach.
Aim, purpose and structure of the report

The economics of health implications of waste management in the context of CE

The concept of a CE creates a new platform for analysis of the efficiency and sustainability of production and consumption, to which it is critical to add health implications. Monetization of health implications or ranking them to demonstrate the significance of each will better communicate them to policy-makers. The purpose of the report is to review approaches and methods for monetizing the health implications of waste management in the context of the CE and possible alternative approaches for indicating the significance of health implications when data for monetization are not available.

Two recent WHO publications, Circular economy and health: opportunities and risks (11) and Assessing the health impacts of a circular economy (12) set the stage for this report. Health impacts are often not quantified and hence not monetized, limiting assessment of the relative significance of different health impacts associated with the transition to a CE. On the basis of these two publications and more recent literature, the report sets a framework for assessing the economics of the health implication of waste management in the context of a CE.

The report covers a number of topics. Approaches and methods for monetizing the health implications of waste management in the context of a CE are reviewed, with alternative approaches to assessing the significance of different health impacts (e.g., expert scoring and estimates of orders of magnitude) when quantitative, monetized estimates are limited. The report concludes with an analysis of the methods and framework proposed. Publications solely on health impact assessments of a CE or the economic impact of a CE on the waste sector were beyond the scope of this report.

The document is intended for readers interested in an approach to evaluation and sound decision-making on prevention of waste and resource recovery in the context of the transition to a CE. Readers will include national and regional public officials, public health experts and managers of organizations, programmes and projects related to the CE and sustainability. The latest literature on the economics of the health implications and references to recent comprehensive recommendations and guidelines will bring new inspiration to academicians and to those involved in planning, designing and evaluating programmes, policies and projects for waste prevention and transformation of the waste sector in the context of the transition to a CE and later to a circular society.

The first section reviews the literature on health in relation to the development and evolution of the concept of sustainability. Subsequently, practical frameworks for
assessing the performance of systems within a CE are presented, in which the three pillars of sustainability (economic, environmental and social) are present to different extents for themes related to waste management. As the main focus of a CE is on material recovery, the current literature is dominated by a techno-economic approach that takes into account environmental aspects. For social aspects, such as changing consumption behaviour, waste prevention and the broader social context of the CE concept, the next stage of a CE, a circular society, is widely used. The changing approach to material recovery is linked to transformation of the waste sector into a sector for sustainable recovery of materials and resources, which is thus most frequently observed and is potentially significantly affected economically. The links between health and waste are discussed in macroeconomic approaches to assessing the impacts of a CE. Tracking of CE sustainability indicators at company and product levels is followed by recycling and health concerns due to circulation of hazardous chemicals.

The second section addresses life-cycle analysis (LCA) and evaluation of health implications in more detail. This approach dominates the field of waste in the CE because of its versatility, as it integrates all impacts on the life-cycle of both individual products and entire waste management systems. In one phase, the LCA unifies, with some simplifying assumptions, health impacts from different sources into a so-called area of protection (AoP) of human health. Then, the health impacts can be valued simply in monetary units. The main monetization tools are compared, and the underlying values for the valuations, including recent updates, are discussed in detail.

In the third section, the principle of health externality and its components and levels are described. Like positive and negative health impacts in health impact assessments (HIAs), environmental economics works with so-called positive and negative externalities in environmental or human health. Externalities are projected in economics as external costs or benefits to individuals or society as a whole that arise from legitimate third-party activity. A brief discussion is given of the link between externalities and economic evaluation of health impacts from waste in the CE and the current limit of traditional approaches to regulating externalities only at large final waste disposal facilities. Systematic management of externalities has led to creation of an extensive monitoring infrastructure with outputs that can be used in practical evaluations, which is described in Annex 1.

Section 4 reviews current topics in health assessment and its economic evaluation. The field of health economics provides methods for measuring changes in the quality of life with a metric of health utility, quality-adjusted life years (QALYs). When the impact of an intervention on health is evaluated in a cost–effectiveness analysis (CEA), the total number of QALYs gained per target population is determined, and then the cost of an intervention is assigned to the measured changes in health. Determination of a publicly acceptable threshold that matches health system capacity is a prerequisite for efficient use of budgets in public health systems and also an important signal to those who design public health programmes. Introduction of threshold values for health metrics in other sectors that significantly affect health is a strategic approach to resource efficiency from an economic point of view. Analogous to the
QALY is the disability-adjusted life year (DALY), a scientifically constructed metric for measuring the burden of disease in epidemiological studies. Methodological differences are unimportant in economic valuation of health impacts, as long as it is unnecessary to distinguish the values for the metric as expert or subjective. Approaches to monetizing DALY and QALY thresholds depend on the context of the overall assessment. The section provides detailed descriptions of the methods usually used to set thresholds and the strengths and weaknesses of each approach, with references to new methods that move towards a holistic approach to measuring well-being.

Section 5 provides methods and alternative approaches to estimating health and economic impacts when data are scarce or only preliminary. An analogy is drawn between use of methods for communicating risk based on preliminary data and communicating uncertainties and unquantifiable impacts. Approaches to equity in the distribution of health impacts and in cost burden are also addressed.

The sixth section provides summaries and analyses of methods for economic evaluation of the health impacts of waste in a CE and examples of implementation or background information for practical application of the methods. It highlights the interrelationship and universality of some of the approaches, preparing the way for development of the framework.

Section 7 presents a framework for economic assessment of the health impacts of waste in the CE and evolution in use of methods in three time horizons for decision-making. The portfolios of interlinked methods correspond to the pillars of sustainability, to which the topic of sustainable waste and resource recovery belongs. The theme of health and well-being in this approach is also linked to these three pillars but through the impacts of waste in the CE on the main determinants of health. Fundamental transformation of the approach to waste in the CE and the extent of dispersion of associated health impacts throughout the public sector require a coordinated approach to eliminating negative and promoting positive public impacts on health and social well-being, e.g., through an HiAP approach.

The final section briefly summarizes topics that are not directly related to economic evaluation but are important in terms of the sustainability of societal well-being in the context of waste. They include susceptibility, ethical issues, quality and safety, waste crime and overall environmental and social responsibility.

Introduction to the concept of CE and waste

The CE brings another level of sustainability to waste management systems. The health implications of waste management are one of the main reasons for extensive systems of pollution control in waste disposal facilities. The current trends in waste generation, however, move attention to upstream processes and the original causes of waste generation. The waste management sector is becoming a resource recovery sector, wherein what was originally waste becomes a resource or a reserve. Health concerns are raised by uncontrolled landfills and waste combustion and persist, despite technological advances and legislative regulation of industrial pollution. Another concern is the rate of waste generation.
in the current linear economy. Traditional waste management systems have limits, and environmentally, socially and economically sound disposal or reuse is a challenge. The priority for safe material flow in the CE is to minimize and control hazardous substances in all cycles of waste disposal.

This document provides an evaluation of current metrics and methods for economic assessment of the health implications associated with waste management and an overview of alternative approaches to estimating health impacts in the context of a CE. Each section systematically traces health valuation in the literature, resulting in a framework for economic health assessment from a static perspective, a life-cycle perspective and a CE perspective. The data sources are identified and relevant methods further analysed. The more comprehensive an analysis of the waste system, the more health becomes absorbed into the environmental and social dimensions of an assessment and the more difficult it becomes to collect reliable evidence on health implications for responsible decision-making. The document is based on earlier publications of the WHO Regional Office for Europe on the CE (11, 12) and further develops the link between health assessment and waste management in that context.
The concept of a CE moves sustainable development to the next level. Every stage has introduced partial improvements and provided a solid base for the next level of sustainability, which emphasizes material flow efficiency with climate neutrality. The wider societal dimension is often not sufficiently perceived, and, for initiatives in the public interest, the term “circular society” is often used (13). In a recent critical review, Walzberg et al. (14) analysed methods for assessing the performance of the CE that have been used in industrial ecology and complex system science. They provided guidance on use of the methods according to scope and described the strengths, weaknesses and limits of each. The limits of the methods are associated mainly with the orientation of material flow, thus marginally addressing assessment of social and health impacts.

A holistic view of sustainability in the CE is necessary with advances in environmental sciences as stronger evidence is found of the links between environmental and human health. This section provides a selective review the literature on assessment frameworks and indicators of the sustainability of waste management and resource recovery. The focus is on systematic reviews of integrative approaches and frameworks that indicate the extent to which health assessment and economic implications are included. Macroeconomic and microeconomic approaches are discussed, with examples of studies relevant to the general impact of waste management and its transformation on resource recovery practices. The review of studies and systematic critical reviews on the health impacts of waste management alone or in the context of the CE provides valuable resources for practitioners and academics involved in CE initiatives.

1.1 Waste and health in a circular economy according to sustainability indicators

Optimizing or comparing the value of resources recovered from waste becomes complex in a CE. Progress in sustainable practices and the evolution of integrated approaches have led to numerous proposed metrics for CE, as noted in two recent reviews (14, 15). Optimizing the multi-dimensional value of resource recovery from waste in traditional environmental, economic, social and technical domains ensures that the proposed transition towards a CE remains sustainable. The metrics and methods used must, however, be chosen carefully in order to avoid oversimplification of the impacts to be understood by decision-makers. Iacovidou et al. (15) discussed the complexity of assessing the value of resources recovered from waste in the context of a CE and reviewed the approaches and decision-support frameworks according to the:
• scope of the assessment (optimizing the given system or comparing alternatives);
• scale imposed by system boundaries (local, regional or national technology, plant, waste management system);
• focus (solid waste management, integrated sustainable waste management, so called “zero-waste” management); and
• method or tool (e.g., LCA, environmental impact assessment, strategic environmental assessment, life-cycle costing, social life-cycle analysis, CBA).

Methods that facilitate the defined dimensions are illustrated in Fig. 1. The authors refer to the framework as “complex value optimization for resource recovery”.

![Fig. 1. Frameworks, methods and tools used to appraise aspects of the domains of resource value](source)

The social metrics or indicators that reflect health implications are: occupational safety, system safety (accidents), not in my back yard (NIMBY) syndrome, noise and odour. All raise health concerns in the segments of the population concerned and affect well-being.

A sustainable assessment performed by integrated modelling (16) provides an illustrative case study of resource recovery from waste. The authors used the “complex value optimization for resource recovery” approach and demonstrated its practical use for assessing changes in value among regions and sectors in transformation towards sustainable energy resources. The approach offers a practical alternative to an assessment of life-cycle sustainability.

### 1.2 Methods for assessing solid waste management

A review of the literature on methods for assessing solid waste management in 2014 (17) showed that the method used most frequently in 151 relevant studies was LCA (41%), followed
by benchmarking (14%), multi-criteria decision-making (10%), risk assessment (7%), CBA (6%), combinations (8%) and others (14%). The studies proportionally represented assessment of treatment plants, waste streams and urban, rural and national systems. The software most commonly use is also described.


HIAs have often been used indirectly for more detailed structures at “recover” or end-of-life stages, when the usual strategy is to evaluate the necessity and efficiency of the treatments used in order to return materials safely back into the cycle. This topic is covered in section 1.6. Health risk assessments and HIA are the dominant methods for identification of health implications and their further economic assessment.

1.3 Framework for water in a circular economy

More tailored assessment methods are often used at sectoral or regional level with a specific material flow because of the extent of the impacts. An example is a sustainable indicator for wastewater management in the paper industry proposed by Molina-Sánchez et al. (19). A recent publication by Nika et al. (20) brings a holistic view to bear on the whole water cycle in a CE and proposes a “circularity assessment framework for complex water systems”. Voulvoulos (21) explored water reuse from a CE perspective and pointed to the potential risk of an unregulated approach, with no direct link to the economics of health. A compilation of studies by the United Nations Economic, Scientific and Cultural Organization (22) on water reuse in the context of CE describes the public health concerns and health risks associated with different type of water management; however, the economics are related only to the technology and market prices of water. The impact pathway from recycled water to contamination of food and feed and consequent impacts on human health can be studied with the method for “risk ranking for prioritisation of food and feed related issues” developed for the European Food Safety Authority (23). The method provides a tool for risk managers who seek a convenient method for comparing certain health risks and, in some cases, also economic appraisal in monetary terms. A subsequent, partly analogous situation is the case of wastewater sludge treatment in a CE, as microplastics, pharmaceutical residues and heavy metals are concentrated, especially in and around urban agglomerations. More detailed information is provided in a review by Gherghel et al. (24) on possible valorization of wastewater sludge and the challenges in the context of a CE; only the costs associated with treatment technologies and their operation are presented. The publications cited above are just examples from the current literature, in which health issues are not appraised economically, indicating opportunities for future work in establishing an evidence base for value-balanced decision-making.
1.4 Framework for a waste-to-energy system

Waste-to-energy is the most effective concept for disposal of hazardous and un-recyclable material. Modern incinerators have significantly improved disposal and reduced emissions, thus reducing the negative impacts on human and environmental health. A recent compilation of studies on waste-to-energy and other CE practices (25) addresses multi-criteria decision analysis for assessing sustainability and ranking of CE approaches and resource recovery from waste technologies in the East Asian context. A framework for waste-to-energy systems proposes a link between sustainability indicators and the LCA phases of the waste treatment cycle (26).

A multidimensional framework is illustrated in Fig. 2. The health implications are under the social dimension. The socio-environmental intersection is not designed exclusively for nongovernmental organizations targeting waste prevention or littering but is an important point of convergence for public health experts and the lay public in risk communication, which is covered in section 5.

![Fig. 2. Social indicators and factors in a proposed life-cycle analysis framework](source: Reference 26, Fig. 5, p. 805. Reproduced with permission of Elsevier.)

The life-cycle is becoming the key concept for strategic multicycle efficiency of material use and assessment of sustainable energy sources. Practical life-cycle sustainability assessments represent a comprehensive approach to three methodological challenges (16):

- lack of a systematic approach for combining a life-cycle perspective with a triple bottom line (economic, environmental and social dimensions) as proposed by Chong et al. (26);
- capturing mutual interdependence of the dimensions; and
- capturing the conflicting interests of stakeholders to ensure evidence for transparent decisions.

Walzberg et al. (14) reviewed the strengths, weaknesses and limitations of the life-cycle
approach. Despite the above-mentioned challenges, the approach appears to play a substantial role in CE assessments, as they cover repetitive life-cycles, and the second step in LCA is life-cycle impact analysis (LCIA), which has both health and environmental components. Application of waste-to-energy can be expected in the health-care sector, which has specific waste management requirements and limited possibilities for recycling, especially of infectious waste. General promotion of the waste-to-energy approach is not, however, desirable because other, better means for material recovery are available in the waste hierarchy.

1.5 Health in macroeconomic modelling of a circular economy

Macroeconomic modelling also addresses the impact on health of the transition to a CE. The indirect effects on health and health-care expenditure are linked to air pollution from energy consumption. The European Topic Centre on Waste and Materials in a Green Economy published a report on systemic modelling tools to assess the transition to a green economy (27). Computable general equilibrium models of transition and causal loop diagrams provide a complex view of the system dynamics applied to technological change, population ageing and fiscal sustainability. The causal (or feedback) loops either reinforce the effect of the intervention or balance it towards equilibrium. The tool offers a systemic view of the transition, the effect of changes in variables and the relations in the system. The changes in health and health-care expenditure are linked to emissions from energy consumption. The impact of air pollution on health was chosen, as it represents the exposure that is most difficult to control. Thus, the energy efficiency of material and resource recovery through various cycles should be carefully controlled in order not to waste the opportunities of the CE.

Although more attention is being paid to the waste management and recycling sector due to its role in the CE, according to a working paper by the Organization for Economic Co-operation and Development (OECD) on macroeconomics of the CE transition (28), material recovery and waste management were poorly represented in multiregional quantitative models used to assess a CE transition, and they indicated that the absence of such models prevents further modelling of the impacts of enabling policies, including a landfill tax and gradual limitation of landfilling by 2030 within the European Union (EU) and recycling quotas. Although the models differ in initial categorization of waste management, all recent models aggregate waste management with other activities, public services and other types of manufacture. The most promising model for waste-related activities appeared to be the EXIOBASE, as it included individual sectors for waste collection, incineration, disposal and metal and non-metal recycling. The quality of the source data for this model was not, however, reviewed, and the health-related effects are therefore unknown until environmentally adjusted indicators are included. The impact on gross domestic product (GDP) was modelled as neutral or slightly positive; however, GDP is not considered the best metric for CE performance, and assessments of a “green GDP” are being considered to capture changes in natural capital stocks and ecosystem services, which represent the main benefits of the CE approach.
The waste and resource recovery sector has direct and indirect impacts on human and environmental health due to complementary logistics services. Exposure to air pollution gives low estimates of the economic effect on population health because possibilities for actually controlling the intake of the pollutants are limited. Circular approaches could change the total amount and distribution of outdoor air pollution across regions and thus the actual distribution of health impacts. Another OECD report, on the economic consequences of outdoor air pollution (29), describes use of the computable general equilibrium model for projecting total welfare costs of market impacts, including the waste sector. The projected costs are linked to either GDP or welfare in general, as GDP alone is limited. Badulescu et al. (30) analysed the relative effects of economic growth, environmental pollution and noncommunicable diseases on health expenditure in EU countries between 2000 and 2014 in order to determine their long-term and short-term relations. The strongest influences on health-care costs in all EU countries were short- and long-term economic growth. According to the OECD study on macroeconomics (28), however, the transition towards a CE is not correlated with significant economic growth.

### 1.6. Health and indicators of sustainability in a circular economy in a microeconomic assessment

A microeconomic assessment of sustainability in the CE showed substantial analogy and partial overlap of topics with circularity metrics. A review of 58 indicators of micro (company-level) and nano (product-level) indicators by de Oliveira et al. (31) shows the broad diversity of products and processes in circulation. The authors systematically reviewed circularity indicators according to their:

- life-cycle stage (take, make, use, recover),
- target level (micro-company or nano-product) and
- sustainability and triple bottom line coverage (environmental, social and economic).

Only one proposed indicator, the circular business model based on sustainability (32), covered the full cycle, the nano and micro levels and all three sustainability pillars. Health issues were covered by the sub-indicator “reduction of toxic substances”, and the health implications were generally minimally covered, either under the social pillar as an issue of occupational health and safety or under the environmental pillar as an issue of human toxicity. The two health-related sub-indicators were covered by one product recovery multi-criteria decision tool (33) and the complementary multi-criteria evaluation method of product-level circularity strategies (34), in which environmental human health toxicity was assessed qualitatively and occupational risk quantitatively. Table 1 lists the key decision criteria and sub-criteria of Alamere et al. Although waste ratios and material flow sub-indicators were mentioned frequently, neither was covered directly by one compound indicator.
Table 1. Decision criteria and sub-criteria

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Criterion</th>
<th>Sub-criterion or indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantitative</td>
<td>Environmental</td>
<td>Life-cycle analysis, end-of-life impact indicator, human health, ecosystem quality, resources</td>
</tr>
<tr>
<td></td>
<td>Economic</td>
<td>Life-cycle costing, disassembly cost, net recoverable value, logistics cost, end-of-life treatment cost</td>
</tr>
<tr>
<td>Qualitative</td>
<td>Social</td>
<td>Job creation opportunity, exposure of employees to hazardous materials, level of customer satisfaction</td>
</tr>
<tr>
<td></td>
<td>Legislative</td>
<td>Effect of legislative pressure, compliance with new and existing legislation</td>
</tr>
<tr>
<td></td>
<td>Technical</td>
<td>Technical state, availability of recovery facilities, separability of materials, advances in technology, presence and removability of hazardous content</td>
</tr>
<tr>
<td></td>
<td>Business</td>
<td>Market demand, competitive pressure, return core volume</td>
</tr>
</tbody>
</table>

Source: adapted from reference 34. Reproduced with permission.

In order to harmonize and standardize assessment of products and organizations on the European market, the European Commission launched the “Product environmental footprint and organizational environmental footprint” project, with a method based on LCA architecture standardized in ISO 14040/44 and linked to ISO 14025 (Environmental labels and declarations — Type III environmental declarations — Principles and procedures). The pilot phase was evaluated and commented on by Bach et al. (35). The main method for assessment of toxicity is the LCIA, which is continuously updated to meet the strategic goals of the category rules. LCIA is further described in section 2.

1.7. Recycling and the market for secondary materials

The traditional perception of recycling as reintroduction of residual materials into production processes has become more fragmented by the CE, and certain segments are related more closely to health concerns than others. The main challenges for the modern recycling sector are reintroduction of hazardous substances into the production cycle and the demand for energy and other resources and thus the emergence of new effects on the environment and health.

Efficient use of resources is linked to the concept of cleaner production, which was introduced earlier. Achievement of efficiency of material and energy resources in processes requires not only careful use of resources but also replacement of hazardous resources. This is a positive impact of the CE on reducing impacts on the environment and health.

1.7.1 End-of-life chemical releases and health

Emissions of pollutants into the environment during resource recovery from wastes are the main causes of damage to health. Risk
assessment of chemical pollutants is challenging because of the large number of uncertainties involved. In a review, Hernandez-Betancur and Ruiz-Mercado (36) critically analysed the indicators of sustainability in end-of-life chemical releases and potential exposure. “End-of-life” refers to the end phases of a product’s life-cycle, and the study addressed the recycling, recovery and disposal phases from a CE perspective. Apart from chemical releases due to disposal in landfills, they found 22 assessments of human health risk and 10 studies on e-waste end-of-life activities. The hazard quotient, the hazard index, carcinogenic risk and chemical intake were reported in many studies. Uncertainty about the composition of chemical waste from different sources favoured use of hazard indexes, which allow aggregation of risk. Most of the indicators of the sustainability of chemical risk were derived from methods of the US Environmental Protection Agency; however, no further analysis was conducted of the monetary value attributable to the risks. The concept of sustainability and end-of-life is a prerequisite for building trust in a safe, healthy CE based on resource recovery.

1.7.2 Legislative framework for hazardous substances in a CE

Delgado et al. (37) discussed guidance with regard to the legislative and regulatory framework for recycling and the secondary material market. The term “end-of-waste” refers to the steps and costs of the procedures necessary in order to comply with all legal requirements in turning waste back into usable materials. Recent nongovernmental organization recommendations on end-of-waste published by the European Environmental Bureau (38) emphasize the preferred hierarchy of waste management, which gives preference to assessment of waste management scenarios in the broader context of a CE. The structure for assessing impacts on the environment and health is analogous to that proposed for LCIA, in which human health is one of three end-points that need not be monetized; however, the document recommends monetization in order to weigh the benefits and costs of a final proposal.

The project led by the Environment Agency in the United Kingdom under the EU Life programme is more regionally focused. Its aim is to provide the practical and technical information necessary for a preliminary statement of scope, an advanced impact assessment and a feasibility study for recycling or substituting products and materials with hazardous content; however, the guidance for assessment (39) and the description of procedures indicate the practical tasks involved. Current practice was introduced in the first case studies by Bodar et al. (40) on management of hazardous substances in waste streams and deciding whether an additional risk analysis is necessary when waste is turned into material. Bodar and colleagues selected three case studies and analysed the impacts of legislative regulation on the secondary market in hazardous substances. The missing link between legal obligations deriving from the EU Registration, Evaluation, Authorisation and Restriction of Chemicals and the Waste Framework Directive creates barriers to biochemical recycling sectors while providing solutions for environmentally questionable activities or ignoring the hazardous “legacy” of the built environment. The studies demonstrate the limited scope of an extended CE market with repeating material cycles and substitution.
of chemicals. Thus, reuse of hazardous materials should assure effective end-of-life treatment and re-use in future cycles. The authors therefore proposed a new, extended role of registration, evaluation, authorization and restriction of chemicals in assessing the second and further life of banned or restricted chemicals and introducing safer alternatives to sustainable circular product design. The authors also pointed out progress in LCIA, which offers the most practical solutions for the CE with regard to risk management through environmental and health impact assessment. Concern about practical implementation remains, however, as also discussed in a position paper by the European Environmental Bureau (41).

The scattered evidence for the health implications of CE actions poses a challenge for monitoring and for health protective measures, not only during the transition period. The health implications should be communicated in a coordinated way, as proposed in the evidence-to-decision framework developed by WHO, in which the aim is to ensure that all the criteria relevant to a decision about health are considered systematically (42). Systematic collection and monitoring of relevant evidence are further integrative tasks. The HiAP approach is a supportive concept, with a platform for integrating health issues into decision-making (43) at country level and guidance on acting on sustainability values in the transition to a circular, climate-neutral economy.

Discussion

Although health and well-being are recognized goals of sustainable development, the CE, centred on material flow, does not directly include health implications. The numerous metrics and indicators used in holistic approaches and frameworks do not offer sufficient insight or evidence for making responsible decisions about implications for health, which are often included among environmental and social criteria of sustainability. The economic impact is associated more closely with the technical dimensions. Monetization of health impacts is recommended in assessments in which the costs and benefits of proposed solutions are weighted. Macroeconomic modelling incorporates health and health expenditure dynamics marginally in relation to the CE, but no further evidence on the health implications of transformation of the waste sector is available. Regulation of chemical releases and issues related to circulation of recovered materials containing potentially harmful substances is still being revised, as legislative and methodological uncertainties persist. The public sector could take advantage of the HiAP coordinated approach to health promotion as a responsible solution. Monetization of health implications provides a common language for communication with stakeholders in the private sector and for assessing the significance of the trade-off between environmental and socio-economic or other determinants of health.
LCA is currently the main method used for assessing sustainable waste management practices in the context of a CE. This section addresses the topic of HIA in LCA, in its second step, LCIA. For health assessment practitioners, this offers insight into a model with some simplifications but which allows cross-scenario or cross-regional comparisons. Major LCA monetization methods are presented, and the methods are compared in a hypothetical example. The underlying values of the methods are analysed in detail, with references to the original methodological literature. The section concludes with links to recent data on selected LCA monetization methods.

Despite the limitations of LCA and derived methods for analysing health implication and economics, the method offers the most advanced information on the basic health impacts for further health and economic assessments (44). The European Environmental Bureau (41) recently issued a position paper on the environmental impact of recycling chemicals based on LCA methods, in which the uncertainties in use of LCA results in making decisions are analysed. The quality of health assessment was not criticized, as LCA is not considered a reliable method for health-related decisions.

The LCA community is aware of the limits of the analysis and has also expressed concern about implicit prioritization of risks by environmental scientists in the past few decades. Owing to the complexity of LCA and the issue of weighting (see section 2.2 on monetization methods in LCA) different mid-point impact categories, the implicit shift in prioritization of research topics dilutes the health implications in the CE. Extensive LCA studies published between 1995 and 2014 demonstrate a clear trade-off of the exclusive health theme for a climate change theme (45). Fig. 3 shows a five-topic model, in which a relatively strong association is seen between health topics and risk topics, with systematic description of the process of analysis. It should be noted that the health theme does not disappear but just loses its exclusivity and has been incorporated to a certain extent into related environmental topics such as climate change.

The waste theme retains its share throughout the period. Since 2007, exclusively health outcomes have been absorbed almost completely into the other themes. This trend is also observable as the environmental impact of the CE, and EU legislation on waste presents outcomes as reductions in greenhouse gases (46). Consolidation of scattered health-related evidence is becoming a serious challenge for future monitoring of LCAs of the health implications in the context of the CE.
2.1 Life-cycle impact assessment

The LCA approach has many desirable qualities for assessing circularity and sustainability (47). The long-term strategy for sustainable waste management is to minimize and control the circulation of hazardous substances in the production and service cycle. In the impact assessment phase of the LCA, LCIA, the results of previous phases are associated with categories of environmental impact. The LCIA has been improved continuously in the past few years and has become established in European policy as a leading method for evaluating the toxicity of products in order to control sustainability in the CE (35). The LCIA translates values for emissions and resource extractions into a limited number of environmental impact scores through so-called characterization factors, which indicate the environmental impact per unit of stressor (e.g., per kg of emission released) (48).

Currently, there are two main ways of deriving characterization factors — at mid-point, along the cause–impact pathway, and at end-point. Simplified relations among elementary flows, the mid-point and the end-point are illustrated in Fig. 4. At the end-point, these factors reflect damage to three AoPs: human health, ecosystem quality and resource scarcity. The original publication in the European Commission Joint Research Centre International Reference Life Cycle Data System Handbook (49) recommended use of impact assessment models in LCA, which was the basis for the recommendations of the Product and Organization Environmental Footprint project and EU and European Commission recommendations for a common method for evaluation of the environmental performance of products and organizations and establishment of the single market of green products. This example of upstream control of resource use and minimization of health and environmental impacts eventually led to end-of-life sustainable practices.
The Handbook provided detailed reviews and exhaustive assessments of the most promising methods for the highly complex LCIA (50). For every impact, relevant methods for further assessment were selected in various categories to identify the maturity of the methods for harmonized use of LCIA. The end-point for the AoP of human health has a single metric — DALYs. Further European Commission Joint Research Centre publications identify new updates and outdated methods and approaches. The most recent method for assessing life-cycle damage in the LCIA family of methods is LC-IMPACT (51), which includes some of the most recent methodological developments and improvements in LCIA models, in particular with regard to spatial differentiation. Other methods are ReCiPe2016 (48), developed by the National Institute for Public Health and the Environment, Netherlands, and IMPACT World+ (52). The impact on human health in the LCIA is expressed as annual DALY/capita. Bulle et al. (52) provide a comparison of ReCiPe and Impact World+ for assessment of human health impact. IMPACT World+ can be used optionally to obtain a single monetized score.

Simone et al. (53) at the European Commission Joint Research Centre published an updated version of the International Reference Life Cycle Data System and evaluated the level of maturity of the recommended models and methods. The models at mid-point for impact category
“ozone depletion and particulate matter/respiratory inorganics” are fully recommended. The models for “ionizing radiation — human health” and “photochemical ozone formation — human health” are satisfactory but require improvement. Models at the mid-point for “human toxicity — cancer and non-cancer effects” should be improved and used with caution. Temporal issues in LCA and LCIA were reviewed recently (54).

LCIA methods are updated continuously in accordance with the current state of knowledge. As they are built on a number of assumptions and simplifications of environmental mechanisms inherited from the original models, they should be interpreted carefully.

2.2 Monetization methods in life-cycle assessment

The following section is based on a recently published comparison of monetization methods in LCA (55), in which the authors analysed various methods for monetization: Ecovalue12, Stepwise 2006, LIME3, Ecotax, Eco-cost/Value Ratio (EVR), Environmental Priority Strategies (EPS), Environmental Prices, Trucost and Milieugerelateerde Materiaalprestatie van Gebouw (MMG) (Table 2). The monetary values derived for the illustrative annual environmental damage by an average EU citizen range between two orders of magnitude for the same impact factor. Six methods provide monetary values for effects on human health. Four of the methods used the damage cost perspective in the non-market WTP approach, which is based on the contingent valuation method in the New Energy Externalities Development for Sustainability project. LIME3 used data from the Discrete Choice Experiment in G20 countries, in which WTP was sought for a tax to reduce DALYs. EPS and Stepwise are based on the human capital approach. The underlying values were of the same order of magnitude.

Table 2. Underlying values in methods for monetizing the human health AoP in relevant impact categories

<table>
<thead>
<tr>
<th>Method</th>
<th>AoP human health</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMG</td>
<td>53 363.5 €\textsubscript{2012}/DALY</td>
</tr>
<tr>
<td>EPS</td>
<td>50 000 €\textsubscript{2015}/years of life lost</td>
</tr>
<tr>
<td>Trucost</td>
<td>Based on New Energy Externalities Development for Sustainability project [corrected for global average income (value not disclosed)]</td>
</tr>
<tr>
<td>Ecovalue</td>
<td>Not explicit at least for acidification and eutrophication but includes well-being</td>
</tr>
<tr>
<td>Stepwise</td>
<td>Ability to pay 74 000 €\textsubscript{2003}/QALY</td>
</tr>
<tr>
<td>LIME3</td>
<td>23 000 US$/\textsubscript{2013}/DALY</td>
</tr>
<tr>
<td>Environmental prices</td>
<td>55 000 €\textsubscript{2015}/DALY</td>
</tr>
<tr>
<td></td>
<td>Mortality: 50 000–110 000 €\textsubscript{2015}</td>
</tr>
<tr>
<td></td>
<td>Morbidity: 50 000–100 000 €\textsubscript{2015}</td>
</tr>
</tbody>
</table>

Source: adapted from reference 55. Reproduced with permission.
When the monetization methods were tested with respect to the domestic yearly environmental damage caused by an average EU citizen, the highest estimate was 35 times higher than the lowest. No comparative analysis has been conducted of the share of costs due to AoP human health.

Fig. 5 (b) shows that each method prioritizes different categories. Therefore, the choice of monetization method will affect the final monetary value. To obtain more reliable results, several methods should be used in order to exclude sensitivity to the choice of method and ensure correct selection. If the method does not cover the crucial impact categories for the subject being assessed (e.g., land use in the case of projects on bioenergy vs fossil energy), the results will be disproportionately undervalued. When the AoP human health is to be studied, the methods with the highest share of the impact categories particulate matter (PM), human toxicity, ozone depletion and ionizing radiation should be included. A high proportion of climate change impact (EPS, Ecovalue, Stepwise) with implicit inclusion of health impacts could result in a higher value for AoP health than previous, almost exclusively health-related mid-point impact categories.

**Fig. 5. Monetary damage per capita and year (average EU citizen) obtained with different LCA monetization methods in € (a) and the respective proportion of the total value in percentage (b)**

Comparison of methods for monetizing the human toxicity impact factor shows that there must be an effect in the underlying toxicity assessment. Despite the high underlying value of DALY in Stepwise, the results are relatively low. More variation is involved in monetization for ozone depletion. The sources of variation are use of non-marginal values.
(EPS) and inclusion of damage to working capacity. Another source of variation is the time perspective, as the values are sensitive to the underlying reference scenarios. PM has impacts mainly on human health, and the calculated damage depends strongly on the exposed individuals and thus on transport models and population density. All the methods with a damage cost perspective showed similar valuations of human health; however, the results differ due to differences in conversion rates of damage from PM$_{10}$ and PM$_{2.5}$ and generally different impact assessments and geographical references.

The differences in the three main impact categories can be summarized as follows. The monetization methods were sensitive to geographical scope. Thus, the richer the region, the higher the values calculated, and the effect of geographical scope on the results was greater than discounting. The general trade-off is universal applicability and global monetization methods vs site-dependent, more meaningful results. As LCAs are usually regional, the monetary values should also be region-specific. Although it is possible to use benefit transfer for WTP estimates, a region-specific study is always preferable. The differences described show the importance of deliberation in selecting monetizing methods for LCA and, if possible, use of more methods to ensure the robustness of the results.

Although the underlying values per DALY are based on different valuation methods, they are similar, indicating that they are not the main source of discrepancy between different LCA monetization methods. Nevertheless, LCA based on regional data might provide more relevant results (see section 4.1.1).

2.3 Recent updates of monetization methods

The original estimates were derived from an EU-funded project, New Energy Externalities Development for Sustainability (56), which set a standard for full evaluation of the costs and benefits of a national or EU energy sector in LCA macro-level analysis. The externalities and associated costs from the project ExternE were included. The non-market valuation methods dominated in valuation of health and environmental context as they better reflect the wider societal perspective of welfare loss. The main metrics used in these projects were value of statistical life (VSL) and value of life year (VOLY). The publication Shadow prices handbook: Valuation and weighting of emissions and environmental impacts by de Bruyn and Korteland (57) summarizes and discusses all possible valuation methods, including those from the New Energy Externalities Development for Sustainability project, and presents the ReCiPe approach to use of the monetary value of a DALY. As the Shadow prices handbook offers methodological alternatives to valuation of human health-related end-points, the monetizing methods were differentiated methodologically. The most recent updates of Environmental prices (58) and MMG (59) introduced monetization of human health metrics, a new interpretation of the results of the New Energy Externalities Development for Sustainability project, use of the Lancet cost-of-cancer study into valuation (60) and a new literature review on VOLY. Martinez-Sanchez et al. (2017) estimated costs for evaluation of externality in life-cycle costing of municipal solid waste management systems.
Discussion

The LCA method is influenced by trends that favour specific sustainability themes. Thus, the assessment is currently fragmented into several themes, making the method difficult to use for accurate HIA. The results provided by LCA monetization methods vary for several reasons, not only in the underlying economic values but also from previous LCIA models. Methodological differences in the monetization methods analysed did not substantially influence the total assessments but played a role in economic assessment of the health implications addressed. Thus, for better understanding of current possibilities for health valuation, the contributions of environmental and health economics should be introduced into health-related decision-making.
Waste management has impacts on health that directly or indirectly affect the economic situation of individuals and society. The impact may be positive or negative in economic terms, representing costs paid or benefits accepted by individuals and society. The costs and benefits associated with health implications do not affect their originator (i.e., the waste sector) and are thus not included in the market prices of the waste services. Negative impacts are known as “negative externalities”, and the costs associated with them are called “external costs”, because the payer cannot control them and must bear them involuntarily. The concept of externalities is studied in environmental economics and became known to policy decision-makers when addressing the negative health impacts of environmental pollution, especially air pollution.

3.1 Monetization of health-related externalities

As the CE directs more attention to the original causes of unsustainable practices with respect to material- and energy-related externalities, attention shifts to regulation that affects upstream processes, which promises greater efficiency and co-benefits globally. In a hypothetical example from the waste sector, if interventions such as introduction of a landfill tax motivate the originators of waste to sort unused material and seek opportunities on the market of secondary materials, the material is reduced in the waste stream, also reducing externalities to the environment and society. Co-benefits can be calculated in terms of the opportunity costs of waste management and of new customers that use the secondary material instead of new material. In the long run, the intervention will decrease a requirement for landfills and thus eliminate the negative externalities assigned to their operation.

Monetary quantification of externalities has a particular purpose in policy intervention: to introduce an economic instrument that compensates for the loss to societal welfare; however, externalities also affect individual well-being. Economists are aware of shifts in perception of the terms “welfare” and “well-being” (62) and their role in sustainable economic development. Nevertheless, the definition of well-being in the economics of health-related implications is generally consistent with the new WHO definition (4). The health and well-being of individuals and society are common values that are mutually dependent in all available definitions; however, for consistency with the theory of the methods and the source of Fig. 6 (29), the change in cost categories, including “disutilities”, is addressed as a change in welfare.
The structure of the economic impact of health-related externalities is more complex, as seen in Fig. 6, where individual and societal perspectives of health impacts are seen from a broader perspective. Externalities comprise a large group of impacts, in which health-related damage is only one theme and is usually interdependent to some extent with environmental, social and purely economic themes from determinants of health.

3.2 Externalities from waste in a circular economy

The external costs of the health implications of waste are estimated by measurement of air, water and soil pollution from waste management activities; however, the circular approach accounts for externalities from other sources of pollution due to inefficient upstream processes. The vision of sustainable waste management in the CE starts further upstream and extends to the origin of all externalities. In order to minimize externalities, multilevel pathways have been defined. The main focus is on prevention of waste generation throughout the chain and, eventually, decreases in most unused material from waste streams by reintroduction into the production process. Although health risks and benefits are not explicitly mentioned, they underlie all CE activities as inherited from previous stages of sustainable development.

3.2.1 Evolution of economic assessment of health impacts

Fig. 6 also provides a scheme for evolution of economic assessment of health impacts with the addition of more perspectives. Direct market costs were given a societal perspective by adding indirect market costs, referred to as the original cost of illness (COI). When the non-market valuation methods were introduced, WTP for pain and suffering was added, and

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**Fig. 6. External costs related to health**

the method named extended COI or COI+. Such additions must, however, be made with care to avoid double counting. This issue is discussed in more detail by Robinson et al. (63) in their recommendations for CBA and also by OECD (29), with air pollution as an example.

COI reference values can be obtained from the WHO project on CHOosing Interventions that are Cost–Effective (CHOICE) (64). The costs of different types of cancer were well documented in a population-based analysis in the EU in 2013 (60). The most comprehensive COI data for 28 countries provide separate estimated costs associated with breast, colorectal, lung and prostate cancers. The societal perspective includes direct health-care costs, informal care costs and productivity losses in an annual timeframe fixed to 2009 prices and adjusted to the purchasing power parity of the countries involved. The study of Luengo-Fernandez et al. (60) was used to monetize part of LCIA human toxicity in an LCA monetizing method and therefore does not include all cost categories.

Non-market costs can be obtained by several techniques, such as stated preferences and revealed preferences methods, and the WTP for avoiding certain disease, health risks or health-related disutility can be assessed. Although WTP estimates do not directly use COI data, it is assumed that the costs can be included implicitly in the hypothetical scenario. A VSL covers the value of the whole box shown in Fig. 6.

The WTP for exposure to hazardous materials should be mentioned with regard to the health implications of the CE, which is included in the socio-economic analysis of registration, evaluation, authorization and restriction of chemicals. In this analysis, the whole morbidity cost category (including disutility), the value of cancer morbidity and the value of statistical cases of cancer are included. The econometric procedures behind the estimation and the final recommended estimates are available on the European Chemicals Agency web portal (65, 66). It should be noted that VSL is a statistical summary unit and not the price of an individual life. The concept of VSL and related metrics have been widely adopted by policy-makers for assessing health-related interventions and is further described in section 4.

3.2.2 Limits of the control-and-command approach

The long-term aim of waste management regulations is to minimize the origins of negative externalities. The well-established traditional approach is applied mainly at end-of-pipe points to regulate the environmental and health impacts of final waste disposal facilities. Registration, evaluation, authorization and restriction of chemicals, strategic environmental assessments, environmental and social impact assessments and environmental impact assessments and integrated pollution prevention are effective means of control, comprising what is sometimes referred to as the “command-and-control” approach. The approach helps in establishing an infrastructure of continual inspections and substantially minimizes the negative externalities at the end of a product’s life-cycle in the linear economy. A linear economy is not sustainable, however, and the high rate of waste generation in developed and developing countries is leading to a shift in waste management practices. The shift began with promotion of recycling (waste hierarchy) and is continuing through regulation
of waste disposal, which has evolved into a CE paradigm (67).

Discussion

The externalities of waste management are interrelated with environmental health and, in the example of the impact of pollution on health, can be monetized with market and non-market values from the perspectives of the individual and of society. The methods for calculating each cost category are discussed in detail below, with a combination of non-market and market valuation methods. From a CE perspective, treatment of externalities shifts to upstream processes rather than traditional end-of-pipe and command-and-control approaches in linear economics. The economic categories of well-being and welfare are intertwined with the WHO definition of well-being, and the interdependence of these categories corresponds to the interdependence of their representation in all three pillars of sustainability (economic, environmental and social).

Waste crime could increase with increasing legislative pressure on circulation of materials, with health impacts associated with uncontrolled waste disposal. Policy-makers and regulators are challenged by new concepts and policies necessary to cover the topic of health impacts and the evidence for assessing them in a coordinated way. In increased investment by the private sector, the importance of intervention will be weighed against the benefits to human health and the environment. Health implications can be expected to be linked to changes in production and consumption patterns. The original linear “full chain” approach to waste production presented by Forastiere et al. (68) thus becomes more diversified and branched, as a CE supports not only changes in demand for resources in upstream production but also extension of technical infrastructure for downstream treatment and processing of material and other resources. This implies significant changes in the distribution of positive and negative health impacts, either directly or indirectly through changes in the determinants of health, especially with respect to the different timing and duration of these impacts for each country or region. The new distribution of these impacts will lead to both positive and negative externalities, such as changes in the logistics of distribution and circulation of materials and waste and thus the transport requirements and health implications of new waste and material processing and resource recovery facilities. The monetary value assigned to these externalities represents the benefit of any future plan, programme, policy or project for which the costs must be justified. Such economic evaluations are most often referred to as CBAs but which no longer address only costs and benefits in the original sense of finance and accounting. This is a very flexible tool with a strong role in evaluation of the health implications of waste in the context of a CE.
The CBA method has been used as a general approach for balancing costs and benefits in monetary values. Finding an appropriate monetary value for “benefits” has been a challenge for several decades, especially for non-market goods such as health and environmental health. The CBA is therefore currently used to refer not only to CBA in its original financial context but also to a large group of input–output analyses for economic evaluation with monetary units. The most common alternative is CEA or, less commonly, cost–utility analysis, which balances costs with other, non-monetary values or utilities. The QALY is used in assessing changes in health state in CEAs. Environmental economists tend to use CBA, in which the value of health-related risks and damages is estimated by non-market valuation methods. The CBA is used in occupational safety and health to provide supportive evidence for investments related to a reduction in fatal risks. CBA has thus become a recognized tool for complex decisions not only in the health sector but also in the protection and promotion of public health. As health topics are on the benefits side, non-market valuation methods are often used and, as monetary units are used, the monetary values of market and non-market valuation methods tend to be aggregated. This is possible, however, only under certain conditions.

As health benefits are often long term, any financial input, e.g., in the form of investments, appears on the “cost” side. The time perspective thus introduces discounting into economic evaluations for both the input (investment) and output (health benefits) and introduces other topics for economic evaluation, such as future impact and return on investment. Detailed recommendations and practical examples are provided by Robinson et al. (9) and publications of the WHO Regional Office for Europe (69).

4.1 Allocation of costs for health

The usual question is: “How much money can we spend to protect and improve health?” CBAs are developed to support such decisions in order to allocate resources to health protection and decide on a budget for a health-related policy or intervention. A recent publication, Reference case guidelines for benefit–cost analysis in global health and development, by a collaboration of academic experts, practitioners and other stakeholders (9) cites specific references to recommend high-quality, comparable analyses in high- as well as in middle- and low-income countries. The guidelines make specific recommendations for evaluating reductions in risks for mortality and non-fatal health outcomes. Other topics include assessment of distributional impacts, dealing with discounting in temporal issues and accounting for uncertainty and non-quantifiable impacts.
Another common question is: “How can we protect or improve the quality of health?” The answer may be derived in a CEA, which is used to determine the specific actions or combination of actions in a portfolio that deliver the best value within given budget constraints (70).

CBAs address the societal perspective in allocation of resources (63). In the case of waste management, the question is: “How much money can we spend to protect the population from health risks associated with waste during transformation to a CE?”

The CEA indicates which intervention or technology for waste in a given situation provides the best ratio of health-related outcome to cost or whether the proposed intervention or upgrading of technology will adequately improve the chosen health metric. The CEA has a place at every stage of assessment, as it allows ranking of preliminary assessments of interventions or scenarios.

An updated version of Monetary valuation of trace pollutants emitted into air by industrial facilities by Nedellec et al. (71) presents a calculation and comparison of the damage costs of the main air pollutants and of so-called “trace pollutants”, which are emitted in relatively small quantities during combustion but are highly toxic. Nedellec and colleagues also provided estimates (Table 7, p. 27) of damage costs based on emission limits for waste incineration and set limits on the emissions of the major pollutants and trace pollutants in an illustrative example for achieving a damage cost equal to 1 €\textsubscript{2013} per tonne of incinerated waste (mg/NNm\textsuperscript{3}). This indicates possible optimization of sectoral regulation with a CEA that goes beyond the general national limits or the National Emissions Ceilings Directive (72).

Use of the CEA to address equity with regard to prioritization in health-care programmes is reviewed and analysed by Cookson et al. (73).

4.1.1 Cost–effectiveness thresholds

CEA in health-care settings is associated with cost–effectiveness thresholds, which are introduced to account for limited resources in a health-care reimbursement system in order to allocate resources most effectively. The thresholds represent the minimal effectiveness that must be achieved by a new technology or treatment in order for it to be included in a reimbursement scheme. The threshold provides an answer to the question: “Is the new treatment or technology efficient enough?” The meaning of cost–effectiveness thresholds and their practical use are described by Culyer (74). The political and social dimensions of a correct, fair threshold have usually been left to international authorities, such as the WHO-CHOICE guideline, which combines thresholds with GDP (75, 76).

Ongoing discussion on the appropriate value of threshold(s) raises practical and ethical questions (77), particularly with regard to publicly financed health care. Thokala et al. (78) comprehensively described the history, current practices and future prospects of cost–effectiveness thresholds and critically reviewed the heuristic approaches of implied and unspecified thresholds used previously in health technology assessment (HTA) agencies. The two main approaches are supply-side opportunity cost (system under budget constraint) and a demand-side societal WTP approach (79–81) derived from EQ-5D\textsuperscript{1–3} based gains in QALY.

\textsuperscript{1} Groups of questionnaires developed by the EuroQol Group
The key issue in choosing a supply- or demand-side approach is that the demand-side thresholds derived from the WTP estimate yield higher values per QALY and might thus improve health outcomes in the health-care system. This effect is similar to that related to a GDP-based WHO-CHOICE threshold, as reviewed by Bertram et al. (82).

The demand-side approach reflects current trends in health metrics and the shift towards well-being measures (83). An approach based on revealed preferences was introduced recently, which is referred to as the “well-being valuation” approach. The main differences between the WTP-based approach and well-being valuation and their strengths and weaknesses are described by Himmler et al. (84), who also address the empirical issues in estimating the alternative to the QALY, “year in full capability well-being”, based on individual data on well-being. “Capability” does not refer only to the physical components of health but is assessed primarily as individual well-being at older ages or when physical deficiencies (e.g., hearing, vision) can be compensated for effectively. This trend appears, however, to be related primarily to health-care decision-making and less to related fields such as HIA.

The supply-side opportunity cost approach is based on estimated DALY thresholds, as it is consistent with the DALY expert-weighting concept. The approach is based on an econometric estimate of elasticity in health-care expenditure and thus reflects practical possibilities within a health-care system. Use of this approach should, however, be considered carefully for countries in which the health-care or public health sector is chronically underfunded or the capacity, financing or accessibility show major deficiencies.

Issues in the opportunity cost approach, including recent progress, are discussed by Ochalek et al. (85), who provided interim estimates for costs per DALY averted for 33 high-income countries and the remaining OECD and BRIICS2 countries, with indications of current challenges and the required research. The main requirement is for national data on the performance of the health-care system. Although the approach covers only the objectives of the health-care system, the opportunity costs represent the net effect for other societal objectives. The theory of further application of thresholds in a broader societal context was developed by Remme et al. (86). Estimates of the monetary value per DALY thresholds for low- and middle-income countries based on the supply-side approach were derived earlier by Ochalek et al. (87).

The Shadow prices handbook (57) provides a demand-side estimate of DALY and also draws attention to the breakdown of DALY (see section 4.2 on health metrics) and specifically the relation between estimated VOLY and the years-of-life-lost component of DALY. This implies the limits of DALY for monetization based on VOLY. For the health end-point, use of VOLY would appear to be justified when years of life lost dominate or only for years of life lost (terminal short disease or fatal incident). For end-points in which years lost due to disability dominate and represent acute damage to health, the actual cost of disease may yield slighter higher values than VOLY weighted by disability.

Thresholds set ceilings for new treatments and health technologies, raising the issues of equity.

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2 Brazil, Russia, India, Indonesia, China and South Africa
and fairness. HTA agencies therefore tend to use intervals of values and different threshold intervals for life-extending treatments for small patient populations at the end of life. National HTA practices in the European Region are reported by Kennedy-Martin et al. (88).

CEA thresholds ensure that decisions are transparent but also raise concern about “gaming” by pharmaceutical and health technology companies in targeting the threshold in order to maximize producer surpluses.

**4.1.2 Multi-sectoral CEA with thresholds**

Thokala et al. (78) pointed out that, so far, no sector other than health care has used thresholds. The CEA threshold approach could therefore be used in a multisectoral perspective, as health determinants are strongly influenced by interventions outside the health sector. The theoretical benefits of such an approach to overall health quality and well-being were explored by Remme et al. (86).

Thresholds were introduced in the healthcare sector to ensure transparent, effective allocation of limited resources. The weakness of the approach is its strategic optimization by suppliers (health technology and pharmaceutical industries). Use of sector-specific thresholds could extend assessment of total health implications beyond the health-care sector. Currently applied integrated pollution prevention control measures are applied mainly in waste management facilities. CEA thresholds could be used to assess technologies that are not currently regulated and in which better health impacts are desirable (e.g., grey water, sludge and municipalities without water treatment).

**4.2 Valuation of changes in mortality and morbidity and other non-fatal health risks**

Several metrics are used in environmental and health economics. Environmental economists use the VSL and the VOLY, while the LCA community adds the monetized DALY or monetized QALYs when addressing only morbidity. Health and health-care economists use monetized QALYs. Most monetized values of VSL and VOLY are based only on non-market valuation methods (Fig. 7).

**4.2.1 Value of statistical life (VSL) and value of life year (VOLY)**

As shown in Fig. 7, the key concepts of monetization for reducing the risk of mortality are expressed as VSL and VOLY, where VSL is the willingness to pay for a small reduction in the risk of premature death, and VOLY represents willingness to pay for an increase in life expectancy of one additional year. VSL and VOLY are comprehensive statistical units that summarize all hypothetical preventive payments by the entire population. The sum of payments by the population is assigned to a marginal reduction in the probability of premature death. VSL was originally developed to assess fatalities in traffic accidents and occupational injuries and was later used to assess chronic exposure to air pollution. VOLY was introduced to account for the number of years at risk in order to value risks that are unevenly distributed across a population.

Premature fatalities due to chronic exposure to air pollution occur mainly in older populations, with life expectancy individually reduced by approximately 10 years in Europe. Use of VSL might therefore lead to overestimates, and thus
the concept of VOLY would appear to be more appropriate. Although the VOLY can be obtained in a stated preference study, it is usually derived from VSL. Derived estimates should nevertheless be considered with the same level of care as benefit transfers, and primary studies are preferred. In Europe, a nine-country study was conducted (89) by contingent valuation to determine the VOLY for mortality due to air pollution. Country-specific life expectancy was introduced in order to obtain realistic outcomes. Revealed preferences methods are usually used only in studies of occupational health and safety. The monetary value of incremental risk is based on a revealed preference approach derived from labour market data through the “hedonic market approach” (90). In relation to a transition to a CE, there are links to workers in the mining and extraction industries (expected decrease) and to the informal waste recycling sector in middle- and low-income countries (unrecognized transaction).

**Fig. 7. Non-market valuation methods and their practical use in the context of waste-related health implications and wider societal concerns**

<table>
<thead>
<tr>
<th>Method</th>
<th>Metric</th>
<th>Application area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revealed preferences</td>
<td>VSL/VOLY</td>
<td>Interim values due to time or resource constraints</td>
</tr>
<tr>
<td>(real markets)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stated preferences</td>
<td></td>
<td>Societal value of injuries/accidents (VSL)</td>
</tr>
<tr>
<td>(hypothetical markets)</td>
<td></td>
<td>Monetized QALY threshold (demand side)</td>
</tr>
<tr>
<td>Benefit (value) transfer</td>
<td></td>
<td>Monetized DALY threshold (demand side)</td>
</tr>
</tbody>
</table>

**Willingness to pay**

The stated preferences approach is based on surveys about WTP for the outcome in a hypothetical scenario, to avoid defined or general risk through payment. The scenario must be designed carefully to ensure that the respondents understand and provide valid answers. Current guidelines for stated preference studies are provided by Johnston et al. (91).

The revealed preferences approach is used to value non-market goods on the basis of observed behaviour and prices on related markets (e.g., change in house and land prices because of the presence of an incineration plant.
or waste facility or different compensation for jobs with a higher risk of injury). Then, econometric methods are used to identify the major influencing factors and their distribution and also bias. Aldy and Viscusi (92) provided guidelines on variation of VSL with age in the case of hedonic wages.

An alternative approach to WTP is “willingness to accept”. The main difference is in the scenario, in which the respondent does not pay for a reduction in risk but accepts compensation for an increase in risk. As willingness to accept is not relevant for pollution control policy, the approach is not further discussed; however, it remains relevant for occupational safety in waste and resource recovery from waste facilities.

**Benefit transfer**

As new primary research requires considerable time and expense, analysts usually rely on existing studies, through so-called “benefit transfer”. This includes careful review of the literature, identification of high-quality studies and estimates of parameters. Although primary research is preferable and provides more tailored estimates, benefit transfer prevails. The short-term recommendations for benefit transfers according to Robinson et al. (63) are:

- choice of an appropriate base value that preferably reflects the same decision context, i.e., the reason for valuing the risk of illness or injury, whether the risk is controlled or uncontrolled and definition of the affected population by e.g., income, age and status;
- adjustment for differences in income due to time and place and use of income elasticity (for sensitivity analysis) (Evidence from stated preferences studies on income elasticity is summarized by Masterman and Viscusi (93) and from revealed preferences studies by Viscusi and Masterman (94); and
- adjustment for age and life expectancy for a policy that disproportionately affects young or old people with VELY for sensitivity analysis, without discounting.

### 4.2.2 Individual gains in QALY and societal QALY

The most common health measure for a CEA is QALY, which captures length and quality of life in a single index. The index thus has two components: quality of life based on individual preferences, which is expressed as utility weight, where 0 is no utility and 1 is full health with no limits, and years of life. The utility weights are based on standardized EQ-5D questionnaires developed by the EuroQol Group in 1990.

In assessing health interventions in health care, the key measure is the incremental QALY, which is obtained as the increased number of QALYs due to the intervention in relation to the additional costs. The aim is to introduce interventions and treatments that result in a maximal increase in QALYs for a given cost. QALYs can be increased by increasing utility weight (solely an incremental increase in the total quality of life) or gained life expectancy as compared with no action. QALYs are usually a combination of the two effects, and this has sparked discussion about differentiation of types of QALY in assigning monetary units and in their use for decision support. The assumption of the homogeneity of the single-value health metric QALY was challenged by Gu et al. (95) in a systematic review of weights from studies of stated preferences in priority health-care settings. (Studies on the general public reflect the societal dimension.) The review led the team to propose a method for differentiating
QALYs by weights according to their main benefit (96) into:

- life-extending QALYs,
- quality-of-life-enhancing QALYs,
- mixed life-extending and quality-of-life-enhancing QALYs and
- life-extending and quality-of-life-reducing QALYs.

The aim of the study was to define the strengths of social preferences for the QALY types to be used in a WTP discrete choice experiment in a nationally representative sample. Preferences for the type of QALY directly affect further decision-making, as each type has its own weight and thus shifts the acceptability of single treatments or even influences thresholds.

4.2.3 QALY and WTP of risk reduction

Hammitt and Haninger (97) linked the concept of WTP for a reduction in health risk with monetization of decomposed QALY by using non-fatal health risk as a function of illness severity and duration and benefit transfer for monetizing. Health conditions were described according to the EQ-5D EuroQol Group questionnaire. The diseases selected (influenza, respiratory infection, skin cancer, bronchitis, lung cancer, migraine, hepatitis, heart disease, liver cancer, liver disease and Parkinson disease) were given EQ-5D profile scores for each severity separately. The practical aim was to determine the possibility of estimating WTP to reduce the risk of a non-fatal health condition by transferring the estimate of the expected QALY loss to WTP with a linear or nonlinear function. The analysis indicated a non-proportional relation between WTP and risk reduction, where the value per statistical case is calculated as a function of severity (elasticity 0.3) and duration (elasticity 0.1) and the result multiplied by the reduction of probability, with adjustments for the value of risk reduction to children (premium).

The use of QALY and the limits of their use have been discussed extensively. Recent trends in health metrics extend the QALY further towards measures of well-being (83).

4.3 Global burden of disease and reduction of disability-adjusted life years

The most common measure of the burden of disease is the DALY, which, like the QALY, is based on the concept of a single index; however, for example, a different approach is used to estimate the severity of morbidity. Although there are many differences between the two concepts, they are often presented as the same metric with opposite signs. A DALY consists of years lost due to disability, which consists of disability weights based on expert judgement (98), with 0 assigned to no disability and 1 to full disability, and years lived with disease, and years of life lost due to premature death.

A DALY is associated with involuntarily acquired disability, such as from environmental pollution, whereas QALY gains from voluntary treatment. Thus, a reduction in DALY is more commonly used in public health and HIA settings when measuring reductions in negative impacts through prevention programmes and thus calculation of DALYs averted.

Disability weights are standardized and regularly updated in the Global Burden of Disease (GBD) study (99), and their values and other data can be obtained from the Institute for Health Metrics and Evaluation (IHME), an independent global health research centre.
at the University of Washington, USA (100). Although national disability weights have been set (101), use of the standard set from IHME is preferred for international comparisons. The WHO Regional Office for Europe has established cooperation between Member States and the IHME to overcome challenges in performing internationally comparable national studies of burden of disease and to increase appropriate use of the DALY concept (102). DALYs and other summary measures of population health are increasingly used in public health reporting systems of burden of disease to prioritize health care and social service delivery and planning (101).

GBD data are further assessed at IHME to provide high-quality estimates and long data series for further sectoral or national macro-level analysis in environmental research. A recent comparative assessment of environmental risk in 195 countries between 1990 and 2017 by Stanaway et al. (103) is a valuable source for further national or regional analysis of industrial pollution control by sector and also for national risk prioritization and further risk assessment.

DALYs and monetary thresholds for DALYs for decision-making in plans, programmes, policies or projects can be derived in two ways. As for QALYs, the societal view and valuation by non-market methods with the WTP technique for averting damaged health is preferred. If the real capacity of the health system is known and the system meets societal needs in the long run, alternative approaches can be used, such as by derivation from opportunity costs (85). Alternative approaches, such as valuation of social and mental aspects of health and well-being have been reported (84) but are not widely used in practice.

### 4.4 Summary of preferences in the choice of market and non-market methods

#### Non-market methods
- primary studies preferred to benefit transfers;
- high-quality benefit transfers preferred to low-quality primary studies;
- uncertainties to be defined;
- reference estimates provided by regional authorities (European Chemicals Agency, EU, WHO Regional Office for Europe) and international organizations (WHO, OECD, World Bank);
- guidelines and methodological advances in assessment also found outside the European Region (South-East Asia, USA).

**Advantages:** may implicitly include social and mental health and well-being components, depending on the study design

**Limits:** biases that are difficult to remove are common, e.g., different initial conditions (background initial risk, risk perception). In WTP estimates for averting damage to health, for which the stated preference method dominates, the transactions are only hypothetical and therefore not a real burden.

#### Market methods
- studies based on directly observed regional and national data preferred;
- studies of background health impact should have addressed uncertainties correctly.

**Advantage:** more accurate

**Limit:** do not offer cost estimates of social or mental health and well-being.
Combination of non-market and market methods

Combining market and non-market approaches to valuing health impacts risks miscounting or double counting, and further analyses are often undertaken in which the impacts are categorized and assessed separately for the specific focus of the overall evaluation. These issues are described in detail in the recommendations for CBAs in the context of global health and development (9) and by the OECD (29). A possible combination for use in practice is an extended COI method for estimating costs according to individual level of benefits. If appropriate WTP studies are available and double-counting of some items can be avoided, the COI approach can be extended to include loss of individual well-being.

Discussion

The market and non-market methods discussed above are derived from environmental and health economics. The methods were originally used mainly for immediate decisions on cost allocation. Thus, in the context of health care, the focus is on individual acute conditions in the event of illness or other health impairment or fatal injury. The quest for financial expression of non-market values for the effects of long-term exposure and prolongation of survival gave rise to new statistical units, controversially referred to as “value of statistical life”, although they do not reflect the value of an individual’s life. Environmental economics has thus introduced a major shift in such analyses to a basic societal perspective on valuing unaccounted-for social and mental aspects of health and well-being. This is done mainly with non-market methods of valuing changes in mortality and non-fatal health consequences (injury, suffering, illness, incapacity), thereby enabling determination of the benefit side of the traditional economic evaluation tools CBA and CEA. Technically, these allow input–output analysis with various extensions (e.g., time resolution). In deciding whether a new health intervention is acceptable, a society-wide financial threshold per QALY or DALY is used for the decision domain (usually estimated with the WTP approach). Each new health intervention is then compared with this threshold to assess its cost–effectiveness. In the health sector, economic assessment is only one domain in the HTA method, and other important aspects (e.g., clinical, organizational, ethical, social, safety) are not neglected. Similarly, for a public health setting, it is appropriate to integrate economic evaluation with other important effects on sustainability (triple bottom line), with the involvement of relevant stakeholders and their evaluation methods. In the context of the transition to a CE, the health theme is dispersed into all sectors of the public space. Implementation of the HiAP framework at national level brings the right stakeholders to the table at the right time to make coordinated decisions on changes that directly impact a range of determinants of health and are already partially anchored within public sector organization. An example would be strengthening of the links between the agendas of public health authorities, environmental protection authorities, the transport sector, the social affairs sector, agriculture and nutrition. To ensure decision-making at this scale, balanced assessment processes should be in place at all stages, despite temporary lack of input data and thus uncertainty about health impacts. To prepare for the next phases of the evaluation and to involve stakeholders, appropriate risk communication is also necessary, as discussed below.
A CE brings another large set of uncertainties to the already complex chain of the causes and effects of waste management on health. Transformation to a CE further complicates the already challenging full-chain HIA and other approaches, such as environmental health risk assessment, because of the additional impacts of unknown magnitude, thus multiplying the uncertainties. The confidence intervals for final monetary estimates may be so wide that they become irrelevant to effective communication of final health implications.

Recent studies, which have been widely cited, of the alarmingly high estimated costs of human exposure to endocrine-disrupting chemicals were critically reviewed by Bond and Dietrich (104), who pointed to the chain of unreported uncertainties throughout risk assessment, which eventually led to extremely high estimates of economic burden. Communication of scientific evidence with high levels of uncertainty must be well balanced, especially if monetary estimates are added, as such results are clearly intended for a wider audience. Guidelines for conducting CBA for economic evaluation of health impacts in global health development were reported by Robinson et al. (63), who also addressed uncertainty analysis and treatment of unquantified impacts. The recommended CBA guidelines for both issues are consistent with HIA procedures, in that the findings should be properly communicated to different stakeholders.

5.1 Qualitative risk assessment and risk communication

In such situations, qualitative or semi-quantitative risk assessments with the expert judgement elicitation approach, risk matrices, flowcharts or scoring methods are appropriate for preparing effective risk communication, which should minimize bias in subsequent monetary valuations of societal WTP estimates based on stated preferences. The WHO Regional Office for Europe reported experience in environmental risk management and communication (105) and noted that communication of health risks for which there is limited evidence and strong uncertainty is common practice, citing recent communication of the risks of nanotechnology (106). The OECD publication on environmental risk perception and behavioural economics (107) summarizes experimental evidence on the limits of theoretical assumptions in behavioural economics. Observed discrepancies between theoretical behavioural concepts and real-life situations help illustrate issues arising in practical communication of health-related implications. The psychology of risk perception by the public and by experts has been discussed, with recommendations for communication in public health (108).
Effective communication makes it possible to prepare and conduct a successful stated preference study for estimating the initial costs and benefits in waste management.

### 5.1.1 Strategic planning: example of siting waste and resource recovery facilities

As mentioned in section 3.2 on transport externalities, logistics optimization and effective multi-stream flow management require thorough strategic spatial planning to ensure optimal location of resource recovery facilities. The location of these facilities has a negative legacy in the public perception of health-related risks associated with waste, as studied in the context of nuclear waste repositories (109). Fischhoff (109) described the reality of risk–cost–benefit analysis, in which the standard method for defining risk is described as the “Concern assessment framework” (see Fig. 8).

**Fig. 8. Concern assessment framework**

The left-hand side of Fig. 8 presents procedures for which estimates were collected for the initial CBA, with assessment of societal concerns on the right-hand side. The original concept was adapted from the terminology for HIA, where “well-being” is part of welfare in a broader sense (3). The equity dimension is based on public and expert views on the distribution of the loss and benefits of well-being. Preliminary analysis and risk estimation enable risk analysis, and, when risk evaluation is added, risk assessment is possible. Communication with decision-makers is essential at every step in order to build and enhance mutual trust. The process of planning is illustrated in Fig. 9, in which the blue boxes indicate communication with stakeholders and the grey boxes indicate the stakeholders involved at different phases.
Discrepancies between expert and public opinion about health risks has led to evolution of public–expert communication strategies with respect to so-called NIMBY and locally unwanted land use and siting of facilities for waste disposal or resource recovery (110–113). This is the case when public concerns are greater than expert assessments of risk and concerns other than health are involved (e.g., a change in local real estate prices). The situation can be resolved by a communication strategy that is prepared with local authorities, providing a win–win solution (114).

5.2 Expert judgement and expert elicitation technique

The perception of risk with regard to waste management in a CE is mixed. According to the State and outlook of the environment report of the European Environment Agency (115), exposure to unknown chemicals is underestimated, and monitoring is insufficient. The cocktail effect of exposure to various chemicals during electronic waste recycling (116) and the quality of secondary material raise concern among experts; however, they do not usually communicate preliminary findings based on limited or uncertain evidence in order to obviate exaggerated reactions by the general public. The price of limited communication may, however, be an unbalanced, alarmist view of the issue. This topic is discussed by Kabat (117) in his publication “Getting risk right” for the general public. To prevent later communication barriers, experts should be involved in preliminary assessment of emerging health risks.
5.2.1 Expert elicitation for research on health-related risks

A recent paper on expert knowledge elicitation (118) identified the main challenges and biases in transforming subjective expert opinion into reliable scientific evidence. The main protocols for eliciting expert opinion recommended by the European Food Safety Authority are: the “Cook protocol”, the Sheffield protocol as a particular case of the SHELF protocol and the classic Delphi protocol (119).

The SHELF protocol was used in a case study of government advice on the probable demand on health-care services in 2035. Elicitation focused on health conditions that require long-term care, such as diabetes, heart disease and respiratory disorders (119).

Knol et al. (120) reported a seven-step procedure for expert elicitation in the context of environmental HIA as part of an integrated assessment of the health risk of environmental stressors in Europe. They did not describe the methods of elicitation but only their potential for an integrated, comprehensive environmental HIA. The seven steps are, in chronological order:

- characterization of uncertainties,
- scope and format of elicitation,
- selection of experts,
- the elicitation protocol,
- preparation of an elicitation session,
- elicitation of expert judgements and
- possible aggregation and reporting.

Each step is discussed extensively, and the strengths, weaknesses and limits of relevant approaches are reviewed, with the main factors that affect design and execution. Specific elicitation methods are listed, with references, and examples of combined elicitation (of both experts and the public) are provided in supplementary materials.

5.3 Risk ranking of health implications

Risks can be ranked by several methods, which are often used in sequence during an assessment. As resource recovery from waste has novel, unmonitored health implications, risk prioritization evolves continuously, with all the methods gradually supplementing the risk management cycle. Communication underlies all steps in risk management, with methods that should combine the perspectives of experts and stakeholders.

A critical review of methods and application of risk ranking for prioritization of food- and feed-related issues according to the size of the anticipated health impact for the European Food and Safety Authority (23) provides a comprehensive systematic review of methods for assessing food-borne risks, with a decision-support table for selecting the most appropriate method for rating food-related hazards in the context of human health. Alternative approaches, with which the significance to health of waste management system design and practice can be estimated, are known as “risk prioritization” or “risk rating” methods. An example of a qualitative assessment is the rating of epidemiological risk from water reuse shown in Table 3. The issue is presented by Voulvoulis (21) in an article on the CE and the risks of unregulated reuse of wastewater.
When risks are assessed in this way, they can be divided into three groups according to the acceptability of practical solutions: acceptable, acceptable with appropriate measures and unacceptable.

The measures could include all technical and economic measures for improving other social determinants, preferably in education and health care, in accordance with the requirements of the community and in cooperation with local government. In the absence of a market, and therefore no economic impact, one non-market value can be compensated for by another, thus balancing the competing effects of the different determinants of overall health. (e.g., socio-economic and environmental).

### Table 3. Qualitative rating of the epidemiological risk to residents of wastewater reuse

<table>
<thead>
<tr>
<th>Exposure pathway</th>
<th>Population</th>
<th>Type of consequence</th>
<th>Measures</th>
<th>Duration</th>
<th>Impact</th>
<th>Uncertainties</th>
<th>Risk rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhalation of infectious aerosol</td>
<td>Residents</td>
<td>Frequent when wastewater used for flushing</td>
<td>Treatments (technical process), disinfectant</td>
<td>Permanent</td>
<td>Minor health effect</td>
<td>Effectiveness against legionella?</td>
<td>Medium</td>
</tr>
<tr>
<td>Ingestion of infected food</td>
<td>Residents</td>
<td>Seldom</td>
<td>Use only on crops and lawns by subsurface drip irrigation</td>
<td>Seasonal</td>
<td>Minor health effect</td>
<td>Gardening</td>
<td>Medium</td>
</tr>
<tr>
<td>Transmission of infection by hand-mouth contact</td>
<td>Residents</td>
<td>Occasional</td>
<td>No use on lawns where small children play</td>
<td>Seasonal</td>
<td>Minor health effect</td>
<td>–</td>
<td>Medium</td>
</tr>
</tbody>
</table>

*Source: Dr Jana Loosová, private communication*

#### 5.4 Uncertainties and unquantifiable impacts in economic evaluations

Every assessment and every analysis has a number of uncertainties. Uncertainty analysis is an essential tool of the scientific method. Communication of the relatively complex conclusions of such analyses to support high-quality decisions is a challenge for any practitioner. The following section presents an approach to these issues based on the recommendations of the authors of the Reference case guidelines for benefit–cost analysis in global health and development (63). The themes of uncertainty and unquantifiable impacts are interrelated, as are the methods and tools to address them. A basic overview of the methods and their application is provided, with a link to decision-making in which not only the health implications are considered but also further effects on benefit in a CBA.
5.4.1 Quantifiable effects and uncertainty

Uncertainties in health implications are cumulative and derive from many sources, as most approaches cover the entire pathway or chain of health effects. This is best illustrated by the basic concept of determinants of health. The interdependence of various determinants thus covers a wide range of scientific disciplines, methods and tools, the conclusions of which must be presented in a fair, understandable way in a final summary as a basis for responsible decision-making. A number of uncertainties stem from a lack of information and time, but there are other factors. Uncertainty analysis is divided into three levels according to its complexity: qualitative discussion, numerical sensitivity analysis and probabilistic analysis.

Qualitative discussion is a necessary part of any analysis or evaluation. It includes all the assumptions and limits of the work and highlights the potential biases that arise from those uncertainties. It can have a significant impact on decision-making. Numerical and probabilistic sensitivity analysis is used, for example, in econometric procedures for determination of WTP. The more emphasis is placed on the robustness of the model and its parameters, the more attention is given to sensitivity analysis and, more importantly, to interpretation of its results. This issue and specific recommendations for practice are discussed in detail by Robinson et al. (63).

5.4.2 Unquantifiable effect and uncertainty

To address unquantifiable impacts, the literature recommends categorization and prioritization in the context of decision-making, including determining the direction of action (e.g., increase or decrease in net benefits). A similar framework for assessing health impacts in a CE is provided in the publication Circular economy: Opportunities and risks (11). The methodological similarity with HIA is evident in the initial screening phase, when important impacts must be defined. If the data collected do not allow full quantification of impacts, a break-even or boundary analysis can be conducted as part of the CBA. Given the nature of these methods, it is advisable to consider in advance the extent of their use and the benefits to the plan, programme, policy or project and to the decision-making process as a whole.

**Break-even analysis**

The principle of this analysis is to determine the threshold of acceptability of an investment. The term “threshold analysis” is often used. In the case of unquantifiable benefits (e.g., specific health implications), the question to be answered is: “How large do the unquantifiable effects have to be to outweigh the costs of protective, preventive measures or compensation?” In the long term, it fulfils the meaning of the term “investment for health” as currently defined by WHO in its glossary of health-promotion terms (4). For the purposes of such decisions, further research should be conducted to determine the return on investment of different types of protective and compensatory measures in the case of investments in waste sector transformation. For more information on investment for health, see the publication of the WHO Regional Office for Europe (69) on investment for health and well-being.

**Bounding or “what if” analysis**

This type of analysis is described by Robinson et al. (63) as a more speculative type of sensitivity analysis, with a procedure similar to sensitivity
analysis applied in standard uncertainty analysis, for which few data and little evidence are available. The principle is to estimate the range of the interval of health implications and then to determine the range of benefits. The interval is then compared with costs to determine the extent to which unquantifiable implications can be expected to influence decision-making. The literature also notes clear distinction of this type of analysis from standard sensitivity analysis because of the speculation involved.

5.5 Change in individual time use in economic evaluations

One of the requirements of decision-makers is inclusion of other aspects of well-being in economic evaluation. Time is often mentioned, with the benefit resulting from division of an individual’s time between work and leisure. Thus, the indirect cost of changing health and well-being are seen primarily as the change in an individual’s observable income and taxes paid to society. The losses resulting from inability to use leisure time for voluntary unpaid activity or leisure cannot, however, be expressed in these terms. Furthermore, changes in the ratio of time spent working between paid and unpaid or leisure activities are often neglected. Although these are relatively small shifts, they can have a significant impact on promoting, for example, individual family well-being in child care. Inclusion of individual time use among benefits, e.g., averted costs of child care, always depends on the context of the plan, programme, policy or project.

In the context of the CE, the theme of time is reflected, for example, in prevention of waste by the population, spending time on waste separation and the absence of products and services to significantly reduce waste separation. Introduction of a plan, programme, policy or project that would reduce the need for separation (e.g., returnable or reusable packaging) would extend the benefits to a population group that does not wish to spend time on separation.

The different issue of the effect of time on health in the case of ambiguous CE impacts is linked to the distribution of QALYs and DALYs in the population, whereby vulnerable populations can be expected to be the first to be affected if DALYs increase. In this respect, the topic of time is closely related to the topic of equity in the distribution of health impacts.

5.6 Equity and distribution of impacts in economic evaluation

The issue of equity in distribution of impacts can be addressed in extended economic evaluation. Recommendations for analysing the distribution of impacts in economic evaluations are summarized by Robinson et al. (63); however, decision-makers and other stakeholders have requested more detailed distributional analysis for CBAs. Although health impact evaluations can provide information on the distribution of benefits in a population, the distribution of costs among stakeholders and within subgroups of stakeholders must be analysed. Therefore, equity enters into decision-making at two levels: health and economics. Similarly, as in the case of an environmental assessment, limits are set for certain pollutants, and high background levels of pollution do not allow for an additional source. Decision-makers must decide whether the cost distribution of
a new plan, programme, policy or project will overburden a certain population group while the benefits go to another group. This kind of analysis may, however, be limited in the CE context, because much of the impact of sector transformation is in meeting medium- and long-term goals and thus falls within the realm of investment assessment. The length of the period may therefore alter perceptions of the equity of such benefits distribution, especially if costs are shifted among social investments for health and well-being. The topic of investment for health (69) moves the definition of long-term benefits to the basis of a strategy for systematic strengthening of all determinants of health in all public spaces (not only HiAP) in which there is a societal shift to a CE and a sustainable circular society.

Summary

Risk communication is generally beneficial, even when multiple uncertainties in the current scientific evidence on the health impacts of the CE are communicated to stakeholders. In such circumstances, alternative approaches for determining the severity of potential health impacts can be used, such as expert elicitation. In subsequent steps, qualitative assessment can be used to illustrate and compare the acceptability of risks, from negative impacts to identification of opportunities to promote positive outcomes.

For subsequent risk communication to be effective, it is often sufficient to use basic qualitative assessment methods and to categorize risks into three groups according to acceptability: acceptable, acceptable with action and unacceptable. The possible measures include any technical or socio-economic measure for improving other social determinants of health, preferably in education and health care, thereby offsetting the impact of the health determinant concerned or possibly strengthening other social determinants of health, thereby improving health and well-being globally. The final choice of measures or mix of measures should be chosen with appropriate involvement of affected communities and their representatives. These measures are thus a means of ensuring equity in the distribution of health impacts.
CHAPTER 6

Analysis and potential use of methods and approaches relevant to assessment of the health implications of waste management in a circular economy

The following section summarizes information about relevant methods and their use in different phases of decision-making. The relevant methods for health and economic assessment target all the main health implications of a CE. The section focuses on methods that can be used to supply missing information for decision-making or provide a framework for seeking consensus in balancing various acceptability criteria. Other topics that are covered include recycling and removing hazardous substances from circulation so that follow-up studies on non-market valuation or expert elicitation can be conducted; using one metric to summarize direct impacts on mortality and non-fatal health implications with QALYs and DALYs; and methods to ensure inclusion of other pillars of sustainability and determinants of health and well-being (multi-criteria decision analysis, WTP).

The strengths and weaknesses of each method are summarized or, where appropriate, complemented with information from previous sections. For each method, a publication is listed or reference is made to the topic of waste and health implications in the context of a CE, with links to further details and practical information. Thus:

- chemical hazards (end-of-life, end-of-waste): scoring methods, risk matrices and multi-criteria decision analysis
- disease burden methods: DALY/QALY
- socio-economic methods: expert judgement (elicitation), economic analysis (cost of illness, WTP) and multi-criteria decision analysis.

Each method is characterized by a description of the approach and brief information on strengths, weaknesses and current and prospective applications in waste management in the CE.

The methods that do not offer an economic overview but which increase understanding of the relative magnitude of the health effects are scoring methods, risk matrices and risk ratings based on DALY and QALY.
If the economic impact is sought and only moderate time and expertise are available, the methods that can be used are COI, multi-criteria decision analysis and expert judgement.

If resources are available, methods that could be further developed are those with no economic impact, such as scoring methods, DALY and QALY and risk matrices, and methods with an economic impact, such as multi-criteria decision analysis, expert judgement and elicitation and WTP approaches.

6.1 Scoring methods

**Approach:** Scoring methods involve assigning scores to individual risk factors (age, length of exposure, gender) that reflect the predicted health risk or implication (risk of lung disease with hospital admission). The score is usually defined as the sum of the weights of the risk factors, preferably obtained by expert judgement.

**Strengths:** Once scores are assigned to the model variables, the methods are easy to use. Stakeholders’ perceptions can be included. Weighting of model variables allows further classification of the importance of the variables, but weights must be obtained in a transparent way. The method has universal application for other impacts.

**Weaknesses:** Semi-quantitative methods are less accurate than quantitative ones. The process of obtaining weights for variables from experts must be well documented or, even better, based on an “expert judgement study”.

**Current and prospective applications in waste management in a CE:** Such assessments are often incorporated into more complex methods, such as sustainability-related LCA or multi-criteria decision analysis, in order to cover all areas of interest. For recommendations on practice in the context of health economic evaluation in CBA, see Robinson et al. (63). The accuracy of scoring methods depends on the criteria selected and background data. Other applications are possible at all levels of assessment in which health implications are prioritized and clearly summarized. The selected criteria and their classifications can be used in risk matrices.

6.2 Risk matrices

**Approach:** The method is used to visualize exposure and effect on separate axes according to criteria, as in scoring. The usual application is for chemical hazards for which no quantitative data are available or for occupational risk management to prioritize preventive measures.

**Strengths:** Visualization provides a clearer insight into the mechanism of risk prioritization and helps a manager to understand the contributions of both exposure and effect to overall risk.

**Weaknesses:** The method is less accurate than quantitative methods; the weaknesses are similar to those of scoring methods.

**Current and prospective applications in waste management in a CE:** In the context of a CE, matrices can be used for preliminary screening and risk analysis of end-of-waste criteria. Visualization of the risk rating is also useful for communicating risks to stakeholders during environmental impact assessments and HIAs for waste and resource recovery facilities.

6.3 Multi-criteria decision analysis or decision-making

**Approach:** Multi-criteria decision analysis or decision-making have typically been used...
in evaluating conflicting criteria in order to make a decision. The methods are semi-quantitative, in which a number of criteria (e.g., toxicity, energy efficiency, economic feasibility, social acceptance) are identified for assessing different areas of interest (technical, economic, environmental, societal). Experts or other stakeholders, including lay people, can be involved. All participants receive technical information on each risk criterion and then assign a score or an ordinal ranking to each. The scores can be weighted, and the collected evidence may be ranked in order to assign weights for further use.

**Strengths:** More perspectives from more stakeholders are assessed, and the criteria can be weighted accordingly. The method is broadly applicable and allows managers and assessors to determine the impact of various criteria on the overall risk rating.

**Weaknesses:** Weights and the range of criteria make the method less clear than risk matrices or scoring methods, and the results are difficult to communicate. Stakeholders should be involved from the beginning to assign weights to the selected criteria.

**Current and prospective applications in waste management in a CE:** The inclusion of non-health criteria ensures that this method is efficient when a stakeholder perspective is required. The method is widely used in the context of the CE. Niero and Kalbar (121) in their work on coupling material circularity indicators and life-cycle-based indicators used life-cycle indicators selected according to their relevance to the assessed product and included them in a multi-criteria decision analysis as substitutes for environmental impact assessments and HIA. Ren (25) edited a collection of papers on “Waste-to-energy: multi-criteria decision analysis for sustainability assessment and ranking”.

### 6.4 Burden-of-disease methodology

**Approach:** The DALY measure of burden of disease has two components: years lost due to disability and years of life lost due to premature death. Years lost due to disability are weighted by expert-derived disability weights. DALY has a value of 0 or 1, where 0 is a year without disability and 1 is years lived with full disability. Monetization of the DALY threshold is an interesting research question because extensive IHME data on calculated DALYs are available for different risks. DALYs are often monetized when used for CEA. DALY monetization is usually based on WTP studies, with the so-called demand-side approach. A relatively new approach to DALY monetization is based on the opportunity costs of the health-care system (85), known as the supply-side approach. The monetary values of DALY are known as CEA thresholds and represent the budget restriction and minimal effectiveness of the proposed intervention or prevention programme. The DALY concept is used in evaluation of public health programmes (101) and in CEA similarly to the use of QALYs in health-care settings; however, QALY weights (utilities) are based on subjective evaluation and should not be considered equivalent to DALY.

**Strengths:** The DALY is a single number that can be compared simply among widely different types of hazard over time and geographical region. The GBD IHME data infrastructure and method are continuously updated. Several DALY calculation tools are available or under development, including a pilot version of the WHO National Burden of Disease Toolkit (23).
**Weaknesses**: Integration of all types of diseases (acute, chronic sequelae and mortality) into a single metric with two components (morbidity and mortality) can be confusing in communicating with stakeholders. The metric does not cover broader measures of well-being, although research is under way to do so (84). The methodological issues are covered in previous sections.

**Current and prospective applications in waste management in a CE**: DALY is the single recommended metric for LCIA studies for end-points in the AoP human health. Several LCA monetizing methods include monetized versions of DALY based on demand-side methods (WTP). The GBD offers environmental comparative risk assessments with attributable DALYs (103), and the European Burden of Disease Network (122) provides methodological and educational support for further use of GBD metrics and methods, including DALY, thus supporting production of high-quality data for health assessments.

### 6.5 Expert judgement

**Approach**: Some expert judgements are in the form of preliminary assessments based on questionnaires or elicitation protocols, and several advanced methods for formal expert elicitations (formal research methods) are available. Experts’ and stakeholders’ judgements are used to assess risk and assign weights to different attributes. Formal elicitation is organized in structured scenarios in which pre-designed protocols are available to assist experts. The collected data, often divergent, are combined by formal semi-quantitative techniques in a way similar to that used in multi-criteria decision analysis.

Methods are also available for quantification of uncertainties (119). These types of elicitation are based on advanced scientific techniques (118).

**Strengths**: Expert judgement provides additional information when technical data are insufficient or incomplete. It can take the form of an estimated parameter or a verbal comment but usually consists of both. It is the usual means for engaging public concern in an assessment or to communicate new projects (such as siting of a waste facility).

**Weaknesses**: The weaknesses are similar to those of all elicitation techniques. Careful design and guidance are necessary throughout the process. There is a strong precondition for proper selection of participants and proper introduction and definition of problems. Many biases may be present, and their control requires certain expertise and experience.

**Current and prospective applications in waste management in a CE**: According to Fels-Klerx et al. (23), the three judgement-based risk-ranking applications are: achieving ranking if there are gaps in the data, reconciling diverse data streams and considerations for problems attributable to various sources and incorporating societal values. These applications are typical for communication associated with NIMBY (109) and were used for risk assessment of nanotechnology-enabled food (123). Potential use includes novel approaches to water reuse, as there is limited evidence and monitoring of the potential health effects of chronic exposure to emerging pollutants.

### 6.6 Cost of illness

**Approach**: The method is based on market quantification of the impact of disease (severity,
duration and mortality) and the costs associated with the health conditions. The method captures the main relevant market costs (direct health-care costs, productivity loss, medication costs) and indirect costs.

**Strengths:** Data are available and easily accessible, especially in high-income countries. The costs are well documented in publicly funded health-care systems. The calculations are transparent, and online calculation tools are available in some countries.

**Weaknesses:** COI does not reflect the societal and mental component of well-being and the associated costs, as it covers only costs recorded in the observable economy. Indirect costs for women, children and the elderly are lower due to their absence from or lower recorded productivity on the labour market. The method is not standardized, and therefore the comparability or transferability of values is limited.

**Current and prospective applications in waste management in a CE:** COI is not usually used as the sole assessment method in the environmental context. As the same underlying data (severity, duration and mortality) are used for DALY, COI is used as a monetary value for the years lost due to disability component of DALY. Specifically, the LCA monetizing method, MMG, includes this approach for calculating the costs associated with a particular disease outcome related to human toxicity (59).

Although the process is relatively transparent, uncertainties may be hidden in the sources of data on incidence and cost factors. When a study requires comparability, a WHO-CHOICE database (124) or regional study (125) would be more appropriate.

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**6.7 Willingness to pay (non-market)**

**Approach:** During the past two decades, WTP studies based on non-market valuation methods have been conducted to estimate the health costs associated with environmental pollution. Stated preference studies are based on carefully prepared hypothetical market scenarios, in which the participants state their preferences with regard to health risks or disease avoidance. They assess how much money a given population is willing to give up to reduce the probability of becoming ill or dying prematurely. The final estimate is a statistical unit (VSL or VOLY) that covers both individual and societal preferences. Studies are often designed for making specific decisions, as individuals and society value differently (e.g., when risks are voluntary or involuntary). WTP is also higher if the risks disproportionally affect children.

**Strengths:** WTP is generally considered to be the most theoretically robust and complete economic measure of the benefits of policies related to the environment and sustainability.

**Weaknesses:** The perception of public risk can be manipulated by alarmists or by unbalanced studies of environmental risks (104). WTP studies are resource intensive and prone to biases and errors, as experts must have experience in econometrics, environmental economics and sociology. Furthermore, several implicit assumptions do not apply in all societal settings.

**Current and prospective applications in waste management in a CE:** This method could be used for pollution prevention measures in the waste management context. It has become a basic metric for monetization of human health
damage in environmentally related CBAs (57). Estimates of VSL and VOLY are the basis for most monetized health benefits introduced recently for strategic decisions in the EU (126). The VSL or VOLY is the basis of the demand-side approach to monetary valuation of DALY and QALY and is acknowledged by the LCIA community (58, 59). Socio-economic assessment of chemicals is based on WTP studies (65). A comprehensive publication on economic evaluation of health and well-being by Robinson et al. (9) is available.

Summary

The methods and approaches described and their basic analysis represent the minimum applicable methods for topics related to waste and health in the CE. The selected methods cover the information necessary to make the right decisions as much as possible. The decisions require sufficient information on all pillars of sustainability. This section provides further support for the social and environmental pillars of sustainability measured by coherent methods for estimating the health and well-being benefits of plans, programmes, policies or projects proposed in a CE, including supportive methods for balanced decision-making. An overview of the links and the main methods and approaches for economic assessment of the health implications of waste management transformation within a CE at different stages of assessment is outlined below.
Gradual process of health impact management: framework for a circular economy

The approach to a sustainable CE requires more dynamic and complex assessment and, of course, uncertainty. In addition, absorption of health topics into a broader environmental assessment is even clearer in a comprehensive multi-cycle assessment of a CE. This is a natural process, as the CE pursues a holistic approach to finding the optimal path for a long-term strategy. The linkages between the determinants of health and well-being and the balancing of influences across the three pillars of sustainability create the foundations for overall societal well-being, although, with greater generalization, the degree of uncertainty increases. The high level of uncertainty in health issues must be carefully documented, as it forms the basis for more detailed assessment of more specific plans.

Fig. 10 shows the main scheme for tracking the topic of health in a CE and the methods that are directly associated with health valuation or at least to relative comparison of health implications. The scheme can be considered a framework for different levels of assessment of health implications, with indications of possible methods for economic evaluation.

The scheme in Fig. 10 shows the three levels of assessment. The basic level is known as the “static perspective”, because it involves an assessment at one time when, for example, a particular decision must be made on whether to accept a particular plan, programme, policy or project. It involves the most specific, detailed assessment of a project or intervention, taking into account the environmental, social and economic dimensions of sustainability, the so-called triple bottom line. The “single life-cycle perspective”, indicated by the dashed-line rectangle, is a more complex level of integrated assessment. The most comprehensive level of assessment of impacts in future cycles is the “perspective of a CE”.

The static perspective is shown in a rectangle with a triple bottom line diagram, and the inputs to assessment are listed outside and inside the diagram. The aim of the static perspective is to provide as accurate economic estimates as possible under the given conditions. Environmental economics contribute to assessment with the CBA approach and WTP methods for assessing health implications. Externalities are not limited to assessment of damage to health but also allow for monetary valuation of social aspects, such as the NIMBY syndrome. The traditional market approach of economics provides market methods for COI.
Occupational health and safety and other acute risks are covered by a risk–cost–benefit analysis. The “willingness to accept” approach reflects the behaviour of workers and is an estimate of a threshold for preventive measures in the workplace. Health and health-care economics provide metrics for measuring changes in health quality. The CEA, which is used in health care, introduces cost–effective monetary threshold values of DALY or QALY to identify optimal levels of efficiency for new public health interventions and plans, programmes, policies or projects. The HIA bridges the social and environmental aspects of assessment. The environmental and social impact assessment, which evolved from environmental impact assessments, addresses non-health environmental and social issues related to strategic projects. Impacts can be monetized either by estimating external costs based on WTP, which represents the demand side, or by DALY thresholds based on the opportunity costs of the health-care system, which represent the possibilities of the supply side. The static perspective is the most common level of assessment. It has been continuously refined since the beginning of awareness about sustainability and offers good economic estimates of health implications, taking into account all the pillars of sustainability. It is with this perspective that the most accurate results can be obtained for making sound decisions; however, such analyses and assessments rapidly lose their validity. The reference case guidelines for benefit–cost analysis in global health and development (9) build on the current general framework for economic evaluation.
from the international decision-support initiative to provide the most comprehensive, practical recommendation for practitioners in economic evaluation of health in general.

The single-cycle perspective comprises integrated approaches to health assessment through connections that provide a unified view of a selected scenario in the system of integrated environmental health. A number of assumptions and simplifications are used to assess the effects of medium-term strategic decisions. Life-cycle impact assessment, sustainability life-cycle assessment and social life-cycle assessment are used to map factors that directly and indirectly affect well-being and health. The extent of the health implications can be measured, and mutual comparison of alternative impacts or no-action scenarios is possible. Nevertheless, accumulation of uncertainties and their appropriate treatment are essential in order to obtain balanced information, especially with regard to health effects. Monetization of health implications is less accurate in absolute values and more suitable for mutual comparison because of the uncertainties accumulated during assessment.

Use of static and single-cycle perspectives in assessments is described by Martinez-Sanchez et al. (127), who provide an example of a life-cycle costing system that includes triple bottom line themes and the impact of the whole waste management system. The topic of health is addressed by social life-cycle costing, which is based on the principle of CBA and non-market approaches based on WTP to determine benefits. The case study offers a comparison of all waste management phases and displays the relative impacts of the whole cycle in two scenarios, in which the main waste treatment consists of incineration, co-digestion and recycling. Practical application of integrated life-cycle costing and HIA was reported by Woon and Lo (128) in a case study in Hong Kong on the choice between landfill extension or construction of a new waste-to-energy plant.

The most comprehensive, multiple-cycle level of the CE perspective is delimited by a dotted line in Fig. 10, because the collected evidence is highly complex; however, the health theme is not at the centre of the assessment, and the outcomes are more indicative than evaluative. The potential long-term health implications are predicted for multiple scenarios, and their relative magnitude can be predicted only roughly. Expert elicitation and scoring methods help to evaluate scenarios for strategic plans and to reach decisions on long-term public health. The main task in addressing health implications is description of uncertainties and preparation of the boundaries for a further, more detailed health assessment. A CEA may be one option, with an estimate of the DALY threshold, which gives the societal perspective on budget constraints. The distant perspective requires a strategic approach to health and well-being. The WHO Regional Office for Europe (69) published a report on the social return on investment for health and well-being, summarizing the findings on this topic and proposing three paths for further investment in order to ensure effective sustainable development. Ensuring a green CE by minimizing waste and negative impacts with sustainable production, consumption and procurement is one of the 12 key public health priorities for investment because of its high social return on investment.
Given the magnitude of the health impacts (including positive ones) in waste prevention and transformation, a coordinated approach such as HiAP is necessary to promote synergies among all affected areas, such as transport, agriculture, environmental protection, public health, education and social services.

Assessment of the health implications of waste management practices in the context of the CE is becoming a multidisciplinary task. Expertise is required in the methods used, and the following experts should be on the assessment team: economists in sustainable waste management, environmental and public health experts, environmental health experts, experts in the technical aspects and efficiency of resource recovery facilities, social science experts in elicitation, waste market analysts and waste technology engineers. Each expert will offer valuable insights into transition of the waste and resource recovery market towards a CE.

A number of literature reviews provide additional evidence for waste management assessment in the context of a CE, not primarily for health. Many describe holistic approaches to sustainable waste management and analyse experience of complex assessment. Observations from the literature on the economics of waste incineration in a sustainable waste management system are described by Massarutto (129). Lee et al. (130) described the transition of waste management to the CE in the EU. Xiao et al. (131) reviewed the literature and analysed the strengths, weaknesses, opportunities and threats of waste-to-energy in the CE and described the Chinese approach. Tisserant et al. (132) conducted a global analysis of solid waste treatment and footprints in the context of a CE. A general framework for complex value optimization for resource recovery (15, 16, 133) was presented in section 1.1 for medium-term strategic assessment in the context of a CE. The publications cited above represent the true breadth of the assessment required for transition to a CE.

7.1 Preliminary assessment

Preliminary assessment methods play two roles, depending on the perspective. The first is the strategic CE perspective described at the beginning of this section, and the other is their traditional role in the chronological advance of process flow, as described in section 7.3. The basic methods that follow identification of the potential health effects of CE-related practice are usually qualitative or semi-quantitative. Flowcharts and decision trees are often used in screening, as in the guidelines for end-of-waste criteria (39). First, exposures and effects are usually judged by expert opinion and reflect public concern. The preliminary methods used in this phase are basic expert judgement, protocols for evaluation of public concern, risk matrices and scoring methods, all of which may evolve as more accurate data become available. Preliminary estimates of economic impact can be added (COI). The simple structure predetermines these methods as useful for communicating health implications to other (often lay) stakeholders or for prioritizing identified risks for further, more comprehensive risk assessment.

The health implications of a particular waste treatment system or the relative impact of different scenarios can be obtained by LCIA or social CBA related to waste management. For example, the reference cost of health damage due to emissions of toxic metals from waste
incineration was described by Nedellec and Rabl (134). Martinez-Sanchez et al. (61) provided the reference external cost of municipal waste management systems for LCA.

An overview or rating of the quality of evidence is usually included as an identified uncertainty in order to distinguish between preliminary and screening versions of risk-rating methods and more advanced ones and to clearly identify the quality of health-related assessments. The hierarchy of methods and of their informational quality is a subject of further interdisciplinary research between those working on impact assessment and those on life-cycle impact assessment.

7.2 Susceptibility and social concerns in health valuation methods

Stated preferences studies (135) on the avoidance of health damage or disease provided clear empirical evidence that societal WTP to avoid health damage to children is higher than that for one own’s protection, with the VSL for children 1.5–2 times higher than that for adults. Ochalek and Lomas (85) proposed a multi-threshold approach for assessing public health interventions with DALYs in order to capture the susceptibility of children under the age of 5 years.

7.3 Non-market valuation methods

Preliminary assessment involves literature searches or meta-analyses, which have been published by OECD and by the European Commission. The European Chemicals Agency has published studies of WTP in relation to health end-points related to exposure to chemicals. The latest estimates of VSL for air pollution in the WHO European Region (136) were presented in a joint publication with OECD, with other methodological issues in health valuation and policy implications. These publications note gaps in valuation of morbidity, indicating that the costs presented are underestimates.

Because of the many uncertainties involved in estimating damage to health, alternative scenarios and sensitivity analyses of uncertain parameters have been used. A World Bank study on the cost of air pollution (137) includes an analysis of VSL uncertainties in Europe and Central Asia and describes the types of uncertainties for groups of countries according to income.

Given the weaknesses of the main WTP approach described above, correct use of this metric in the future should be based on well-prepared primary studies and precise benefit transfers. Johnston et al. (91) provided contemporary guidance for both. To overcome the lack of primary data, estimated income elasticities for stated preferences studies provided by Masterman and Viscusi (93) can be used, who also provided income elasticities for revealed preferences (labour market, occupational safety) (94).

Comparison of health-related monetizing methods (Table 4) allows a quick overview of the costs addressed by different methods. The colours indicate similarities in methods for estimating costs, with direct costs in blue and indirect or opportunity costs in grey. Stated preferences from WTP studies are shown in light violet, and light orange indicates new methods for construction of an alternative to QALY — a monetized year in full capability or well-being, which includes not only the physical component of well-being but also the mental
and social components. More information on the well-being valuation approach is provided by Himmler et al. (84). These new methods are not commonly used but provide possible solutions to current issues of practical economic assessment of health impacts.

Table 4. Comparison of methods according to type of costs covered from a societal perspective

<table>
<thead>
<tr>
<th>Method</th>
<th>Health-care costs</th>
<th>Productivity loss</th>
<th>Indirect costs</th>
<th>Welfare loss</th>
<th>Well-being (capability)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>COI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WTP pain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Widely used</td>
</tr>
<tr>
<td>VOLY/VSL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New</td>
</tr>
<tr>
<td>DALY/QALY supply side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Widely used</td>
</tr>
<tr>
<td>DALY/QALY demand side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year in full capability (well-being)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New</td>
</tr>
</tbody>
</table>

Source: Dr Jana Loosová, private communication

Assessment process flow

The following description of a health assessment process flow is an example for planning a waste-to-energy facility. The methods used in this first phase of planning are analogous to those potentially used in the multi-cycle CE perspective. The difference is in the scope of the assessment. The aim of screening and preliminary assessment in the static perspective is to identify risks and their magnitude, while a broad strategic assessment in the CE perspective has the same purpose.

During planning (static perspective), the environmental impact assessment or environmental and social impact assessment and, where applicable, the HIA, must reflect the specific challenges and requirements of the strategic transition to a CE from the strategic environmental assessment. The assessment should include the environmental and health impacts of the transition to CE. Thus, the growing necessity for waste disposal by incineration due to the closure of landfills should not force emerging sorting and recycling technologies out of the market for resource recovery from waste. An environmental impact assessment demonstrates these connections to strategic environmental assessment through recommended “corrective measures”. The strategic environmental assessment can cover the single-cycle perspective and should also, if possible, include the CE perspective. As the transition towards a CE advances, the capacity of waste-to-energy technologies must be flexible in order to avoid environmentally unfavourable market solutions (such as import of waste to be incinerated), especially in the context of the Paris Agreement and the Stockholm Convention.

Initially collected health impact data can be expressed in factsheets on the risks and common measures for their mitigation. An example of a waste-to-energy factsheet is shown in Fig. 11. All direct health effects of
possible alternatives can be summarized in factsheets based on current knowledge from a literature review. Experts rate the risks qualitatively to provide a preliminary overview of the magnitude of potential risks. An example of a preliminary risk rating for a waste-to-energy facility is shown in Table 5 as a qualitative risk rating that accounts for corrective measures for the selected risks. A document from the European Commission Joint Research Centre on best environmental management practice for the waste management sector (138) offers minimal health-related information on waste treatment alternatives and only basic information on the Industrial Emissions Directive (2010/75/EU).

![Fig. 11. Example of a waste-to-energy factsheet](source)

The flow of decision-making and use of basic elicitation protocols are shown in Fig. 12. The black arrows represent the process and the blue arrows the inputs from elicitation protocols. Preliminary economic estimates of morbidity and mortality can be included, with a risk matrix. Health impacts can be obtained from literature on past (139) and current performance of corrective measures for air pollution from waste incineration (140, 141).

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*Polychlorinated dibenzo-p-dioxins*
Table 5. Preliminary qualitative risk rating of selected risks, waste-to-energy facility

**Air pollution (particulate matter)**

<table>
<thead>
<tr>
<th>Population</th>
<th>Consequence</th>
<th>Measures</th>
<th>Duration</th>
<th>Impact</th>
<th>Uncertainties</th>
<th>Risk rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers</td>
<td>Frequent</td>
<td>Technical, organizational, personal protective equipment</td>
<td>During work</td>
<td>Minor health effect</td>
<td>Working residents</td>
<td>Medium</td>
</tr>
<tr>
<td>Residents</td>
<td>Occasional</td>
<td>Technical and organizational</td>
<td>Permanent</td>
<td>Slight health effect</td>
<td>Vulnerable groups—asthmatics</td>
<td>Low</td>
</tr>
</tbody>
</table>

**Air pollution (particulate matter)**

<table>
<thead>
<tr>
<th>Exposure pathways</th>
<th>Population</th>
<th>Consequence</th>
<th>Measures</th>
<th>Duration</th>
<th>Impact</th>
<th>Uncertainties</th>
<th>Risk rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air, inhalation</td>
<td>Residents</td>
<td>Occasional</td>
<td>Technical, personal protective equipment for workers</td>
<td>Permanent</td>
<td>Slight health effect</td>
<td>—</td>
<td>Low</td>
</tr>
<tr>
<td>Food, ingestion</td>
<td>Residents</td>
<td>Seldom</td>
<td>No agriculture near the incinerator</td>
<td>Seasonal</td>
<td>Minor health effect</td>
<td>Local gardening by residents</td>
<td>Medium</td>
</tr>
</tbody>
</table>

**Noise**

<table>
<thead>
<tr>
<th>Source</th>
<th>Population</th>
<th>Consequence</th>
<th>Measures</th>
<th>Duration</th>
<th>Impact</th>
<th>Uncertainties</th>
<th>Risk rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incinerator</td>
<td>Residents</td>
<td>Frequent</td>
<td>Technical</td>
<td>At night</td>
<td>Minor health effect</td>
<td>Sensitive groups of population at night: children, chronically ill and older people</td>
<td>Medium</td>
</tr>
<tr>
<td>Workers</td>
<td>Frequent</td>
<td>Personal protective equipment for workers</td>
<td>Noisy workplace</td>
<td>Minor health effect</td>
<td>—</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Traffic</td>
<td>Residents</td>
<td>Frequent</td>
<td>Technical, organizational (limit traffic at night)</td>
<td>At night</td>
<td>Slight health effect</td>
<td>Sensitive groups of population: shift workers (sleep during the day), children, older people</td>
<td>Low-medium</td>
</tr>
</tbody>
</table>

Source: Dr Jana Loosová, private communication
Economic assessment of health end-points is usually based on non-market valuation methods and even more often on previous studies. For some health end-points, direct market costs are used. Advanced methods, such as benefit transfers and treatment of uncertainties, are usually performed by an economist or an analyst with experience in econometrics, preferably related to health and environmental topics. Recent studies on the costs of health damage from incineration and waste-to-energy are summarized by Nedellec et al. (71).

**Summary**

The choice of methods for economic evaluation is related directly to the requirements at each stage of HIA and other health-related assessments. For HIA, the choice of methods depends on the areas defined by the focus of the evaluation (scoping). For health impact evaluations, the challenge for the CE is the more distant cycles of impact evaluations and the associated higher levels of uncertainty. With transformation of the sector, health impacts are becoming more disperse because of requirements to establish additional,
intermediate stages for resource recovery near upstream sources. This raises the issue of equity of distribution of impacts across population groups and equitable distribution of costs. As the time horizon changes, the level of uncertainty increases, which must also be addressed correctly, including unquantifiable uncertainties.

The focus in a CE on consumer behaviour and waste prevention requires greater involvement of the supply side of products and services (upstream processes) in waste prevention programmes. The goal is to create economically affordable, health-promoting, sustainable products and services. Although the available literature does not directly refer to economic evaluation of health impacts from waste prevention, economic evaluation methods offer some flexibility in this respect through non-market valuation methods.
Health and waste — beyond economics

This section raises issues that should not be overlooked, because, in a CE, all good and all bad things return to the cycle.

8.1 Susceptibility

The economic consequences of the health effects related to waste are distributed unevenly by population, mainly according to the initial health state. Vulnerable groups include infants, the elderly and other sensitive groups with limited and impaired health. The economic impact is generally higher on these groups than on the general population, including direct healthcare-related cost per patient with a co-morbid condition. The formal human capital costs of this group are, however, low, as the most susceptible segments of a population contribute marginally to the formal economy (142). Chronic exposure to pollutants, including from the waste sector, mainly affects sensitive populations who are already economically vulnerable due to their suboptimal general health.

8.2 Ethical concerns: exportation of health-related externalities

Transformation to a CE raises concern because of the well-known past reaction of the mining, production and manufacturing sector, which is to export pollution and other environmental burdens. The stricter the regulations on the resource recovery industry, the more likely it is to try to situate itself out of regulatory reach. The speed with which they can leave EU territory depends on many factors, including the cost of relocation, the capital intensity of the technology and the level of expertise required for effective, safe operation. Achievement of a well-balanced environment of control and motivation is a challenge for successful transition to a CE.

An emphasis on refurbishment and longer operational life of goods will have to overcome barriers set by the current market inertia in relation to the diminished perception of the quality and reliability of goods. When a CE exists already, instruments such as “performance-based business models” are emerging, whereby the customer pays for the “utility” of the product and not for its quality or volume. Such sustainable business models have limits, however, and not all businesses can follow the path to a CE immediately.

Resale of used and refurbished goods also has positive and negative sides. Less efficient or environmentally less sound technologies and goods have been sold to less developed countries for a long time, even within the EU (143–145). In the short term, this can be interpreted as a mutually beneficial strategy, especially in view of growing consumption, but as less favourable in the long term with regard to the environment and ethics because of life-cycle costs, the impact of distribution on life-cycles and possibilities for end-of-life management.
These approaches and models of a CE must therefore be responsibly assessed according to the CE perspective. Otherwise, the health-related risks of waste management are just exported from a territory with a CE and strong pollution control to less-developed settings without the appropriate infrastructure, business model or regulatory framework for efficient management (146). The CE values high ethical principles, which must be applied beyond national and regional borders.

8.3 Quality and safety concerns

Extension of the waste sector back into the supply chain raises concern about general quality and safety (40). Control of the quality of reintroduced or reused materials would shift the costs in the chain; however, sectors such as health care would face strong resistance because of the high priority of health. The new risks and benefits must be carefully assessed, and extension of circularity measures to highly vulnerable and health-risk sensitive environments like health care must be selective. Further research on harmonization of safety-sensitive sectors and CE practices is complex (147), as partly recognized by several institutions and initiatives, such as Health Care Without Harm and the Cochrane Collaboration, and more support is necessary to overcome current resistance in the sector.

Thus, application of sustainability to waste management is only the beginning of the challenges of environmental pollution management and control, which go beyond national strategic cooperation. Transition to a CE is a long-term task involving all the stakeholders in the production process stream of the current linear economy and systematic resolution of all the partial inefficiencies that lead to negative impacts on the environment and public health.

8.4 Waste crime

The external costs of pollution are exported both formally and informally, depending on market regulation, taxation and other costs associated with waste management. This applies to both the production sector and the waste sector. The impact of waste electrical and electronic equipment is clearly described in a report on countering illegal trade in these wastes, with a market assessment, legal analysis and recommendations (143).

The more comprehensive and strict the policies on waste management are, the higher the costs for their execution. If the requirement for such controls is underestimated, however, informal waste management is introduced, and the consequent health risks cannot be managed efficiently. Such findings are reported by EnviCrimeNet (146), an organization supported by Europol. Waste crime is persistent, and hazardous waste from the health-care sector represents a particularly serious threat to public health (148).

8.5 Waste management and challenges to social and environmental responsibility

Waste management must include residual inefficiency in the product or service chain that has accumulated in previous stages of the linear economy. Such inefficiency has several sources, the most common being technological limitations, limited knowledge of the real impacts, limited resources, time constraints and combinations of these. This results not only in a mixture of hazardous materials in waste but also a mixture of difficult impacts on
the environment and health. In business and financial terms, management strategies are optimized to ensure that the processes and services with the highest impacts on the overall economic performance of the organization are used under all the above-mentioned limits and constraints. This also applies to the waste management sector. Making the highest profit under given conditions and regulations remains the strongest driver of the economy, although social responsibility and environmental sustainability have been adopted to a certain extent by the business culture, depending on the development of countries.

Summary

Further challenges are related mainly to transformation of the waste sector and the infrastructure of supportive, sustainable resource recovery from waste facilities in a climate-neutral economic policy. The possibilities for effective transformation of the waste sector differ among countries in the European Region, as strong regulation and little control (enforcement) can push waste management outside the formal economy and thus increase the negative impacts on public health and the environment. In view of the differences within the Region in transformation of the national waste sector in the context of the CE, one solution would be to ensure that plans correspond to the capacity and requirements of each country.

Economists are aware of the limitations of the current approach to prosperity through GDP growth and the limits of current economic methods for tracking sustainability, even in the area of environmental health and social well-being. Until the necessary transformation also takes place in the field of economic reporting and evaluation, communication with stakeholders must be maintained to promote concepts such as HiAP. Transformation of a traditional linear economy into an equitable, well-being-enhancing CE cannot take place in isolation in one country or region, such as Europe: this is an international challenge. Each individual country has different conditions and capacities for successful transformation of the waste sector and different possibilities for changing consumption patterns and attitudes towards a healthy lifestyle.

Specific requirements in terms of public health impacts will be better perceived on closer assessment of national baseline situations for, e.g., strategic planning of resource recovery capacity in view of a gradual decrease in non-recyclable waste, the degree of control of the chemical load of recovered materials and resources or introduction and enforcement of end-of life criteria for new products. Subsequent economic evaluation of health impacts will guide efficient allocation of funds in accordance with the significance and influence of health determinants. The dispersion of the health theme throughout different economic sectors and policy areas has led to HiAP. The HiAP framework for national implementation is particularly relevant in the context of a transition to a climate-neutral CE, as it offers a coordinated approach to continuous promotion of health and well-being in the public space.

The necessary condition for successful progress towards a CE is the availability of a balanced assessment of the health implications of enabling actions. The CE perspective of assessment ensures evidence for responsible decisions that are not based on short-term, purely economic interests but will achieve generally optimal, efficient, sustainable long-term solutions.
References


All references accessed 9 January 2023.


Annex 1. Infrastructure for integrated environmental impact assessment

The organizations mentioned in this supplementary material and their outputs provide important evidence for assessing the global impacts of the transforming waste sector in the CE on population health. Changes in the distribution of exposure to pollution can be expected due to changes in the logistics of materials and waste, as well as avoidance of environmental burdens in the form of contaminated sites. Epidemiological data indicate that the burden of disease in the population can be compared and expressed economically in terms of avoided external health costs or negative changes in the form of additional external health costs.

Expected changes in the distribution of externalities are in exposure at contaminated sites (e.g., landfills, industrial waste sites, slower expansion of mines, new material processing plants), in transport schemes and material logistics (collection, processing and redistribution) and consequently in air and water pollution related to waste management. Changes in consumer behaviour that decrease rates of waste generation have a synergistic effect on the health impacts of the CE and decrease negative health-related externalities and external costs. Most global public health implications of waste management are assessed as environmental pollution. Valuable information on environmental effects on health due to a transition to a CE can be obtained with continuously developing economic methods, monitoring tools and integrated assessment and management approaches to environmental externalities.

The strong link between health and environmental pollution has led to a global monitoring infrastructure. For example, the Lancet Commission on Pollution and Health (1) provides scientific information for further assessment, and the GBD study in 2015 provides estimates and 25-year trends in the burden of disease attributable to air pollution (2). The global monitoring infrastructure thus provides valuable data for assessments and important references for assessing previous regulations on environmental pollution.

Instruments and incentives have been developed since the late 1990s to promote prevention of negative environmental externalities or for their internalization. The definitions and links between HIA, comparative risk assessment and integrated environmental health impact assessment have been reported by Briggs (3). In the transition to a sustainable
economy, priority was given to energy efficiency, because of the high external cost of the energy sector, and later to the transport sector, due to the growing demand for mobility, especially in road transport (4). The full chain process approach is somewhat analogous to a life-cycle assessment on a macro (regional or sectoral) level. Both the energy and the transport sectors are closely linked to current CE-related waste management practices. An important source of data and information for assessing transition of the waste management sector is the research infrastructure of the European Region. The Integrated Environmental Health Impact Assessment System (5) provided a “common case study” for testing the system, and that on waste management in Lazio (Italy), which follows the full chain process approach, demonstrates the potential of the method for evaluating regional waste management strategies. The full chain comprises waste production, collection, transport, recycling, treatment and disposal for two scenarios — no action and green policy — in the long term, and the health impacts have been monetized within deliverable 4.1.2 of the project (6).

Further studies used the integrated environmental assessment approach for monetizing impacts related to health and the environment. Traditional market methods and new, non-market valuation approaches were combined in order to capture economic damage and “disutility” from all perspectives, as discussed above. The more holistic the approach used, however, the more the health theme was distributed into many research fields. Although this is to be expected, as the determinants of health are linked to almost every human interaction with nature, addition of the new dimension of circularity to assessments reveals contradictory effects of policies and a risk of suboptimal solutions.

External costs of transport in Europe

An updated version of the handbook on external costs of transport and a final report for the European Commission, DG-MOVE (4), covered externalities attributable to transport, which comprise air pollution, the costs of accidents and health impacts due to noise; however, up- and downstream (end-of-life) costs were not included. A more recent publication on external costs of transport (7) adds “well-to-tank emissions” to the costs of fuel distribution. More structured up- and downstream externalities and links to studies related to LCA of vehicles and infrastructure are provided by Korzhenevych et al. (4).

The external costs of transport must be considered in future strategic decisions on management of material and product streams and the spatial distribution of recycling plants. As road transport accounts for most of the external costs of all means of transport, it makes a higher demand on the efficiency and sustainability of waste logistics. The CE will challenge business and public waste management because most waste is transported by heavy-duty road vehicles powered by fossil fuels (8). At a business level, optimization is covered by reverse logistics planning. Logistics models are based on commercial consultancy or scattered research themes (9). Optimization of municipal waste management might face logistics challenges in the future with introduction of multi-stream material flow and lack of appropriate recycling facilities near municipalities.
Progress in evaluation and monitoring: European topic centres and continuous reporting on environmental pollution

The European Environment Information and Observation Network is a partnership between the European Environment Agency and 38 members and cooperating countries. The Agency has also established a consortium of organizations in environmental research and information in Member States that cooperate in seven European topic centres, including one on waste and materials in a green economy, which covers European Environment Agency strategic areas 2.1 (Resource-efficient environment and economy) and 2.2 (Environment, human health and well-being). Since 2019, reports have addressed the CE, waste management and prevention, sectoral integration and the green economy and the state and outlook of the environment.

State and outlook of the environment report and the waste sector in transition

The State and outlook of the environment report 2020 (10) covers all the important aspects of the impact of waste management on health, and chapter 9 is dedicated to waste in the CE. The health implications of the growing grey waste economy of illegal activities in south-east Europe are described, as the waste sector attracts many organized criminal groups (reported by Europol and EnviCrimeNet). Unregulated and illegal activities in the waste sector not only pose risks to human health but also represent the loss of valuable materials.

Minimal space is given to the waste industry in the chapter on industrial pollution, which describes trends in air and water pollution in major sectors, including the waste sector. The chapter concludes that industrial air pollution is regulated more effectively than water pollution, as new pollutants in water are not adequately monitored. The health risks from industry, and especially the release of hazardous chemicals, is underreported and the externalities are therefore underestimated. The chapter on chemical pollution offers a pessimistic outlook on the health effects of many unmeasured substances, such as polyfluoroalkyl substances, which are present in many products. A recent study by the Nordic Council of Ministers (11) indicated that the estimated annual health-related cost of exposure to these compounds was € 2.8–4.6 billion for the five Nordic countries and € 52–84 billion for all the countries in the European Economic Area. The costs were estimated according to European Chemicals Agency recommendations on socioeconomic assessment of exposure to chemicals (12). It was noted that reuse of waste water as drinking-water raises health concerns. The chapter on air pollution offers a mixed outlook, noting high potential improvement in the development of sustainable transport. Land use is outside the jurisdiction of current policies, and land degradation is continuing, the main sources of contamination being industrial and municipal waste and industrial emissions and leaks. More than 70% of contaminated sites are not inventoried, and currently less than 10% of registered sites are investigated. Another source of degradation is intensive land management. The health impact of waste management during transition to a CE is a cross-cutting issue in all environmental themes.

Studies on the health effects associated with contaminated sites are another source of information, as are studies on remediation
of waste-disposal sites. The WHO Regional Office for Europe (13) has published a review of scientific evidence on this topic.

**European cost–benefit analysis of air pollution**

The revised strategy for clean air for Europe of 2005, with improved mortality functions from the study of health risks of air pollution in Europe, provides projections in terms of health impacts due to air pollution in various scenarios. Holland (14) provided a CBA of policy scenarios for the EU Clean Air Package and updated HIA values for the effects of ozone, PM$_{2.5}$ and NO$_2$. The mortality valuation data that dominate this CBA remained unchanged, despite a suggestion from the OECD (15) to increase the value of VSL and a suggestion by Desaigues et al. (16) to use a slightly lower VOLY. Holland (14) also provided background comments on health-care costs related to mortality and morbidity due to air pollution. When a systematic assessment of costs was not available, the WHO CHOICE database was used.

The WHO Regional Office for Europe and OECD estimated the economic cost of the health impact of air pollution in the WHO Europe Region (17).

**References$^4$**


$^4$ All references accessed 9 January 2023


Annex 1. Infrastructure for integrated environmental impact assessment
The WHO Regional Office for Europe

The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

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WHO/EURO:2023-5536-45301-64839

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