doi: 10.2166/9781780409566

Chapter 14

Economic analysis of resource recovery

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14.1 INTRODUCTION

Resource recovery aims to create value from waste materials associated with the production and consumption of goods and products in modern-day society. It is an essential part of a sustainable circular economy concept focused on waste reduction, reuse and recycling. Materials of potential value contained in waste products can be extracted through further processing and recovery methods, as described in the many chapters in this book. Concepts and paradigm shifts like *circular economy* and *cradle-to-cradle* are driven by our desire to make production and consumption sustainable. Here, we define sustainable processes as those that are long-lasting without compromising future generations' resource access and welfare levels, but also have clear financial and economic drivers and motivations. Various life cycle assessment (LCA) based methods and approaches exist to assess the material flows associated with production and consumption, many of which are discussed in this book. These LCA methods are key to our understanding of how efficient current production and consumption processes are in terms of our use of available biotic and abiotic natural resources.

Resource recovery is economically of interest because many of these natural resources (e.g., minerals, energy, water) are becoming increasingly scarce worldwide. Scarcity is core to economic thinking. Goods, products and services have economic value because they are scarce, meaning that demand is higher than supply. Resource recovery is particularly of interest because the costs of recovery technologies and processes are presumably lower than their benefits. This discrepancy between costs and benefits will only increase as the development of new technologies, as seen over the past years for example with struvite recovery or the removal of fibers with fine sieve technology unburdening the rest of the wastewater treatment process, results in lower recovery costs or overall treatment costs and raises resource value over time. Hence, thereby increasing the opportunity costs or benefits forgone of not recovering the resources. The increase in value and/or the reduction in costs or cost savings drives resource recovery innovation initiatives so as to not let residual values literally go to waste. In other words, it makes economic sense to recover resources as long as the benefits outweigh their costs. This is what economists refer to as efficiency.

The chapter is from the book *Resource Recovery from Water: Principles and Application*, Ilje Pikaar, Jeremy Guest, Ramon Ganigué, Paul Jensen, Korneel Rabaey, Thomas Seviour, John Trimmer, Olaf van der Kolk, Céline Vaneeckhaute, Willy Verstraete (Eds.)

14.2 LEARNING OBJECTIVES

This chapter focuses on the economic analysis of resource recovery. It aims to explain and clarify basic economic concepts and methods using practical, real-world examples. Specific learning objectives are:

- Familiarize the reader with the concept of economic analysis of resource recovery.
- Explain the difference between financial and economic analysis.
- Describe the concept of Total Economic Value.
- Characterize relevant economic valuation methods.
- Increase understanding of the use and usefulness of cost-benefit analysis to support policy and decision-making regarding resource recovery.

14.3 FINANCIAL AND ECONOMIC ANALYSIS

Economics should not be confused with finance or financial analysis, which is about the money or cash flows associated with the material flows. Economic welfare analysis is broader than simply tracing money flows or managing financial budgets, and typically involves both monetary and non-monetary consequences of policy actions or investment decisions. The non-monetary side-effects of resource use are referred to in economics as externalities. They accrue, often involuntarily, to third parties that are not directly involved in the decision-making to extract or use a resource. Examples include the impacts of mining on downstream water quality or fossil fuel use on climate change. Externalities can be positive or negative and add to the complexity surrounding resource exploitation decisions. They refer to important economic trade-offs between the positive impacts (benefits) and negative impacts (costs) of resource extraction and use. For example, oil and mineral extraction generates significant regional employment benefits besides market revenues, but they may result at the same time in significant pollution on-site and downstream in rivers.

Furthermore, these resources are often finite, and their extraction and use now reduces the potential for future consumption. The latter future benefits foregone or opportunity costs are also referred to as resource costs and should theoretically be included in an economic analysis to maximize the economic gains over time of exploiting a non-renewable resource. The calculation of these resource costs are based on the so-called Hotelling's rule. Readers interested in finding out more about Hotelling's rule in non-renewable resource extraction are referred, for example, to Dasgupta (1993). Accounting for the flow of future costs and benefits is what economists refer to as dynamic efficiency (e.g., Griffin, 2016).

14.4 COST-BENEFIT ANALYSIS

Cost-benefit analysis (CBA) is carried out in order to evaluate and compare the economic efficiency of alternative resource recovery projects or technologies. The benefits from such a resource recovery project are contrasted with the associated costs within a common analytical framework. Money is used as the common denominator to allow comparison of these costs and benefits, which can be related to a wide range of productive resources, including the resource to be recovered, and are measured in differing units. Although a set of common steps can be identified to carry out a CBA, as shown in Table 14.1, a CBA is typically context specific and hence no 'standardized' CBA exists. More specifically, the CBA aims to answer the following two questions:

(1) Is the resource recovery technology project worthwhile from an economic perspective, that is, do the benefits outweigh the costs?
(2) If so, which alternative technology project yields the highest net benefit, that is, benefits minus costs?

A CBA can be used to evaluate and compare the costs and benefits of multiple alternative technologies or just one. In the latter case, the costs and benefits of a new technology are compared

Table 14.1 Steps in a cost-benefit analysis of a resource recovery technology project.

Step 1: Define the objective of the resource recovery technology or project
Step 2: Define the baseline situation or technology: What would happen if no action is taken?
Step 3: Define the alternative resource recovery options to achieve the objective
Step 4: Quantify the investment costs of each option
Step 5: Identify and quantify the positive and negative welfare effects of each alternative option compared to the baseline situation
Step 6: Value all relevant effects in monetary terms, using market prices and economic valuation methods
Step 7: Calculate the present value of costs and benefits occurring at different points in time using an appropriate discount rate
Step 8: Calculate the Net Present Value (NPV) and Benefit-Cost (B-C) ratio of each alternative option
Step 9: Perform sensitivity analysis
Step 10: Select the economically most efficient resource recovery technology or project

to the status quo, where either no resource recovery technology is in place or an existing resource recovery technology is the point of reference and the incremental costs and benefits of the new technology are compared to the existing technology.

As before, an important distinction in CBA is that between a financial and economic CBA: A financial CBA, also referred to as a financial analysis of expenditures and revenues, evaluates advantages and disadvantages of a resource recovery technology in terms of the expenditures and earnings directly associated with its implementation for the investor. Originally devised for investment decisions, the tool can also be used to assess budgetary impacts of technology development projects for resource recovery. An economic CBA evaluates the costs and benefits of a resource recovery project or technology in a broader sense, taking into account all positive and negative effects on people and the environment at the appropriate spatial and temporal scales.

The time horizon in an economic CBA is not defined by the time it takes to implement the project as is typically the case in a financial analysis where the payback period is an important evaluation criterion, but by the time over which its impacts manifest themselves. This period may extend beyond the lifetime of the project. Similarly, the appropriate spatial scale over which impacts are (expected to be) observed may go beyond the location where a new resource recovery technology is implemented. The costs and benefits addressed in an economic CBA may furthermore include indirect (second-order) effects and non-priced external effects on society and the environment. An example of an indirect effect of phosphorous recovery from wastewater may be a change in the existing market price of phosphorous in fertilizer applications, while an example of an external effect of phosphorous recovery would be the improvement of water quality of wastewater receiving water bodies.

Carrying out a CBA is a multi-disciplinary process, involving expertise from different fields and the input from technology developers and investors. In general, the steps presented in Table 14.1 are followed in a CBA. Lazurko (2018) identifies eight steps relevant for conducting a CBA for resource recovery and reuse: framing, identifying, prioritizing, quantifying, monetizing, discounting, quantifying uncertainty and presenting. Steps 2, 4, 5 and 6 correspond with steps 4–7 presented here. Step 7 in Lazurko (2018) is similar to step 9 in Table 14.2. While economists are involved in all steps, technical expertise of many kinds may also be needed, especially in steps 3, 4 and 5. In order to ensure that the various options are technically feasible, input from engineers is required especially in step 3, and often also in step 4 to specify the exact nature of the resource recovery technology and estimate the associated engineering costs. Input from technology developers and investors is essential when defining the objective of the resource recovery project and identifying the expected incremental effects from each resource recovery option compared to the relevant baseline technology that is already in place. A key role of the economist in the whole process is to frame the relevant issues in economic terms, developing the CBA framework and ensuring it includes all relevant financial and economic stakes and stakeholders. The effects of the resource recovery project have to be identified

Table 14.2 Example of a cost-benefit analysis of phosphorous recovery. The costs refer to the incremental costs of the new technology, while the benefits are in this case study the cost savings as a result of the new phosphorous recovery technology. Note that the results of a CBA are typically presented as a balance sheet, meaning that a gain or loss is presented as a balancing item, equating total costs and benefits.

Costs	€/year	Benefits	€/year
Capital cost reactor	307 000	Reduced costs dewatering	131 000
Energy costs	26 000	Reduced costs sludge processing	649 000
Labour costs	60 000	Reduced costs transportation costs sludge	32 000
Maintenance costs	92 000		
Use of magnesium chloride	182 000		
Use of ferric chloride	134 000		
Costs	801 000	Revenues	812 000
Financial gain	11 000		
Total costs	812 000	Total revenues	812 000

Source: Adapted from Veltman (2012).

and quantified, first perhaps in physical terms (e.g., kgs of a resource recovered) and then converted into monetary terms (e.g., by multiplying the recovered resource amount in kgs by its market price in \$/kg to estimate the total market revenues).

It is important to point out that the CBA is just one of the various evaluation studies that is typically carried out. Besides economic efficiency, other decision criteria such as technical feasibility and acceptability, risk management, or environmental impacts may play an important role too. The CBA has to be carefully aligned with these other studies, for example to quantify the technical performance or environmental impacts of a new technology. The various steps in a CBA will be further elaborated in the next sections.

14.5 MAKING AN ECONOMIC CASE FOR RESOURCE RECOVERY

The first steps in a CBA are summarized here in general terms. The use of resources in production and consumption results in different types of solid, liquid or dissipated waste downstream of the supply chain that can have different levels of eco-toxicity and hazard levels to human and ecosystem health. Resource recovery means that parts of this waste are used and transformed into valuable resources that can be reused in the same, similar or other production and consumption processes. This reduces the negative externalities related to potential human health and ecosystem risks, while simultaneously generating new economic value by making the recovered resources available for re-use.

Examples include the use of fossil fuels and the emission of carbon dioxide into the air. Carbon captured from a fossil fuel power station can be utilized to make other substances like plastics, concrete, or biofuel. Technologies include Bio Carbon Capture and Sequestration (CCS) Algal Synthesis where CO_2 and other greenhouse gases are injected into membranes containing wastewater and select strains of algae (Stavrakas *et al.*, 2018). Using sunlight or UV light, this process produces an oil-rich biomass that can be used as oil for plastics, fuel and feed.

Another example is the removal of phosphates from wastewater. Although many countries around the world have banned phosphates from laundry detergents in the past (e.g., EU, US, Canada, Australia), it is still an important source of pollution in domestic wastewater (e.g., sewage, dish detergent). Phosphorous is an essential input in fertilizer for agricultural food production. It comes from phosphate rock, the mining of which takes place in a limited number of countries around the world, and is becoming increasingly scarce, which affects its price and that of phosphorous-containing fertilizers (Cordell & White, 2014). Current phosphorous use in fertilizers has been qualified as inefficient causing eutrophication problems worldwide. Phosphorous is removed in wastewater treatment using chemical or bio-based technologies. The removed phosphorous ends up in sewage sludge, which is then subjected to anaerobic digestion, dewatering and incineration.

Only a handful of studies exist that have looked at the costs and benefits of phosphate removal from wastewater. Most studies indicate that the costs for phosphate recovery largely exceed the costs for phosphate from rock mining (Cornel & Schaum, 2009), making it a less attractive option for the fertilizer industry. However, in wastewater treatment phosphorous recovery, in particular controlled struvite crystallization, has the potential to reduce operating and maintenance costs by reducing the reliance on chemicals (chemical precipitation) and the downtime for cleaning uncontrolled struvite formation from recycled streams (Shu *et al.*, 2006). Further cost savings may be achieved because sludge without phosphate has been shown to dewater better than sludge with phosphate, while phosphorous recovery by applying sludge on agricultural land for food production also reduces the otherwise required amount of landfill area (Evers *et al.*, 2016).

An example of a CBA of the application of the phosphorous recovery technology Airprex in the wastewater treatment facility Amsterdam West, the Netherlands, with a treatment capacity of 920 000 inhabitant equivalents, is presented in Table 14.2. The most important benefits in this case study are the cost savings as a result of the introduction of the new phosphorous recovery technology. The new technology piloted in this urban wastewater treatment facility replaces the existing Modified University of Cape Town (M-UCT) process for biological phosphorous removal, which can result in high phosphate levels in the recycled water from the fermentation-based sludge processing, and clogging of pipes and tanks. By adding magnesium-chloride ($MgCl_2$) in combination with aeration, controlled crystallization of struvite improves the dewatering of the sludge through centrifuge and consequently reduces the amount of sludge for processing and transportation. The recovered struvite is of such high quality that it can be sold to the fertilizer industry (Veltman, 2012).

14.6 COST AND EFFECTIVENESS OF RESOURCE RECOVERY TECHNOLOGIES

Resources may be recovered using different technologies, and these technologies may have different costs (step 4 in Table 14.1). Economists aim to do things at the lowest cost possible. If various options exist to recover resources, a cost-effectiveness analysis of the available options helps to answer the question which resource recovery option is cheapest, bearing in mind that the outcome of such an analysis may be highly site and context specific. The purpose of a cost-effectiveness analysis is to find out how an objective (e.g., resource recovery) or predetermined target (e.g., recovering a certain amount of resources from wastewater) can be achieved at least cost (e.g., Lise & Van der Veeren, 2002; Tietenberg, 1992). The cost-effectiveness analysis hence does not account for any benefits as in a CBA, it just focuses on the least cost way of resource recovery. In its most simple form, the analysis can be depicted as shown in Figure 14.1.

Various possible resource recovery technologies (1, 2, 3,….*n*) are ranked in increasing order of their marginal costs ($/kg), that is the costs ($) to recover one extra unit (kg) of a particular resource. Besides a different marginal cost (on the vertical axis), each technology also has a specific recovery potential or capacity (on the horizontal axis). The least cost technology is the one that is able to recover 1 kg of a resource at the lowest cost. If a predetermined target has to be reached, as illustrated in Figure 14.1 by the environmental standard, multiple complementary technologies are activities which may have to be employed, since individual technologies may have a limited recovery potential. The total costs of implementing these technologies are found under the marginal cost curve from the origin until the point where the resource is recovered (e.g., until the environmental standard). Typically, recovering the last units of a resource is most costly, for example to reach the environmental standard. Whereas marginal and total costs are often relatively low for recovering the first units of a resource, these costs can go up exponentially once the cheapest options have been exhausted.

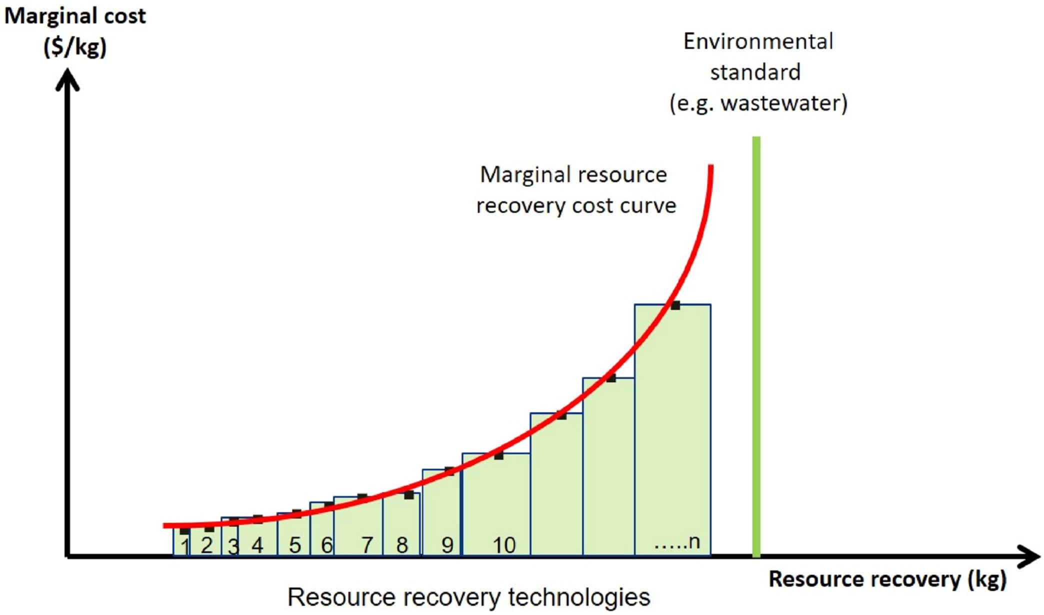


Figure 14.1 Simple form cost-effectiveness analysis.

A cost-effectiveness analysis is also a multidisciplinary exercise, requiring the input and collaboration of different scientific disciplines, such as scientists (physical effects of technologies), economists (costs of technologies), and engineers (other relevant details about the technologies such as recovery potential). Furthermore, the analysis often also needs the input and collaboration of policy and decision-makers as they determine the scope and objective of the analysis (e.g., the environmental standard).

14.7 BROADER SOCIETAL EFFECTS OF RESOURCE RECOVERY

Strictly speaking, a CBA only includes those costs and benefits that can be quantified in monetary terms. However, it will hardly ever be possible to monetize all impacts all the time. Those impacts that cannot be monetized are often left out of the analysis. Non-monetized impacts, if considered relevant, can nonetheless be included in a qualitative discussion accompanying the discussion of the CBA results. While a textbook CBA requires that all impacts be monetized, in practice different approaches exist to include non-monetized impacts in the CBA. In some approaches, they are listed as '*pro memoriam*' items on the balance sheet, expressed in qualitative or quantitative form. For example, the environmental impact of a project for which no monetary value could be calculated, like the improvement of water quality in a river or lake and the positive impact this may have on fish and other life below the water, or the spatial contours of a project like a reduction in the necessary landfill space to dump waste if it is processed and reused instead. In other cases, such impacts, if left unquantified and non-monetized, will either be ignored, left for a subsequent environmental impact analysis, or only partially monetized. The approach of monetizing impacts where possible, and including them in another form where full monetization is not possible, marks a deviation from the textbook ideal but does not discredit the CBA method as such.

In practice, investment decisions by public sector (e.g., government departments) and private sector (e.g., companies) agents are often evaluated primarily on the basis of their financial budgetary costs, as these can be assessed relatively easily. The calculation of economic costs and benefits, especially non-priced external environmental effects, is a more difficult task. An economic CBA is a more appropriate method for evaluating resource recovery technologies and projects that have significant impacts on public environmental goods, such as the improvement of water and air quality or climate change mitigation. As a result, the environmental changes induced by resource recovery projects may have an impact that goes beyond an investor or government agency and affects society as a whole. Such impacts should consequently be valued and evaluated from a societal perspective, not from the perspective of the investor or government agency alone.

An example of an economic CBA that addresses both the financial and broader economic impacts of resource recovery is given in Table 14.3. In this example, the so-called shadow price of phosphorous is also taken into account. A shadow price is the calculated or simulated price of a good or service for which no market price exists. The shadow price hence aims to reflect what this price would be if it had been traded on a market. As in this chapter's previous example (Table 14.2), the study focuses on magnesium ammonium phosphate, also known as struvite. Recovering struvite from residential wastewater reduces the chemical costs of wastewater treatment because it reduces sludge generation. Consequently, the landfill area needed for sludge disposal is also less. Struvite has been shown to be a valuable agricultural fertilizer (Evers *et al.*, 2016). In the study by Molinos-Senante *et al.* (2011), approximately 1 kg of struvite can be recovered from 100 m^3 of wastewater. The estimation of the shadow price for phosphorous recovery in this study varies between 18 and 80€/kg of recovered phosphorous based on 20 wastewater treatment plants in the coastal zone of Valencia in Spain.

Note that the costs and benefits in Table 14.3 are presented as annual values and are not discounted. The latter is preferred if the annual values occur at different points in time. For example, it may take a while before the ecosystem recovers from previous damages and hence before the avoided damage costs manifest themselves. If this is the case, the present value of the estimated damage costs would go down. If we take, for example, a discount rate of 5%, the present value of the avoided environmental

Table 14.3 Example of a financial and economic cost-benefit analysis of phosphorous recovery in 20 wastewater treatment plants in Valencia, Spain. The economic CBA includes on the benefit side the estimated avoided environmental damage costs, which were valued using a shadow price method. Note that the results of a CBA are presented as a balance sheet, meaning that a gain or loss is presented as a balancing item, equating total costs and benefits.

Costs	**€/year**	**Benefits**	**€/year**
Investment	70 887	Revenues from struvite sale	2378
Operation and maintenance	14 000	Savings in operation costs	10 000
Financial costs	4253		
Costs	89 140	Revenues	12 378
		Financial loss	76 762
Total costs	89 140	Total revenues	89 140
Costs	**€/year**	**Benefits**	**€/year**
Investment	70 887	Revenues from struvite sale	2378
Operation and maintenance	14 000	Savings in operation costs	10 000
Financial costs	4253	Avoided environmental damage costs	170 960
Costs	89 140	Revenues	183 338
Economic gain	94 198		
Total costs	183 338	Total revenues	183 338

Source: Adapted from Molinos-Senante *et al.* (2011).

damage costs would be around €134 000 if they would only occur after five years, €105 000 after 10 years or €82 000 if they would only occur after 15 years. A break-even point would be reached after year 16, when the present value of the avoided damage costs would dive under €76 000. This illustrates the sensitivity of the results to discounting future benefits (step 9 in Table 14.1). How to discount future costs and benefits will be addressed later in this chapter.

In a financial analysis, the upscaling of phosphorous recovery technologies in urban wastewater treatment plants stands little chance as long as the financial costs of phosphorous recovery are orders of magnitude larger than the current market price of rock phosphate, unless there are significant cost savings involved, for example in operation (e.g., energy, labor) or material (e.g., chemicals, water) costs, as shown in Table 14.2. However, accounting for the environmental externalities caused by unrecovered phosphorous discharged from wastewater treatment plants (eutrophication) and the pollution caused by phosphate mining due to the release of toxic wastewater (e.g., Reta *et al.*, 2018) and other beneficial aspects of phosphorous recovery (e.g., Mayer *et al.*, 2016) produces a different outcome. In this case study, the avoided external costs outweigh the implementation costs of phosphorous recovery.

14.8 ECONOMIC VALUATION OF RESOURCE RECOVERY EXTERNALITIES

Many environmental resources, such as water and air, are often not priced in monetary terms, creating important challenges for projects aiming to recover resources and protect the environment at the same time. For many goods and services provided by environmental resources (e.g., clean air or freshwater) there is no market where they are traded, and therefore no market price is available which reflects their economic value. There are, however, several economic valuation methods, which allow placing a monetary value on these non-market goods and services. The economic valuation of environmental resources compares people's willingness to pay for and the opportunity costs of the goods and services supplied by the resources involved. Accordingly, a wide range of environmental goods and services can be explicitly recognized in the CBA.

In economics, value is expressed as the degree to which people want to give up scarce resources, such as money or time, to acquire or retain something. Value exists in this sense only through the interaction between a subject (individual) and an object, and is therefore not considered an intrinsic quality of something (Pearce & Turner, 1990). As in other social sciences, the value people attach to something like the benefits associated with resource recovery is based upon a hypothesized positive relationship with their observed behavior or verbal responses. In economics, the value that an individual assigns to something is usually revealed through market behavior and measured in monetary terms by that individual's willingness to pay (WTP). For instance, an industry is willing to pay to some extent the market prices for the minerals it needs in its production process, a consumer is willing to pay for bottled water or a farmer is willing to pay the market prices for fertilizer to improve crop growing conditions and/or reduce the risk of crop failure. In cases where resources do not have market prices, one can ask hypothetical questions about someone's WTP. For example, visitors to recreational lakes can be asked for their WTP to improve the quality of these lakes, thereby improving their recreational experience and reducing potential health risks due, for example, to harmful algae blooms.

In their survey focusing on upgrading a local wastewater treatment plant, Paola *et al.* (2018) asked 400 residents in the city of Ferrara in north Italy's Po valley for their WTP for using reclaimed water from the local wastewater treatment plant in a constructed wetland located in a publicly-accessible green urban park surrounding the treatment plant. On average, they found a positive one-off WTP of €48 per household for the combined supply of treatment and recreational services. Aggregated across all the residents in the city of Ferrara served by the local wastewater treatment plant and living in the surroundings of the green space around the plant, the aggregated WTP provides an indicator of the total economic value (TEV).

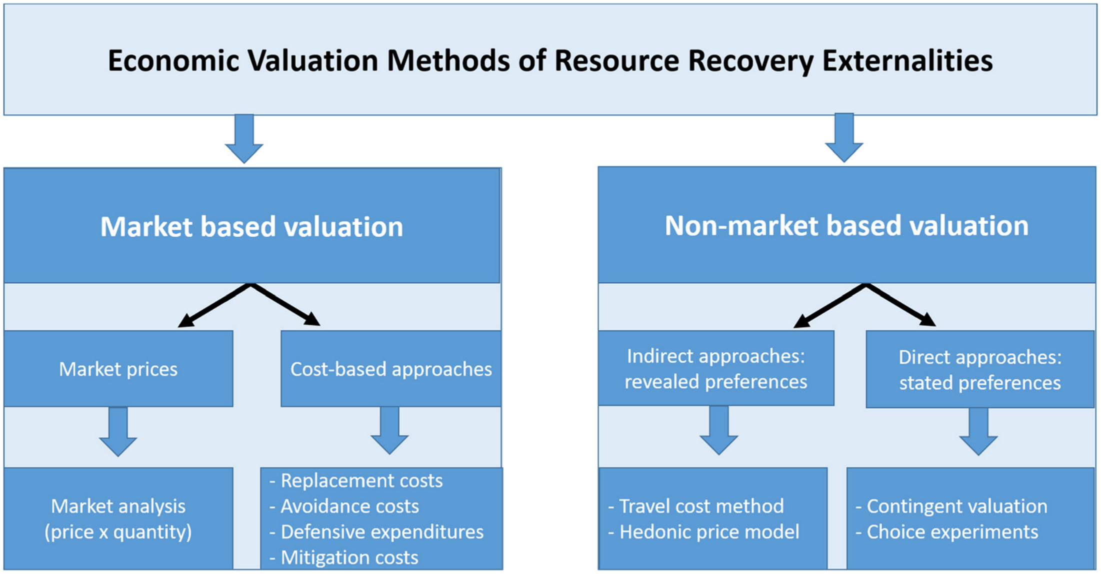


Figure 14.2 Overview of economic valuation methods for resource recovery externalities.

Environmental economists have introduced a taxonomy of this TEV, distinguishing between use and non-use values, in order to account for the various reasons and motives people may have to value environmental change. Use values are associated with the actual or potential future use of a recovered resource (e.g., fertilizer, irrigation water). In contrast, non-use values refer to values attached to resource recovery and reuse based, for example, on how the resource will benefit future generations.

A range of valuation methods exists for assessing the economic value of resource recovery externalities (Figure 14.2). The estimation of a shadow price, as presented in Molinos-Senante *et al.* (2011), is one approach (falling under the market-based valuation methods). Depending on the nature of the specific resource to be recovered, the potential externalities associated with its recovery, the presence of a market where the resource is exchanged and data availability, economic values can be estimated using various techniques, including direct and indirect market and non-market-based methods.

Market valuation means that existing market behavior and market transactions are used as the basis of the valuation exercise. Economic values are derived from existing market prices for inputs (production values) or outputs (consumption values), through more or less complex econometric modeling of dose-response or damage functions. Examples include the economic value of phosphorous in fertilizer, which is sold on a market (market analysis), the costs of replacing impaired environmental riparian functions such as nutrient retention and export through the installation of a wastewater treatment plant (replacement costs) or the costs of a water filter on tap water (avertive behavior or defensive expenditures).

Where market prices exist for the resource, these may have to be adjusted for market distortions such as taxes or subsidies in order to obtain their real or shadow prices, but otherwise they are likely to provide a relatively simple means of assessing economic market value. More advanced economic models (so-called applied general equilibrium models instead of the partial equilibrium methods discussed here) are needed if these prices are expected to change as a result of significant shifts in demand and supply of the resource involved or its alternatives.

In the absence of market prices for water or other resources, the economic value of the goods and services provided by these resources can be estimated with the help of direct and indirect non-market valuation methods. Non-market valuation means deriving economic values outside existing markets in cases where such markets are non-existent or distorted. Direct methods (also called stated preference methods) refer to contingent valuation (CV) and discrete choice experiments (DCE), where individuals are asked directly, in a social survey format, for their WTP for a specified environmental change.

WTP can also be measured indirectly through revealed preference methods by assuming that this value is reflected in the costs incurred to travel to specific sites (travel cost studies), prices paid to live in specific neighborhoods or wage differentials to account for occupational hazards (hedonic pricing studies). The latter approaches measure (environmental) use values because they typically relate to the use of a specific resource (e.g., a lake or green urban space), while stated preference methods like CV and DCE are able to also measure so-called non-use values by asking survey respondents to pay for resources without any intention to actually use them (e.g., simply because they value clean air or water or the preservation of natural resources for future generations).

In the context of the economic evaluation of resource recovery, the application of revealed and stated preference methods is limited. In theory, the choice of one of these methods depends on the relevant environmental impact of resource recovery and reuse. Travel cost studies may, for example, be appropriate if resource recovery and reuse have a positive impact on the quality of water resources that are used for recreational purposes and hence are expected to have recreational value (e.g., if phosphorous levels in wastewater effluent discharged into surrounding water bodies are reduced). Hedonic pricing studies can be applied in cases where resource recovery and reuse results in public health risks (e.g., microbial hazards or exposure to hazardous chemicals), and workers involved in resource recovery and reuse activities may only be willing to accept exposure to increased health risks in their workplace if they receive a risk premium on top of their salary. Stated preference methods such as CV and DCE have primarily been applied to measure consumer and farmer acceptance of and WTP for (partially) untreated wastewater in agriculture as an alternative water source in water scarce areas (e.g., Lienhoop *et al*., 2014; Ndunda & Mungatana, 2013).

Wastewater reuse brings various economic and environmental benefits. Economic benefits include the supply of irrigation water and nutrients (in addition to cost savings in wastewater treatment), while environmental benefits mainly relate to reduced pollution loads into water courses that protect water quality and dependent ecosystems. Wastewater reuse is widespread worldwide due to its year-round availability and nutrient content, contributing to food security especially in those parts of the world facing serious water resource constraints (e.g., Jaramillo & Restrepo, 2017). However, it may result in a variety of negative health effects, both for those applying wastewater such as crop farmers and those handling (traders) and consuming (households) the crops grown with (partially) untreated wastewater. Partially treated and untreated wastewater reuse has furthermore been directly linked to diarrheal diseases in epidemiological studies focusing on farmers and farm workers (Helmecke *et al*., 2020). Foodborne outbreaks due to salmonella or *Escherichia coli* related to the consumption of fresh produce like lettuce are well documented (e.g., Adegoke *et al*., 2018). These outbreaks may negatively impact public opinion and acceptance of food products grown with (partially) untreated wastewater.

In general, public acceptance of wastewater reuse is higher for non-potable applications (e.g., irrigation of public parks or flushing toilets) (Boyer *et al*., 2012). Baghapour *et al*. (2017) conducted a public survey among a representative sample of 562 residents living in Shiraz, one of the largest cities in Iran, and found that public tendency to accept the reuse of wastewater in various applications is greater among respondents who have a higher level of awareness of wastewater treatment processes. A possible explanation could be that better informed residents may be more capable of assessing the public health risks involved. This outcome furthermore suggests that it may pay off to invest in information and awareness raising campaigns to communicate the risks involved.

Studies applying stated preference methods like CV and DCE are summarized, for example, in Bouzit *et al*. (2018), who find an average WTP for treated wastewater and its reuse of $56 per household per year (price year 2010) based on 22 studies conducted mostly in Greece and Australia. The majority of these non-market valuation studies estimate WTP for improving the capacity or technology of wastewater treatment plants. Thirteen studies examined consumers' WTP for wastewater reuse in food production, while eight of the 22 studies focus on farmers' WTP for wastewater reuse, and one study (Menegaki *et al*., 2007) investigated both farmers' and consumers' WTP for using and eating food crops irrigated with recycled wastewater. Those stated preference studies that included a so-called 'yuck' factor in their analysis, that is where respondents expressed a disgust for the use wastewater, yielded a significantly lower mean WTP value, while respondents' knowledge of wastewater reuse and trust in the local government significantly increased household WTP.

An example of the inclusion of the non-market benefits of wastewater reuse in CBA is given in Alcon *et al*. (2013). The costs and benefits of reclaimed water use on an experimental citrus farm in southeast Spain are compared with those of using surface water and a mixture of water sources. The non-market benefits of reclaimed wastewater were estimated based on a CV survey in the Region of Murcia, in which 352 residents were interviewed. Respondents were informed about the amount of money they currently pay for wastewater treatment and were asked if they would be willing to pay more to raise wastewater purification up to a level that would make it suitable for use in agriculture. They were told this would contribute to the preservation of the river's ecological status by reducing the pressure on the resource, while at the same time ensuring water supply for agriculture. The maximum amount respondents were willing to pay was an average of €5.13 per household per month on top of their current water rate. The CBA overview, including the estimated WTP, is presented in Table 14.4.

Table 14.4 Example of an economic cost-benefit analysis of wastewater reuse in irrigated agriculture in southern Spain.

	Surface Water	Mixed Water	Reclaimed Water
A) Annual revenues			
Yield (kg/ha)	45 625	50 566	37 955
Price (€/kg)	0.27	0.27	0.27
Total revenues (€/ha)	12 136	13 450	10 096
B) Annual costs			
Material input costs	32	33	23
Irrigation water	1927	2014	1243
Fertilizer	797	797	797
Plant protection	353	353	353
Electricity	456	456	456
Other	306	306	306
Labour costs			
Irrigation maintenance	606	606	606
Pruning	531	531	531
Phytosanitary treatment	344	344	344
Other	186	186	186
Machinery equipment	349	349	349
Tax and insurance	253	253	253
Total costs (€/ha)	6108	6195	5424
C) Financial gross margin (A-B) (€/ha)	6028	7255	4672
D) Environmental benefits (€/ha)	0	385	1927
E) Economic gross margin (C + D) (€/ha)	6028	7640	6599

Source: Alcon *et al.* (2013).

14.9 INTERNALIZING EXTERNALITIES

In some cases, governments and public agencies try to internalize the externalities of resource use, for example through the creation of a carbon tax or carbon trading scheme. By pricing externalities, investors and other decision-makers are more likely to factor them into their decisions and change their behavior accordingly. Money is a common language, often more persuasive and powerful than words or even rules and regulations. Many resources (e.g., minerals) are traded in economic markets, and their scarcity should theoretically be reflected in their market price. We would expect higher scarcity to result in a higher market price, although a straightforward relationship between geologically scarce minerals and their long-term price levels may not always exist (Henckens *et al.*, 2016). As the market price of a mineral increases, the more lucrative it becomes to develop technologies that allow us to extract it from less accessible locations or media at higher cost (e.g., oil sands). Higher prices are also expected to result in the search for alternatives or substitute resources (e.g., biofuels). In the oil industry, a distinction is therefore made between technically and economically recoverable resources (Miller & Sorrell, 2014). A similar distinction can be made for other types of resources, for example wastewater.

There are also resources, including water and wastewater, that do not necessarily have markets where they are traded and hence that do not have market prices to signal their scarcity and value. Or they have a market price (water is e.g. traded in different parts of the world where water markets were created), but this price is somehow distorted and as a result does not reflect the true value of the resource that is being used or depleted. Water pricing is a good example of such potential distortions, where water is considered an economic good (1992 Dublin Statement on Water and Sustainable Development) on the one hand, and a basic human right (to safe drinking water at an affordable price; UN Human Rights Council Resolution A/HRC/15/L.14) on the other. Economists argue that if prices do not properly reflect scarcity conditions, decision-making aimed at economic efficiency may be misinformed. These non-market resources will have no market price (i.e. are provided 'free of charge') or a very low price (e.g., due to market distortions). As a result, they may not be fully accounted for in policy and decision making and remain outside any financial analysis based on market transactions and cash flows. Regulation and standard setting may in these cases be the only option, or a combination of regulation and pricing. For example, by ensuring that every person or household is supplied a minimum amount of water for free or at an affordable low price, and a volumetric price system for every cubic meter of water consumed over and above this minimum supply standard to reconcile the views above that water is a basic human right and an economic good at the same time. Or imposing water quality standards as in the US Clean Water Act and allow water quality trading based on compliance with effluent limitations (Morgan & Wolverton, 2008).

14.10 DISCOUNTING

Costs and benefits may occur at different points in time. The expression goes that you have to invest time, effort or money before you can expect anything back. Similarly, costs and benefits associated with a project implementation often look like the flow of values in Figure 14.3. Negative values indicate costs, positive values benefits. One-off investment costs like the purchase of a new technology or the construction of a new building result in relative high negative values (costs in red) at the beginning of a project while positive annual values (benefits in blue) may only arise after a few years, after the technology has been installed and becomes operational until the end of the technology's lifetime.

In order to make costs and benefits comparable over time (e.g., the costs of a resource recovery project at the start of the project in its first year of implementation with project costs that would occur e.g. five or 10 years after the start of the project), economists discount future flows of costs

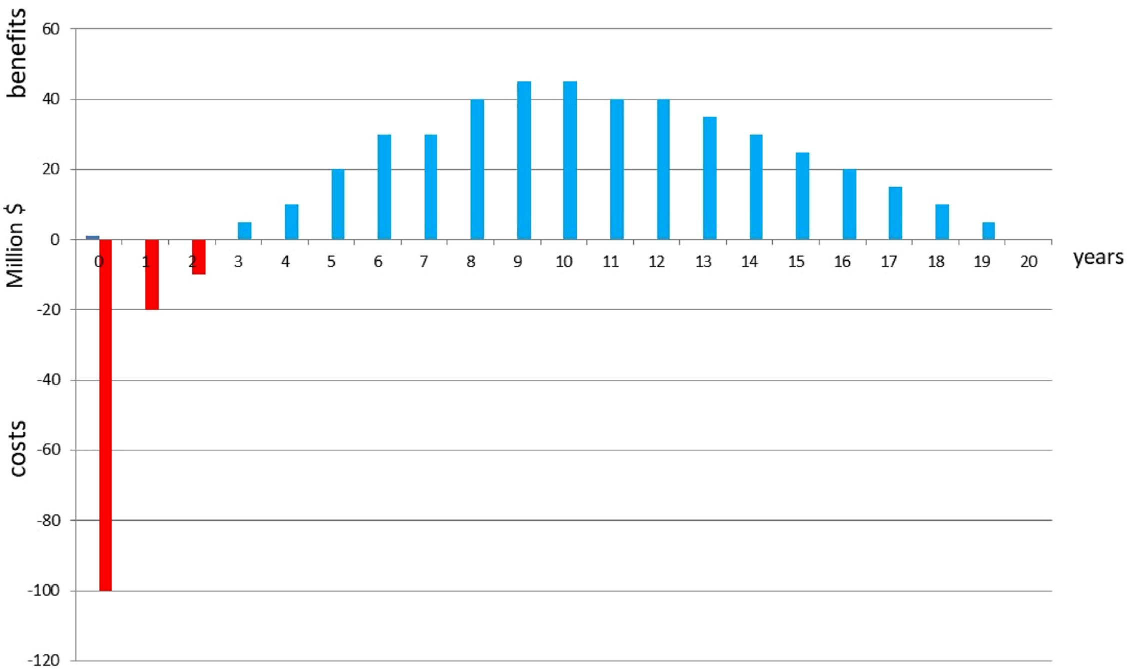


Figure 14.3 Typical flow of costs and benefits in project evaluations.

and benefits to their present value (step 7 in Table 14.1). Discounting means that the value of a future cost or benefit is weighted and modified to reflect its value at the time of starting the implementation of the project in 'year 0'. There may be various reasons for discounting future costs and benefits, including time preferences (people prefer to have money now than later in the future) and the opportunity costs of capital (investing money in one project means that it cannot be invested in another project or put in a savings account in a bank where it would generate interest revenues). Discounting is a standard economic practice in project appraisal (see e.g. the UK's HM Treasury 2018 Green Book for Central Government Guidance on Appraisal and Evaluation, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf).

14.11 ECONOMIC DECISION CRITERIA

Ultimately, a CBA compares the costs and benefits of different technologies or resource recovery projects in monetary terms. The results of this analysis can be presented in different ways (step 8 in Table 14.1):

(i) As a net present value (NPV): the present value of the benefits minus the present value of the costs, where a positive NPV indicates that the technology or project is economically beneficial.
(ii) As a benefit-cost ratio (BCR): the present value of the total benefits divided by the present value of the total costs, where a ratio larger than 1 indicates that the technology or project is economically beneficial.

(iii) As an internal rate of return (IRR): the discount rate where the NPV is equal to zero, or the project breaks even, that is where the present value of the benefits is equal to the present value of the costs.

The choice for one or multiple decision criteria depends on the purpose of the presentation of the results. The first two criteria directly answer the first question in Section 14.4: is a project worthwhile from an economic perspective? A project is worthwhile undertaking if the NPV >0 and the BCR >1. An NPV >0 automatically also means a BCR >1. If multiple project alternatives are evaluated, these two criteria also answer the second question in Section 14.4: which project yields the highest net benefit? Here the project with the highest NPV or BCR is preferred.

The IRR is usually used to examine the opportunity costs of capital or to see how patient or impatient an investor is when discounting future flows of costs and benefits. The IRR can be compared to the rate of return when bringing the investment sum to a bank for example, or to the IRR of an alternative investment project. The IRR therefore helps to answer the second question and determine the preferred course of action by selecting the most profitable project, where the project with the highest IRR is preferred, since this is the discount rate at which the costs and benefits break even. A lower (higher) discount rate means that a future flow of net benefits breaks even more (less) rapidly. Typically, a project would have an IRR > central bank interest rate. If not, it would be more profitable to put the investment needed for the project in a bank account and earn interest on it.

A related criterion, often used in the private sector, but not based on discounting, is the payback time. This is the number of years it takes before an investment is earned back through the net benefits it generates. For example, if an investment of $200 000 generates a net benefit of $20 000 per year, the payback time is equal to 10 years ($200 000/$20 000/year = 10 years).

A pre-programmed excel sheet is included in the Appendix to this chapter which can be used to calculate the three different decision criteria mentioned above (NPV, BCR and IRR).

14.12 SUMMARY

This chapter described the most important decision-support tool in the economists' toolbox: cost-benefit analysis. Cost-benefit analysis (CBA) is an economic evaluation method, comparing in a structured and systematic way the positive and negative effects of resource recovery across one or more recovery technologies. CBA can be used to evaluate one resource recovery technology (comparing the incremental impacts of resource recovery to a situation of no resource recovery) or multiple technologies (comparing the effects of different resource recovery technologies). In the latter case, the resource recovery technology yielding the highest net benefits is preferred, while in the former case, the 'with' (resource recovery) situation is preferred to the 'without' (resource recovery) situation as long as the net benefits of resource recovery are positive.

CBA can be used before the start of a new resource recovery project, during the project implementation and afterwards. Ideally, costs and benefits are monitored throughout the lifetime of the project and thereafter, to learn and adapt based on new insights. It is usually difficult to predict all possible impacts before the start of a new resource recovery project, and costs and benefits may only become clearer and quantifiable once the project has been implemented. Insofar possible, all these effects are quantified and expressed in monetary terms, but that often proves to be challenging in practice, especially for non-priced environmental impacts.

The difference between financial and economic cost-benefit analysis was explained. Costs and benefits are ideally expressed in monetary terms, but that is not always possible. Non-monetary effects are also included in a CBA. Resource recovery is expected to have long-lasting impacts on the environment and possibly future generations, justifying the use of a broader economic or societal analysis instead of a narrow financial cash flow analysis for an individual investor. It is especially these longer-term environmental effects that are typically hard to capture in monetary terms. Moreover, using a positive discount rate implies that longer-term benefits are valued less than costs and benefits that occur nearer in the future. Systematically identifying and qualifying the different effects associated with resource recovery with the relevant decision-makers and stakeholders involved can in itself be a valuable exercise, raising awareness of the pros and cons of resource recovery. Involving and consulting different parties allows them to help identify all the relevant impacts, voice possible concerns, open up information sources, identify relevant uses and values, and ultimately make outcomes of a CBA more acceptable, because all relevant interests have been heard and are represented in the CBA.

14.13 DISCUSSION QUESTIONS

Question 14.1: Why is it important to make a distinction between financial and economic analysis of resource recovery?

Question 14.2: Discuss which internal stakeholders will be convinced by a cost-effectiveness analysis and which will be convinced by a cost-benefit analysis.

Question 14.3: Discuss why economists use non-market valuation methods in cost-benefit analysis.

Question 14.4: Discuss why economists include a project or policy intervention that fall outside existing economic markets into their cost-benefit analysis.

Question 14.5: Discuss why economists discount future costs and benefits.

Question 14.6: Discuss why and under which conditions resource recovery is an economic problem.

Question 14.7: What are important social and economic drivers and barriers to resource recovery?

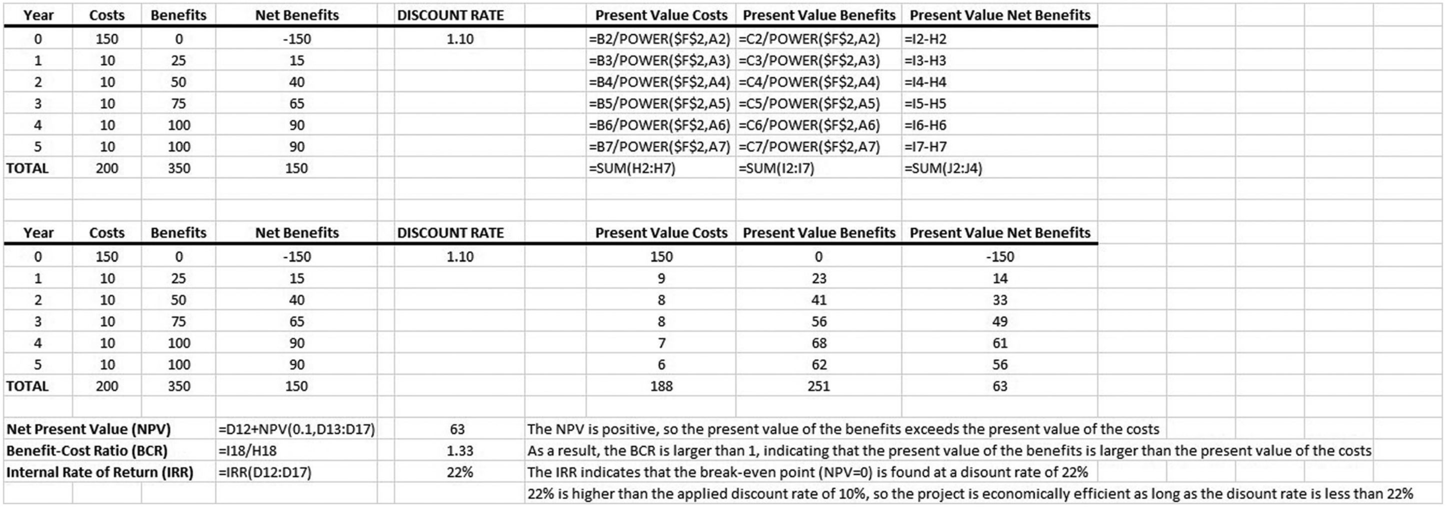
Question 14.8: What are important pre-conditions to establish an economic market for resource recovery? Give examples of existing markets for marketed resources and potentially new markets for currently non-marketed resources.

Question 14.9: Discuss what role economic policy instruments like pricing, taxes or subsidies can play to incentivize resource recovery. Give practical examples where possible.

Question 14.10: Assume you are the innovation manager of a large municipal wastewater treatment plant, facing increasingly limited local government budgets. You are assigned to present a master plan to the board of directors for the coming 10 years to extend the current treatment capacity (from 400 000 to 600 000 Population Equivalents, currently with conventional activated sludge processing) and at the same time find ways to increase revenues for the different services the wastewater facility is able to provide, targeting different customers, positioning yourself strategically in an increasingly circular economy. How would you justify your master plan economically speaking? What would be key success or failure factors to implement your master plan?

Mixed water includes surface and ground water and 20% reclaimed water. Reclaimed water originates from a wastewater treatment plant with tertiary treatment. Differences in irrigation water influence irrigation water costs and yields. Using reclaimed water allows more water to remain in the river system, yielding ecological benefits. Accounting for the environmental benefits of reclaimed water, makes this economically speaking a preferred option to the use of surface water.

Appendix: Setting up your cost-benefit analysis in Excel



Year	Costs	Benefits	Net Benefits	DISCOUNT RATE	Present Value Costs	Present Value Benefits	Present Value Net Benefits
0	150	0	-150	1.10	=B2/POWER(F2,A2)	=C2/POWER(F2,A2)	=I2-H2
1	10	25	15		=B3/POWER(F2,A3)	=C3/POWER(F2,A3)	=I3-H3
2	10	50	40		=B4/POWER(F2,A4)	=C4/POWER(F2,A4)	=I4-H4
3	10	75	65		=B5/POWER(F2,A5)	=C5/POWER(F2,A5)	=I5-H5
4	10	100	90		=B6/POWER(F2,A6)	=C6/POWER(F2,A6)	=I6-H6
5	10	100	90		=B7/POWER(F2,A7)	=C7/POWER(F2,A7)	=I7-H7
TOTAL	200	350	150		=SUM(H2:H7)	=SUM(I2:I7)	=SUM(J2:J4)

Year	Costs	Benefits	Net Benefits	DISCOUNT RATE	Present Value Costs	Present Value Benefits	Present Value Net Benefits
0	150	0	-150	1.10	150	0	-150
1	10	25	15		9	23	14
2	10	50	40		8	41	33
3	10	75	65		8	56	49
4	10	100	90		7	68	61
5	10	100	90		6	62	56
TOTAL	200	350	150		188	251	63

Net Present Value (NPV)	=D12+NPV(0.1,D13:D17)	63	The NPV is positive, so the present value of the benefits exceeds the present value of the costs
Benefit-Cost Ratio (BCR)	=I18/H18	1.33	As a result, the BCR is larger than 1, indicating that the present value of the benefits is larger than the present value of the costs
Internal Rate of Return (IRR)	=IRR(D12:D17)	22%	The IRR indicates that the break-even point (NPV=0) is found at a disount rate of 22%
			22% is higher than the applied discount rate of 10%, so the project is economically efficient as long as the disount rate is less than 22%

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