UNIONE EUROPEA
Fondo Sociale Europeo

Ministero dell'Istruzione, dell'Università e della Ricerca

PON
RICERCA E INNOVAZIONE
2014 - 2020

UNIVERSITY OF SALERNO

Ph.D. Course

in

Risk and Sustainability in Civil, Architectural and Environmental Engineering Systems

XXXIII Cycle (2017-2020)

INNOVATIVE MODELS FOR THE ECONOMIC ANALYSIS OF INVESTMENT RISK AND FOR ESTIMATING THE EXTRA-FINANCIAL EFFECTS OF INTERGENERATIONAL PROJECTS

Ph.D Coordinator:
Prof. Fernando Fraternali

Ph.D Student:
Gabriella Maselli

Tutors:
Prof. Antonio Nesticò
Prof. Shuquan He
Dr. Rosa Maria Caprino

Ministero dell'Istruzione, dell'Università e della Ricerca

UNIVERSITY OF SALERNO

Department of Civil Engineering

Ph.D. Course

in

Risk and Sustainability in Civil, Architectural and Environmental Engineering Systems

XXXIII Cycle (a.a. 2019-2020)

INNOVATIVE MODELS FOR THE ECONOMIC ANALYSIS OF INVESTMENT RISK AND FOR ESTIMATING THE EXTRA-FINANCIAL EFFECTS OF INTERGENERATIONAL PROJECTS

Gabriella Maselli

Tutor
Prof. Antonio Nesticò

Co-tutors
Prof. Shuquan He
He Shuquan
Dr. Rosa Maria Caprino

Ph.D. Course Coordinator
Prof. Fernando Fraternali

Table of Contents

Abstract 9
Premise and research topic 9
Research purposes and novelties 10
Findings 11
Practical and social implications 11
Structure of the work 11
1. A critique of the Cost-Benefit Analysis (CBA) in the evaluation of risk, and social and environmental benefits 13
Summary 13
1.1. Recalls on CBA 13
1.2. CBA in the European and extra-European legislative landscape 17
1.3. Critical parameters of the CBA 21
1.3.1. Time horizon 22
1.3.2. Risk and uncertainty 23
The lack of data often leads the valuer to estimate cash flows under conditions of uncertainty or risk. 23
1.3.3. The discount rate 24
2. Risk-neutral and probabilistic approaches to address economic, environmental, social and cultural risk analysis 28
Summary 28
2.1. Risk and uncertainty: preliminary notions 29
2.2. The risk-management process in the safety field 32
2.2.1. Goal and stages of the process 32
2.2.2. The ALARP principle for risk assessment 35
2.3. The risk management in the economic evaluation of investment projects 38
2.3.1. Techniques for uncertainty analysis 40
2.3.2. Techniques for risk analysis 42
2.3.3. Critical issues 58
2.3.4. Risk assessment in inter-generational projects 60
2.3.5. The legislative landscape 69
3. Setting thresholds of risk acceptability with the As Low As Reasonably Practicable approach 75
Summary 75
3.1. The ALARP principle for the assessment of investment risk 76
3.2. The steps of the investment risk management process 80
3.3. ALARP and CAPM. A novel model for the financial risk management 83

3.3.1. Phases of the risk assessment model 84
3.3.2. A statistical methodology for the estimation of the tolerability and acceptability thresholds of the investment risk..88
3.4. Estimation of the threshold values for the investment risk. Applications to different sectors in Europe and China...90
4. The Social Discount Rate in the assessment of extra-financial risks............100
Summary...100
4.1. Concept and novelties of the model..101
4.2. The steps of the model...102
4.3. An innovative methodology to estimate the economic discount rate and environmental discount rate..106
4.3.1. The Environmental Performance Index to estimate the environmental quality...107
4.3.2. The operational phases for estimating the economic declining discount rate and declining environmental discount rate...110
4.4. The estimation of the DDRs for Italy and China 114
5. Analysis of extra-financial risks associated with China's Belt and Road Initiative (BRI)...129
Summary...129
5.1. Objectives, challenges and risks related to the BRI...................................129
5.2. The Belt and Road in the Euro-Asian continent 135
5.3. An in-depth look at China-Italy collaboration in the BRI...........................138
5.4. Investment sectors, regions and cooperation formats of the projects involved in BRI 142
5.5. Critical variables and extra-financial externalities of the investment projects involved in the BRI...146
6. Economic analysis with the Environmental Performance Index and Stochastic Growth Rate of Consumption Model: Case study for Chinese urban development investment...151
Summary...151
6.1. Rationale and outputs of the investment program 151
6.3. Financial analysis and management of the investment program.................169
6.4. Economic analysis of the investment program 171
6.5. Implementation of the economic risk assessment model............................186
6.5.1. Subproject "Eco-Dike" (embankment)...187
6.5.2 Subproject "Wetland area development" 204
6.5.3. Subproject "Ecological preservation of bare hills" 209
7. Conclusions 218
References...223
Sitography...233

Appendices 234
Appendix 1 234
Appendix 2 249
Appendix 3 252

Index of Figures

Figure 1. Steps of the Risk Management Process (source: own elaboration) 34
Figure 2. Representation of the ALARP principle (source: own elaboration) 37
Figure 3. Structure of a decision tree (source: own elaboration)..............................52
Figure 4. Examples of stochastic dominance (source: own elaboration) 56
Figure 5. Societal risk evaluation criteria: example of a risk curve on the F-N plane (source: own elaboration)..79
Figure 6. Example of probability density function of IRR (source: own elaboration) 82
Figure 7. Example of cumulative distribution function of IRR (source: own elaboration) 82
Figure 8. Risk Analysis steps in the economic evaluation of the projects (source: own elaboration) 83
Figure 9. Acceptability and tolerability of the investment risk (source: own elaboration) 86
Figure 10. Acceptability and tolerability of the investment in terms of cumulative probability of ENPV (source: own elaboration)...105
Figure 11. The phases of the model (source: own elaboration)..............................110
Figure 12. The relationship between EPI and GDP per capita (source: own elaboration) 117
Figure 13. The relationship between EPI and GDP per capita to estimate δ (source: own elaboration) 118
Figure 14. Probability distribution for g_1, r_c and r_q for Italy (source: own elaboration) 120
Figure 15. Probability distribution for g_1, r_c and r_q for Italy (source: own elaboration) 122
Figure 16. Term structure of economic discount rate r_{ct} and ecological discount rate r_{qt} for Italy (source: own elaboration) 124
Figure 17. Step structure of economic discount rate r_{ct} for Italy (source: own elaboration) 124
Figure 18. Step structure of environmental discount rate r_{qt} for Italy (source: own elaboration) 125
Figure 19. Term structure of economic discount rate r_{ct} and ecological discount rate r_{qt} for China (source: own elaboration) 126
Figure 20. Step structure of economic discount rate r_{ct} for China (source: own elaboration) 126
Figure 21. Step structure of environmental discount rate r_{qt} for China (source: own elaboration) 127

Figure 22. The Belt and Road Initiative: economic corridors spanning Asia, Europe, and Africa (source: Mercator Institute for China Studies, MERICS). 133
Figure 23. Project of Italian ports 142
Figure 24. The sub-projects locations (source: ADB's Environmental Impact Assessment) 156
Figure 25. The "Eco-Embankment" sub-project (source: ADB, 2018, Environmental Impact Assessment) 157
Figure 26. The "Sponge City" project (source: ADB, 2018, Environmental Impact Assessment) 157
Figure 27. The "Wetland area" project (source: ADB, 2018, Environmental Impact Assessment) 158
Figure 28. Landfill area after closure and restoration (source: ADB, 2018, Environmental Impact Assessment)...159
Figure 29. Overview of the Green-Wedge (source: ADB, 2018 Environmental Impact Assessment) 160
Figure 30. Post restoration of bare hills (source: ADB, 2018, Environmental Impact Assessment) 161
Figure 31. TVET photo rendering (source: ADB, 2018, Environmental Impact Assessment) 162
Figure 32. Probability distributions of critical variables for sub-project "Eco-Dike" (source: own elaboration)...189
Figure 33. Probability distributions of ENPV for the case 1 and case 2, for sub-project "Eco-Dike" (source: own elaboration)..193
Figure 34. Cumulative probability of ENPV for the case 1 and case 2, for sub-project "Eco-Dike" (source: own elaboration)...196
Figure 35. Cumulative probability of ENPV post mitigation for the case 1 and case 2, sub-project "Eco-Dike" (source: own elaboration) 204
Figure 36. Probability distributions of ENPV for the case 1 and case 2, wetland area development (source: own elaboration) 207
Figure 37. Cumulative probability of ENPV for the case 1 and case 2, for sub-project "Wetland area development" (source: own elaboration)............................208
Figure 38. Probability distributions of ENPV for the case 1 and case 2 for sub-project "Ecological preservation of bare hills" (source: own elaboration).............212
Figure 39. Cumulative probability of ENPV for the case 1 and case 2 for sub-project "Ecological preservation of bare hills" (source: own elaboration).........................213
Figure 40. Probability distributions of ENPV for the case 1 and case 2 for sub-project "Ecological preservation of bare hills" (source: own elaboration).............216
Figure 41. Cumulative probability of ENPV for the case 1 and case 2 for sub-project "Ecological preservation of bare hills" (source: own elaboration).........................217

Index of Tables

Table 1. Critical issues in risk analysis techniques (source: own elaboration)..........59
Table 2. Investment risk assessment according to European Commission guidelines (2014) (source: own elaboration based on EC information) 72
Table 3. Principles to apply in Data Handling for Probabilistic Risk Analysis 74
Table 4. Panel of companies analysed by sector and territorial context....................91
Table 5. r_t and r_a estimation for Europe...93
Table 6. r_t and r_a for China 94
Table 7. Estimation of $WACC_t$ $WACC_a$ for the three investment sectors in Europe 96
Table 8. Estimation of $WACC_t$ $WACC_a$ for the three investment sectors in Europe 98
Table 9. The Environmental Performance Index (Source: Wendling et al. 2018) ..109
Table 10. Mortality rates for Italy and China over the 30-year period 1991-2020..115
Table 11. Statistical indices for g_1, r_c and r_q for Italy 121
Table 12. Statistical indices for g_1, r_c and r_q for China 123
Table 13. Sectors, regions and cooperation formats of the projects involved in BRI (source: https://beltandroad.hktdc.com/en/project-database) 144
Table 14. Key variables and externalities by sector/type of project (source: own elaboration based on information from Asian Development Bank and European Commission, 2014)..147
Table 15. Estimate of costs by category of expenditure (source: ADB, 2018) 170
Table 16. Conversion Factor for Civil Works (source: ADB, 2018) 172
Table 17. Economic Analysis, Eco-dike (source: ADB estimation).......................174
Table 18. Economic Analysis "Sponge" city interventions (source: ADB estimation) 176
Table 19. Economic Analysis, Wetland area development (source: ADB estimation) 177
Table 20. Economic Analysis, Landfill closure, restoration, and after-use (source: ADB estimation)..179
Table 21. Economic Analysis, Green wedge (source: ADB estimation) 180
Table 22. Economic Analysis, Ecological preservation of bare hills (source: ADB estimation)...181
Table 23. Economic Analysis, R&D platform for equipment for the service industry (source: ADB estimation) 182
Table 24. Economic Analysis, Testing and inspection facilities for equipment for light industries (source: ADB estimation)..184
Table 25. Economic Analysis, Technical and vocational education and training (source: ADB estimation) 185

Table 26. Base Case Economic Internal Rates of Return and Economic Net Present Values (source: ADB estimation) 186
Table 27. Sensitivity analysis for sub-project "Eco-Dike" (source: ADB estimation) 187
Table 28. Environmental DDR (r_q) and Economic DDR (r_e) 190
Table 29. Risk analysis statistics in the two cases, sub-project "Eco-Dike" (source: own elaboration) 194
Table 30. Investment costs to infrastructure the urban park (source: own elaboration) 198
Table 31. Estimation of the cultural offer can be evaluated in terms of willingness to pay for the cultural services (source: own elaboration)..200
Table 32. Benefit deriving from the increase in real estate value (source: own elaboration) 202
Table 33. Risk analysis statistics post mitigation interventions in the two cases, sub-project "Eco-Dike" (source: own elaboration) 203
Table 34. Sensitivity analysis for sub-project Wetland area development (source: ADB estimation) 205
Table 35. Sensitivity analysis for sub-project "Wetland area development" (source: ADB estimation) 209
Table 36. Risk analysis statistics in the two cases for sub-project "Ecological preservation of bare hills" (source: own elaboration) 211
Table 37. Estimation of costs and benefits for trees for sub-project "Ecological preservation of bare hills" (source: own elaboration) 214
Table 38. Risk analysis statistics in the two cases for sub-project "Ecological preservation of bare hills" (source: own elaboration) 215

Abstract

Premise and research topic. The *ex-ante* assessment of the investment risk for civil works is an essential part of the decision-making process. In fact, when it is not possible to express with certainty forecasts on the critical variables of a project, both practical requirements and regulatory guidelines make it necessary to consider the risk by evaluating economic performance indicators in stochastic terms. In this regard, it is worth emphasising from the outset that EU and non-EU regulatory references explicitly require the investment risk rates to be included, in relation to the size of the project and the availability of necessary data.

It is necessary to distinguish the issues related to the estimation of investment risk in the two cases of: (i) *financial evaluations*, i.e. made from the point of view of the private investor; (ii) *economic evaluations*, i.e. carried out from the point of view of the public operator, who aims at maximising the welfare of the community.

With reference to case (i), the main limitation of investment risk analysis is the lack of acceptability thresholds in the legislative framework. This makes it difficult to make economic judgements based on shared criteria and objective data.

In the case of economic evaluations (ii), in addition to the problems mentioned above, there is the need to give due "weight" to the environmental, social and cultural externalities of the project. In this regard, the result of the Cost-Benefit Analysis (CBA) is significantly influenced by the choice of the Social Discount Rate (SDR), a parameter that allows to make the Cash Flows economically comparable when they occur at different times from the moment of the evaluation. However, the use of traditional discount procedures - based on constant rates - ends up underestimating costs and benefits progressively further away in time, not guaranteeing in the long run a balance between environmental integrity, intergenerational equality and economic efficiency.

Research purposes and novelties. With reference to *financial evaluation* (i), the aim is to characterise an innovative risk management model able to support the investor in the decision-making process by overcoming the limitations and criticalities identified. This can be done firstly by defining the minimum levels of acceptance of the investment risk; then by characterising a methodology for the estimation of the threshold values. With regard to the definition of threshold values, the novelty is the use of the As Low As Reasonably Practicable (ALARP) logic, which has never before been used for the economic assessment of investment risk. According to the ALARP principle, which is used whenever the risk of loss of human life has to be estimated, the risk assessment is related to two thresholds: the threshold of acceptability and the threshold of tolerability. Specifically, a risk is defined as ALARP if it falls between these two thresholds, i.e. if the costs of mitigating the risk appear disproportionate to the benefits to be gained. Once the risk acceptance criterion has been established, it is necessary to define a methodology for estimating the limit values of acceptability and tolerability of the project risk. The idea is to use both the Capital Asset Pricing Model (CAPM) and statistical survey tools, thus making it possible to estimate risk thresholds according to both the investment sector and the territorial context in which the project is located.

In the case of economic evaluation (ii), the aim is to define an evaluation protocol that considers both the investment risk, which tends to increase over time, and the need to give due weight to the environmental and social impacts of the project: while it is true that these terms are not known with certainty, the joint "risk-discounting" effect would lead to underestimating significant environmental and social effects.

If the reference for the evaluation of the investment risk is again the ALARP logic, the main novelty concerns the characterisation of an innovative model of economic-environmental discounting that allows to estimate a discount rate of the strictly economic components different from the one to be used for the evaluation of the environmental externalities. There are two main innovative elements of the model: the first concerns the definition of environmental quality as a function of the Environmental Performance Index (EPI), which makes it possible to establish how close countries are to achieving the UN's 2015 Sustainable Development Goals; the second novelty concerns the growth rate of consumption, modelled as a risky variable.

Findings. The estimation of risk acceptability and tolerability thresholds to be used in financial evaluations is conducted for both the European and Chinese economic context in the following sectors: Engineering-Construction; Environmental & Waste Services; Green & Renewable Energy. The calculations show that the risk thresholds differ significantly depending on the country and the investment sector. Specifically, these thresholds have much higher values in China than in Europe, due to the different systematic risk.
The estimate of the discount rates to be used for Italy and China shows how the higher uncertainty related to environmental quality compared to the uncertainty on the evolution of the macroeconomic framework, leads to a lower environmental discount rate than the economic one. In addition, the faster decreasing functions of the economic discount rate and the environmental discount rate for the Chinese economy show that China has a more pressing need to invest in green projects than Italy.
Finally, the application of the proposed model to an investment programme for urban development in China, along the route of the Belt and Road Initiative (BRI), allows to effectively guide the analyst in the selection of risk mitigation and residual risk of the investment.
Practical and social implications. The two models that the research outlines for investment risk management allow for a consistent triangular balancing of risks, costs and benefits, making the entire decision-making process more transparent and rational.
In addition, the study demonstrates the weight of the Social Discount Rate on the outcomes of economic evaluation. The use of dual and declining discounting allows to give a fair value to environmental damages and benefits that are more distant in time: the use of conventional discounting procedures would lead to unsustainable choices, as the decision-maker would be oriented towards investments with high initial returns, but with long-term environmental repercussions. Remarkable are the policy implications that research results can bring about in terms of a more sustainable allocation of resources.
Structure of the work. It is divided into seven chapter. The first chapter analyses the critical issues of Cost-Benefit Analysis with respect to: the assessment of the investment risk, the choice of the analysis time horizon, the estimation of the discount rate. Chapter 2 deals with a critical review of the

relevant literature. The third and fourth sections are devoted to the characterisation of the protocol for project risk management, respectively in the case of financial and economic evaluation. A relevant part of section 4 is the definition of an innovative econometric model of economic-environmental discounting.

The last part of the paper deals with the application case, an investment programme in support of the Belt and Road Initiative (BRI). The case study was selected during the research semester at the School of Economics at Shanghai University. Section 5 describes the initiative under analysis, section 6 reports the implementation of the proposed model and returns the results, section 7 renders concluding remarks and relevant economic policy implications.

Keywords: *Economic evaluation of the projects; Cost-Benefit Analysis; Investment risk; ALARP logic; Social discounting; Environmental externalities.*

1. A critique of the Cost-Benefit Analysis (CBA) in the evaluation of risk, and social and environmental benefits

Summary

The *ex-ante* risk assessment of civil investments is an essential part of decision-making. In fact, when it is not possible to express with certainty forecasts on the critical variables of the project, it becomes necessary to consider the investment risk by expressing the outcome of the Cost-Benefit Analysis (CBA) in stochastic terms. Therefore, it is essential to outline the theoretical framework of CBA, a technique which allows to express a judgement on the economic convenience of the investment, highlighting its limits and critical aspects. Thus, this chapter intends to provide a critical examination of the Cost-Benefit Analysis through three main sections. Section 1.1 recalls the essential theoretical elements on which CBA is based. Section 2.2 frames the legislative landscape that guides the decision maker in assessing the economic performance of the investment. Finally, Section 3.3 analyses the critical aspects and parameters of CBA, with a focus on: (i) risk and uncertainty, (ii) Social Discount Rate; and (iii) time horizon. In summary, this chapter introduces the two main issues which are the leitmotifs of this work: the assessment of investment risk and the evaluation/actualisation of the extra-financial effects, including long-term effects, that the investment project generates on the territory.

1.1. Recalls on CBA

Cost-Benefit Analysis (CBA) is a technique traditionally used to evaluate the economic performance of an investment and to choose between alternative projects. It is related to economic and financial evaluations, which concern investment decisions aimed at allocating both private and public resources.

While financial evaluation is conducted from a private point of view, i.e., from an entrepreneurial perspective, economic evaluation is conducted from a public point of view, i.e., investments are not evaluated with respect to the individual, but with respect to the community as a whole.

In other words, the financial evaluation is based on the comparison between costs and revenues generated by the initiative and aims to ascertain that the investments guarantee conditions of financial convenience in terms of maximizing the profits of the companies. Economic evaluation, on the other hand, considers the costs and benefits of investment from the point of view of society as a whole, i.e. from the point of view of the entire nation. If economic evaluation is conducted by seeking the costs and benefits that flow from investment to the community without regard to its distribution among the various social groups, then it is generally referred to as an efficiency analysis; if, on the other hand, it considers the distributive effects of investment, i.e., the effects produced for each social group, then the analysis is more properly defined as one of equity.

The apparently clear distinction between economic and financial evaluation should not lead to error since one does not preclude the other. On the contrary, even when it is necessary to evaluate projects involving the allocation of public resources, it is not possible to conduct an economic feasibility analysis without a preliminary financial analysis. In fact, it is necessary to first verify whether the public project can “pay for itself” during its life. On the other hand, the financial perspective alone fails to capture the overall growth of society, so an estimate of economic costs and benefits becomes necessary (Asian Development Bank, 2013).

The financial analysis is conducted using only the elements of company accounting and employing market prices. The objective of financial analysis is to use project cash flow forecasts to estimate indicators of return on investment. Although CBA goes beyond merely assessing the financial performance of the project, most of the cost and benefit data used in it comes from financial analyses. These analyses provide the evaluator with essential information about inputs and products, their prices, and the time schedule structure of revenues and expenditures.

The object of economic analysis is to define the project’s contribution to the economic well-being of the region or country. The economic analysis examines the costs and benefits of investment in terms of maximizing the welfare function of the community, using so-called shadow prices, synthetically defined as those prices that can measure the net impact on social welfare of an incremental unit of that good available in the public sector

(Drèze J. & Stern N., 1987, p. 911) [1]. Shadow prices reflect the social value of a good or service, corresponding to the opportunity cost of any resource allocation, i.e., they reflect society's avoidance of producing alternative goods. Generally, shadow prices differ from market prices because of distortions created by both government and the private sector. Tariffs, export taxes and production subsidies, duties and sales taxes are the main distortions created by governments. Additional distortions are introduced by monopolies that can be induced by both government and private sector actions. Finally, market distortions arise from the nature of products and services: the value to society of common public services such as water, transportation, and electricity are often greater than the financial costs at which they are purchased by people (Belli, Anderson, Barnum, Dixon, & Tan, 1998, p. 48)[2].

The transition from financial to economic analysis is expressed firstly by the transformation of market prices into account prices (which correct prices distorted by market imperfections); then by taking into account possible externalities that cause social benefits and costs not considered in the financial analysis, because they do not generate real monetary outputs or revenues - consider, for instance, possible environmental impacts or redistributive effects. This is made possible by assigning a conversion coefficient to each input and output item to transform market prices into account prices. In international practice, some standard coefficients have been defined for some categories of income/expenditure, while for others specific coefficients have to be estimated. The economic analysis, therefore, consists of: 1) tax corrections; 2) correction for externalities; 3) conversion of market prices into account prices to include also social costs and benefits.

It has been said that both financial and economic evaluations are traditionally covered by the Cost-Benefit Analysis (CBA), which can be considered a three-dimensional technique, since it requires the estimation of: costs, benefits and the time in which each cost item is incurred and each benefit item is realised. Thus, once the time horizon has been defined, i.e. the

[1] Pag 911*: ‹‹The shadow price of a good measures the net impact on social welfare of a unit increase in the supply of that good by the public sector››.*

[2] Pag 48*: ‹‹Tariffs, export taxes and subsidies, excise and sales taxes, production subsidies, and quantitative restrictions are common distortions created by governments. Monopolies are a market phenomenon that can be created by either private or public sector actions. Some market distortions are created by the nature of the good or service: the values to society of common public services, such as clean water, transportation, road services, and electricity, are often significantly greater than the financial prices people are required to pay for them››.*

maximum number of years for which Cash Flows (CFs) forecasts are provided, CBA is substantiated:

1. in the forecast of the costs and benefits that the project initiative generates in the analysis period;
2. the subsequent discounting of the CF, given by the difference between revenues (or benefits) and costs;
3. then in the estimation of the performance indicators: the Net Present Value (NPV), the Internal Rate of Return (IRR), the Benefit/Cost ratio, the Payback Period.

If the evaluation criterion is the Financial Net Present Value (FNPV), in the case of a financial analysis, or the Economic Net Present Value (ENPV), in the case of an economic evaluation, then a project is economically viable when the sum of discounted Cash Flows is positive and sufficiently large:

$$FNPV = -C_0 + \sum_{t=1}^{n} \frac{R_t - C_t}{(1 + r_F)^t} > 0 \quad (1.1)$$

$$ENPV = -C_0 + \sum_{t=1}^{n} \frac{B_t - C_t}{(1 + r_E)^t} > 0 \quad (1.2)$$

Where: C_0 is the initial investment; R_t and C_t are the financial revenues and costs over time; B_t and are the economic benefits and costs generated by the project over time; r_F and r_E are the financial discount rate and the economic discount rate (or Social Discount Rate), respectively.

The difference between ENPV and FNPV is that the first one uses account prices or opportunity costs of goods and services and not distorted market prices, and also includes as far as possible any environmental and social externalities. As shadow prices and externalities are included, many projects with a low or negative FNPV may have a positive NPV.

The Financial Internal Rate of Return (FIRR) and the Economic Internal Rate of Return (EIRR) are defined respectively as those values of the discount rate that cancel out the FNPV and the ENPV:

$$-C_0 + \sum_{t=1}^{n} \frac{R_t - C_t}{(1 + FIRR)^t} = 0 \quad (1.3)$$

$$-C_0 + \sum_{t=1}^{n} \frac{B_t - C_t}{(1 + EIRR)^t} = 0 \quad (1.4)$$

Thus, if the FIRR (or EIRR) is considered as a performance indicator, a project is economically viable if its value is at least equal to the value of the discount rate used to estimate the FNPV (or ENPV).

Again, an investment initiative is sustainable if the ratio of the present value of revenues (or benefits) to costs is positive:

$$-C_0+\sum_{t=1}^{n}\frac{(R_t/C_t)}{(1+r_F)^t} \quad (1.5)$$

$$-C_0+\sum_{t=1}^{n}\frac{(B_t/C_t)}{(1+r_E)^t} \quad (1.6)$$

Finally, the Payback Period corresponds to the number of years needed to compensate the initial investment through positive cash flows. According to this criterion, the shorter the payback period, the preferable the investment.

1.2. CBA in the European and extra-European legislative landscape

The European legislative landscape recognises the centrality that Cost-Benefit Analysis must have in the decision-making process concerning the allocation of financial resources. In this respect, the selection of high-quality projects, which ensure the best value for money and impact on growth and employment, is a key success factor for the overall EU cohesion policy strategy. In this perspective, CBA is explicitly requested, along with other instruments, as a basis for decision-making on the co-financing of major projects included in the Operational Programmes (OPs) of the European Regional Development Fund (ERDF) and the Cohesion Fund (CF).

As mentioned above, CBA is an analytical tool to assess the variation in social welfare resulting from an investment decision and, consequently, its contribution to the achievement of cohesion policy objectives. The purpose of CBA is thus to facilitate a more efficient allocation of resources by demonstrating the societal value of a particular intervention in comparison with possible alternatives.

Specifically, the European Commission (2014) first describes the legal requirements and the scope of application of CBA in the assessment of intervention initiatives, as set out in EU regulations; then outlines the role of CBA in the broader EU policy framework in the light of the Europe 2020 Strategy, the objectives of priority initiatives, major sectoral policies and cross-cutting policies, including climate change and energy efficiency, while also highlighting synergies with other EU financial instruments, first and foremost the "Connecting Europe Facility".

As regards the scope of the CBA, it is explicitly required in the case of "Major Projects". Pursuant to Article 100 of Regulation (EU) No 1303/2013, a Major Project is an investment operation comprising «a series of works, activities or services intended to accomplish an indivisible task of a precise economic and technical nature, with clearly identified aims and a total eligible cost more than EUR 50 million». This cost represents the part of the investment eligible for EU co-financing. In the case of operations covered by Article 97 (Thematic Objectives) of EU Regulation 1303/2013, on the other hand, the financial threshold for identifying the major project is set at €75 million.

Specifically, to obtain co-financing for a major project, the European Commission requires:

a) details regarding the body responsible for implementing the major project and its functions;
b) a description of the investment and its location;
c) the total cost of the work and the total eligible cost;
d) the feasibility studies carried out, including the analysis of options and their results;
e) the cost-benefit analysis, including an economic and financial analysis, and a risk assessment;
f) the environmental impact analysis, taking into account climate change mitigation and adaptation needs and disaster resilience;
g) arguments on the consistency of the major project with the relevant priority axes of the operational programme, the expected contribution to the achievement of the specific objectives of these priority axes, as well as the expected contribution to socio-economic development
h) the financing plan, including an assessment of physical and financial indicators to monitor progress taking into account the identified risks;
i) the timetable for the implementation of the Major Project (Art. 101 of EU Regulation 1303/2013, information required for the approval of a Major Project).

Although the CBA is only one of the required information elements, it is closely interconnected with all the other documents and is also an integral part of the overall project preparation. The importance of the CBA is undoubted, as the results of the analysis must demonstrate that the project meets the following requirements:

1. it is coherent with the Operational Programme (OP), i.e. that the results expected from the project contribute significantly to the achievement of the specific objectives of the priority axis of the OP and the underlying policy objectives;
2. requires co-financing. This condition is assessed on the basis of the results of the financial analysis and, in particular, through the calculation of the Financial Net Present Value and the Financial Rate of Return of the investment (respectively the FNPV and FIRR). In order to request the contribution of the Funds, the NPV must be negative and the FIRR lower than the discount rate used for the analysis;
3. it is desirable from a socio-economic point of view. This condition is assessed on the basis of the results of the economic analysis and, in particular, by the presence of a positive Economic Net Present Value (ENPV). In order for the results of the CBA to properly support the evaluation of a major project, it is necessary to demonstrate that the methodology used to draw it up is solid and consistent.

In this regard, also the *Asian Development Bank* in the "*Cost-Benefit Analysis for Development: A Practical Guide*" (2013) emphasises the extreme importance of CBA in the evaluations. In addition to its role in the evaluation of individual projects, CBA is an important aid in the design of sector strategies, for example in road, rail and air transport and in the social sectors of health and education. Even where public funds cannot be used directly, it can still be used to assess the greater or lesser attractiveness of the various options under analysis.

Several Organisation for Economic Co-operation and Development (OECD) governments regularly use CBA to assess public sector projects. For example, the UK regularly produces guidance notes on the application of economic analysis. In fact, where there are quantifiable benefits and costs, these must be formally incorporated into assessments (HM Treasury, 2018). This approach is applied as standard practice in the UK road sector, where project economic analysis is combined with wider transport modelling. The UK Treasury also uses the CBA framework to assess projects to tackle climate change.

The Asian Development Bank (ADB) and other Asian regional development banks continue to emphasise that a rigorous application of project economic analysis is a key component of the planning process.

However, according to the ADB, the results of the analysis should not only be presented in terms of estimated individual performance indicators (ENPV and FNPV), but the likelihood of occurrence, i.e. in terms of risk and uncertainty, should be assessed. Furthermore, the *ex-ante* economic analysis must be carried out at different stages of the project's life, both to monitor progress, anticipate or remove possible problems, and to learn "lessons" for similar future projects.

According to ADB, 10 key areas are necessary to analyse the economic feasibility of a project:

1. Macroeconomic assessment;
2. Investment sector assessment;
3. Demand assessment;
4. Economic logic;
5. Analysis of project alternatives;
6. Cost-Benefit Analysis;
7. Financial and institutional sustainability;
8. Analysis of the distribution of the advantages/benefits of the project;
9. Sensitivity and risk analysis;
10. Monitoring and evaluation.

In addition to the economic analysis, it is necessary to implement the environmental impact assessment, the social safeguard assessment, including resettlement, gender, and poverty issues. These additional assessments provide additional information for the economic analysis and, in general, the costs of implementing an environmental management plan and a resettlement plan, including compensation payments, are included in the project costs.

In summary, for several types of projects, such as transport, water, energy or, more generally, for investments with social and environmental impacts, financial appraisal alone, although important as a guide to long-term viability, rarely provides a complete picture of the economic value of a project. Thus, for these projects, a related but separate economic analysis is both relevant and necessary (Asian Development Bank, 2017a).

In the United States, the Guidelines for Preparing Economic Analyses (2020) is the main scientific reference for carrying out economic analyses of

environmental regulations and policies, as it considers recent advances in the field of environmental economics. For this reason, the addressees of the Guidelines are those who carry out or use economic analyses, including policy makers, regional offices and contractors who provide economic reports to U.S. Environmental Protection Agency (EPA).
The Guidelines fulfil multiple functions, namely:

1. assist policy makers in developing regulations that achieve the highest environmental and human health quality standards at the lowest costs;
2. they provide analysts with the information they need to prepare high quality economic analyses;
3. establish a general framework for economic analyses across the Agency and among EPA program offices;
4. ensure that important topics, such as uncertainty, timing, and evaluation of costs and benefits, are addressed consistently in all EPA economic analyses.

In addition, the guidelines are intended to address key analytical issues concerning:

- the reduction of health risks and the improvement of environmental quality;
- the discounting of benefits, costs and impacts over time;
- the identification of data sources available to conduct economic analysis;
- the presentation of the results of the economic analysis, including non-monetary information.

1.3. Critical parameters of the CBA

The main difficulty of CBA is the analysis of the three "dimensions", which involves comparing costs and benefits after expressing them in monetary terms and making them homogeneous – and therefore comparable – by means of financial discounting operations at the time of estimation. It is important to emphasise that, of the project effects considered according to the degree of detail of the analysis, the CBA reduces them all in monetary terms. The aim is to make them comparable with each other and to provide the results through a single indicator. However, this is also the major limitation of the tool, especially in economic analyses where the environmental and social externalities of the investment need to be assessed. In fact, even if it is difficult to express them in quantitative terms, they represent considerable contributions in the case of projects with environmental effects. It is therefore impossible not to take them into account. In essence, it is the heterogeneity of the project's effects and the uniqueness of the assessment criterion that is a limitation of CBA. The assessment of external costs and benefits can sometimes be difficult, although it is on the whole easy to identify them. It is extremely important to at least list the non-quantifiable externalities to provide decision-makers with more elements to make their decisions, weighing the quantifiable aspects, expressed by the economic rate of return, against the non-quantifiable ones, expressed by qualitative indices and assessed with the support of multi-criteria analyses.

Another critical issue concerns the correct estimation of the parameters that influence the final value of the economic performance indicator:

1. the time horizon t of the project;
2. the cash flows CFs;
3. the financial discount rate r_F and the economic discount rate r_E.

1.3.1. Time horizon

The time horizon is defined as the maximum number of years for which forecasts are provided. Forecasts on the future performance of the project should be made for a period commensurate with its economic life and extend over a period long enough to capture the likely impact in the medium to long term. It follows that the choice of the time horizon may significantly influence the estimate of the profitability indicators and, consequently, the results of the valuation.

The identification of the time horizon of a project is linked to the sector in which the specific investment is located. According to the Cohesion Fund (CF) guidelines: «The life cycle varies according to the nature of the investment: it is longer for civil engineering works (30-40 years) than for technical installations (10-15 years). In the case of mixed investments, which include civil engineering works and installations, the life cycle of the investment can be set based on the life cycle of the main infrastructure (in this case, replacement investments of infrastructure with a shorter life must be included in the analysis. The life cycle can also be determined by legal or administrative considerations: e.g. the duration of the concession where a concession has been granted». According to the ISPA guidelines: «Infrastructure projects are typically assessed over a period of 20-30 years, which is a rough estimate of their economic life. Although physical assets can last significantly longer – for example, a bridge can last 100 years – it is generally not appropriate to attempt estimates for longer periods. In the case of physical assets with a very long life, the residual value reflecting the potential liquidation value, or the value of continued use should be included at the end of the period».

Again, plans, programmes, and projects whose benefits are felt by generations after those who implemented them are common. We need only think of investments with strong social implications, such as those in the field of human resources: education, training, research, and preventive healthcare. But also all environmental initiatives, where the beneficiary generations are often different from those bearing the costs (Nesticò & Maselli, 2019). In such cases, the definition of the time horizon is not only complex but also crucial for the evaluation. In fact, the identification of an insufficiently long analysis period would end up not considering certain effects – generally environmental, social and cultural – which are felt in the long term.

1.3.2. Risk and uncertainty

The lack of data often leads the valuer to estimate cash flows under conditions of uncertainty or risk.

In the first case, i.e. under *conditions of uncertainty*, the economic operator does not have enough information to associate a probability with the occurrence of future events. In this case, it is necessary to implement a sensitivity analysis, the purpose of which is to detect the effects of uncertainty related to the trend of the parameters capable of significantly affecting the results of the valuation. To this end, the change in the performance index of the initiative is recorded when the measurement of one parameter changes, if the others remain unchanged. Repeating the operation for all the selected factors, it is possible to recognise to which of these the project is most responsive (Nesticò, 2019).

In the second case, i.e. under *risk conditions*, each event can be associated with a probability of occurrence. Thus, the impossibility of expressing CF deterministically leads the analyst to estimate economic performance indicators in probabilistic terms. This can be done by implementing risk analysis, which allows the riskiness of the investment to be assessed. In a nutshell, the CFs generated by the project are treated as random variables; then, the probability distribution of the profitability index is estimated; finally, from the results obtained, it is possible to envisage interventions to mitigate the risk of failure of the investor. In this way, in order to take into account the riskiness of the investment, lower CF values will be obtained compared to those which would be obtained by implementing deterministic analyses.

Another possibility to consider the investment risk is to “act” on the discount rate, increasing the representative rate of non-risky assets with a term able to express the premium for the investment risk. For a more detailed discussion of the main risk analysis techniques currently used in practice, see Chapter 2. In fact, we would like to mention only the main limitation of investment risk assessment, namely the lack of rigorous and objective criteria in the literature to determine whether the investment risk and the residual risk, i.e. the risk that remains despite the proposed mitigation measures, is acceptable for the investor or for the community.

1.3.3. The discount rate

The discount rate is another critical parameter of CBA. It makes it possible to make the costs and benefits that the investment generates over time financially comparable. Thus, even small variations in its value significantly influence the results of the analyses and, consequently, the order of priority of the interventions to be financed where there is a need to select between several initiatives. This is true about both the financial discount rate r_F and the economic discount rate (or Social Discount Rate) r_E. However, the issue becomes even more complex for problems of social discounting, i.e. in the case of evaluations conducted from the point of view of the community.

First, in spite of the wide bibliography and the attention that scholars devote to the subject, there is still no convergence on the methodology and techniques that make social discounting possible. It is enough to think of the substantial differences between the three main recognised theoretical approaches, that of the Social Rate of Time Preference (SRTP), that of the Opportunity Cost of Capital (SOC) and that of the Shadow Price of Capital (SPC). Each of these, moreover, corresponds to different analytical formulations, with results that are also markedly different in the measurement of the rate in the first two cases and of the Net Present Value (NPV) in the last

(Zhuang, Liang, Lin, & De Guzman, 2007). In this regard, it should also be noted that many Governments do not provide indications on the methodological principles to be followed for the evaluation of the Social Discount Rate, simply referring the analyst to the generic value reported in some document, thus neglecting the socio-economic specificities of the territory in which the investment is to be made (Nesticò & Maselli, 2020).

Secondly, the question is even more theoretical and operational when the projects to be subjected to a cost-benefit test are those that have their effects on a long-time horizon. In such a case, the use of a discount rate deduced through traditional estimation procedures may lead to very limited present values of cash flows far from the time of the evaluation, thus strongly reducing their weight on the performance ratios.

Plans, programmes and projects whose benefits are felt by successive generations are frequent. In this regard, it is worth mentioning, among others: multi-objective water basin redevelopment schemes, concerning the supply of water for industrial and civil purposes, soil protection, and electricity production; reforestation projects, which reach their full operating phase 15-25 years after planting; investments in nuclear power plants, which are characterised by significant environmental risks only after the first 20 years after the power plants become operational; projects aimed at reducing greenhouse gas emissions, whose initial costs are very high, while the benefits are felt for centuries (Arrow, Cropper, Gollier, Groom, & al., 2013).

Thus, the long “life” of social policies, infrastructure investments, environmental projects, and cultural heritage initiatives, generating benefits, costs and in some cases risks over a period that goes beyond that of the generations evaluating them, requires the use of methods and techniques that allow these benefits, costs and risks to be taken into account in the relevant analyses.

This issue has important consequences in the discounting of cash flows estimated for projects subject to economic evaluation according to the logic of Cost-Benefit Analysis (CBA). In fact, conventional discounting procedures, i.e. conducted through constant or time-invariant discounting rates, cause an accentuated and sometimes unacceptable contraction of the very cash-flow values that are produced for future generations, thus ending up by underestimating the environmental and social effects of the investment.

To overcome this problem, some scholars propose using time-declining discount rates (or DDR) instead of constant ones, so as to give progressively greater weight to the long-term effects (Weitzman, 1998; 2001; Newell & Pizer, 2003; Groom, Koundouri, Panopoulou, & Pantelidis, 2007; Freeman, Groom, Panopoulou, & Pantelidis, 2013; Cropper, Freeman, Groom, & William, 2014). Kula & Evans (2011), on the other hand, argue that discounting has a critical impact on sustainability, so that even the use of DDR could give more weight to the present and the near future. Thus, in accordance with this vision, several scholars believe that environmental effects should be discounted differently and separately from economic impacts. (Price, 1993; 2003; Hasselmann, Hasselmann, Giering, Ocana, & von Storch, 1997; Plambeck, Hope, & Anderson, 1997; Yang, 2003; Weikard & Zhu, 2005; Viscusi, Huber, & Bell, 2008). This means that especially at a time of great stress on the global environment such as the one we are currently experiencing, a dual discount rate should be adopted in the cost-benefit analysis for projects with substantial environmental impacts:

- a rate to discount strictly financial cash flows;
- another rate, with a lower value, for the valuation of environmental externalities. (Gollier, 2010; 2012; Almansa & Martínez-Paz, 2011).

It is evident that two of the major problems of CBA, namely the assessment of investment risk and the choice of the discount rate, are not only closely related, but also in antithesis of each other. In fact, on the one hand, in order to take into account the investment risk, one could replace the so-called "risky" cash flows with "certainty equivalent" flows of lesser magnitude; or, alternatively, by increasing the discount rate with a rate expressing the investment risk premium. On the other hand, a discount rate that is too high in economic evaluations would end up underestimating the extra-monetary impacts - social, cultural and environmental - especially inter-generational impacts that occur progressively further away in time.

Thus, the aim of this thesis is to try to find solutions to the main limitations of CBA, with particular focus on investment risk analysis, distinguishing between financial and economic analysis.

In the case of financial analysis, the main limitation concerns the lack of thresholds for accepting risk, both in the literature of the sector and in national and EU regulatory guidelines.

In the case of economic analysis, in addition to the above-mentioned problems, there is the need to give the right "weight" to the social and environmental benefits and costs of the investment, which often occur at a time far removed from the time of the assessment and which would risk being underestimated or not considered at all in the analysis. To solve this problem, an innovative econometric model is defined for the estimation of discount rates able to give the right weight to the environmental effects of the investment, even in the long term. The rates estimated in this way then become an integral part of the characterisation of the project risk management model in the case of assessments conducted from the point of view of the public operator.

2. Risk-neutral and probabilistic approaches to address economic, environmental, social and cultural risk analysis

Summary

The aim of this chapter is to provide a critical review of the state of the art of the techniques currently used for project risk assessment, and of the main European and non-European regulatory references. In fact, the systematic study of the literature in the sector highlights critical points and limits to be overcome, first the lack of criteria for the acceptability of investment risk, which makes it difficult to express judgements of economic convenience based on shared criteria and objective data.

The chapter is structured in three main sections. The first section distinguishes between risk and uncertainty, clarifying their meaning and highlighting their differences. The second section focuses on the risk management process in safety and the As Low As Reasonably Practicable (ALARP) principle. This is because the ALARP approach - widely used to assess the risk of loss of human life in the nuclear, energy and Oil&Gas sectors - represents a general way of thinking applicable whenever the main objective is the triangular balance between costs, benefits and risks. Thus, we aim to show how ALARP can be an essential theoretical reference to overcome the problem of investment risk acceptability.

Finally, the third section examines the risk management process in the economic evaluation of projects. This is done both by comparing criteria and techniques and by analysing the main issues that arise: (i) in the case of financial appraisal, i.e. conducted from the point of view of the private operator; (ii) for public appraisals, i.e. conducted from the point of view of the community. An in-depth look at legislative issues both within and outside Europe concludes this chapter.

2.1. Risk and uncertainty: preliminary notions

For more than 30 years “risk assessment and management” has been regarded as a real scientific field, so much so that «several attempts have been made to establish broadly accepted definitions of key terms related to concepts fundamental for risk field» (Aven T. , 2016).

As far as purely qualitative definitions are concerned, there are many definitions of risk in the literature. According to the Society of Risk Analysis (2015), risk is understood as: «a) the possibility of an unfortunate occurrence; b) the potential for realization of unwanted, negative consequences of an event; c) the exposure to a proposition (e.g. the occurrence of a loss) of which one is uncertain; d) the consequences of the activity and associated uncertainties; e) the uncertainty about and severity of the consequences of an activity with respect to something that humans value; f) the occurrences of some specified consequences of the activity and associated uncertainties; g) the deviation from a reference value and associated uncertainties».

Again, the ISO 31000 standards (2009) refer to risk as «the possibility of generating a certain effect». The UK Cabinet Office (2002) refers to it as «uncertainty of an outcome». Also, about systematic terminology and approaches for risk assessment and management, there are variations both in relation to the scientific field and depending on the needs and objectives to be achieved (Steen, 2015).

What is generally recognised, however, is the centrality of risk whenever a problem must be solved or a decision made (Aven T. , 2018). So many international bodies and organisations have issued risk management guidelines. It is intended that ISO 31000:2009 be utilized to harmonize risk management processes in existing and future standards. Similarly, the International Atomic Energy Agency (1995), the Health Safety and Executive (2001), the European Commission (2002), and the World Health Organization (2002) have defined etymological aspects, standards and procedures for safeguarding human life in high-risk sectors.

In addition to purely qualitative definitions, the Society for Risk Analysis (SRA) also provides risk metrics (2015).

In terms of risk metrics, risk R can be defined as the combination of the probability of an event occurring and the severity of the consequences of the event. In formula:

a) $R = f(s_i, p_i, c_i)$,

where s_i denotes the i-*th* scenario, p_i is the probability that the i-*th* scenario has of occurring, and p_i expresses the consequence of the damaging event, with i = 1, 2, 3, ..., N.
Also consider the following relationship:

b) $R = f(C', Q, K)$,

with C' the consequences of the event, Q a measure of the risk associated with C with Q expressed in probabilistic terms, and K the background knowledge associated with C' and Q.

But risk can also be measured in terms of expected consequences, i.e. in terms of loss and/or damage, for example as:

- number of fatalities expected in the time interval of one year (Potential Loss of Life, PPL) or per 100 million hours of exposure (Fatal Accidental Rate, FAR);
- product of the probability P that the hazardous event has of occurring, of the probability $\overline{P}$ of exposure to the risk of the object in question and of the relative expected damage D:

$$R = P \cdot \overline{P} \cdot D$$

- expected disutility.

Finally, a further possibility is to express the risk R as a probability distribution related to the damage (SRA, 2015).

The latter definition was already proposed in 1921 by Knight F.H., according to whom there is risk precisely when the occurrence of events can be measured on a probabilistic basis, as opposed to what happens in conditions of uncertainty, characterised by the absence of significant data on the statistical frequency of the phenomenon and therefore appreciable only in a "subjective" manner.

Knight F.H. (1921) also focuses on the measurability of uncertainties, distinguishing between measurable uncertainties, properly called risks, and non-measurable uncertainties, the latter being true uncertainties: «It will appear that a measurable uncertainty, or "risk" proper, as we shall use the term, is so far different from an unmeasurable one that it is not in effect an uncertainty at all. We shall accordingly restrict the term "uncertainty" to cases of the non-quantitative type. It is this "true" uncertainty, and not risk, as has been argued, which forms the basis of a valid theory of profit and accounts for the divergence between actual and theoretical competition». According to the interpretation given, the effect of risk factors can have either negative or positive characteristics, thus configuring possible losses but also opportunities for the creation of greater value.

Later, Luce and Raiffa (1957) echoed Knight's differentiation between risk and uncertainty, distinguishing between certainty, risk and uncertainty. According to this definition, decision makers are in the realm of certainty, if they know the outcome to which their decision will lead; decision makers are in the realm of risk, if it is known that their decision will lead to a certain outcome with a certain probability; and they are in the realm of uncertainty, if the probabilities associated with the outcomes are unknown or meaningless.

It follows that the fundamental distinction between risk and uncertainty lies in the quantifiability of the number of possible decision outcomes and the probabilities of their occurrence. Uncertainty often refers to aspects of the decision-making process that are not easily quantifiable. Quantifiability is the key characteristic of risk but defining and measuring risk is not straightforward. Indeed, the process of defining risk in real life often reflects a political process that depends on the decision-maker, the technologies considered and the characteristics of the decision problem (Fischhoff, Watson, & Hope, 1984). These factors influence the process in two different stages of risk definition: the first is to determine which consequences or outcome dimensions to include; the second is to construct risk indices based on the consequences selected in the previous stage.

Also, according to the most recent definitions by Park and Shapira (2017), risk refers to decision situations in which all potential outcomes and their probability of occurrence are known to the decision maker, while uncertainty refers to situations in which the outcomes and/or their probability of occurrence are unknown to the decision maker. How decision makers perceive risk and uncertainty depends on both the context of the decision and the characteristics of the decision maker.

It is evident that the distinction between risk and uncertainty that was initially proposed by Knight (1921) has been widely taken up in the literature, also giving impulse to numerous researches concerning: (a) the classification of risks and uncertainties; (b) methodologies and techniques of risk analysis; (c) actions and strategies to be implemented in order to implement their effects. This concerns both risks and uncertainties related to business management and investment initiative.

Indeed, these concepts are widely shared in very different fields of application: from finance to safety engineering, from health to transport, as well as in supply chain management (Althaus, 2005). Nevertheless, the whole process of risk assessment and management is essential to make cost-effective judgements on investment initiatives. This is especially true for civil engineering projects, where the risk components are not only economic but also environmental, social and cultural (Nesticò, He, De Mare, & Maselli, 2018).

In this dissertation, the focus is on the *ex-ante* risk assessment of investments in the civil sector. However, before going into the merit of the techniques of investment risk analysis generally used in practice, it is necessary to define the logical-operative process of risk management and the phases of which it is composed, that is, in extreme synthesis: the identification of risks; the corresponding analysis and evaluation; then, the development of appropriate strategies for the control of the risks detected.

2.2. The risk-management process in the safety field

2.2.1. Goal and stages of the process

The main purpose of the risk management process is to ensure that people, the environment and resources are protected from harmful consequences resulting from human activities or natural events, while ensuring that planned activities are both economically viable and socially desirable (Yasseri, 2013). In other words, risk management makes it possible to plan strategies to contain the dangers/threats of an activity or, if unavoidable, to reduce their potential damage (Aven & Renn, 2009). In sectors such as nuclear and oil & gas, risk management was generally based on a prescriptive regulatory regime, where the regulator specified requirements for plant design and operation (Aven & Vinnem, 2007; Kumamoto, 2007). This approach has gradually been replaced by more goal-oriented regimes, which emphasise what to achieve rather than the means to do it. The goal-oriented regime, which implicitly recognises that risk must be managed because it can never be eliminated, has been enthusiastically supported by various sectors and international organisations alike (IPCS and WHO, 2004; European Commission, 2002). Indeed, such an approach to risk management is believed to deliver higher levels of performance in terms of both productivity and risk reduction.

In these new approaches, Quantitative Risk Assessment (QRA) is a key tool. It identifies possible hazards/threats, analyses their causes and consequences, and describes the risk. QRA provides the analyst with a useful basis for characterising the likely impacts, for assessing whether the risk is tolerable or acceptable, and for choosing the most efficient method of risk reduction.

Three strategies are generally used to manage risk: risk-informed, cautionary/precautionary and discursive.

The first strategy refers to the planning of mitigation actions resulting from the accurate qualitative, quantitative or semi-quantitative assessment of risky activities. The second strategy, also called resilience strategy, favours actions of containment, monitoring and screening of risks. The third, on the other hand, is based on actions aimed at reducing uncertainties, clarifying the evolutionary dynamics of risky processes, or involving those affected by the activities under examination (Renn, 2008; Aven & Renn, 2009).

Risk Management (RM) is therefore the set of processes useful for identifying, analysing, quantifying, eliminating and monitoring the risks linked to the performance of any activity and is substantiated in the logical-operational phases described below (Zio, 2007; Meyer & Reniers, 2013; Aven T. , 2015).

The first step is to establish the context, i.e. to define the scope and objectives to be pursued, taking into account both the costs and benefits of risk management.

This is followed by the second step of Risk Assessment (RA) which includes:

1. identification,
2. analysis and
3. risk estimation.

Step (1) allows to recognise potential hazards that would prevent the achievement of the objectives defined in the previous step.

Phase (2) is useful to understand the nature of risk events and to determine their causes and consequences.

In step (3) the information gathered from the identification and analysis is used to determine whether the risk is acceptable or whether mitigation strategies need to be undertaken. In this phase, each identified risk is given a ‘weight’ to draw up a priority list to guide the next risk treatment phase. Assigning the "weight" means estimating the level of risk as a function of the probability of occurrence of the event and its consequences.

The next step after the assessment is Risk Treatment (RT) which includes:

1. the selection of mitigation measures;
2. the implementation of the prepared plan;
3. the analysis and evaluation of the residual risk, i.e. the risk that remains despite the mitigation strategy undertaken.

The mitigation strategies can be of retention, if the risk cannot be reduced, avoided or transferred; of avoidance, if the source of risk is eliminated or the activity is interrupted; of transfer if the risk is transferred to another activity; of control if the probability of occurrence of the event or its consequences are acted upon by reducing one of the two terms or both; of acceptance when there is no possible and/or sustainable mitigation intervention so that the risk is accepted as it presents itself.

Communication and Consultation and Monitoring and Review are also essential, but they are continuous processes that accompany all phases of Risk Management (ISO 31000, 2009; Banks & Dunn, 2003; Teng, Thekdi, & Lambert, 2012).

Figure 1 summarises the phases of the Risk Management Process (RMP).

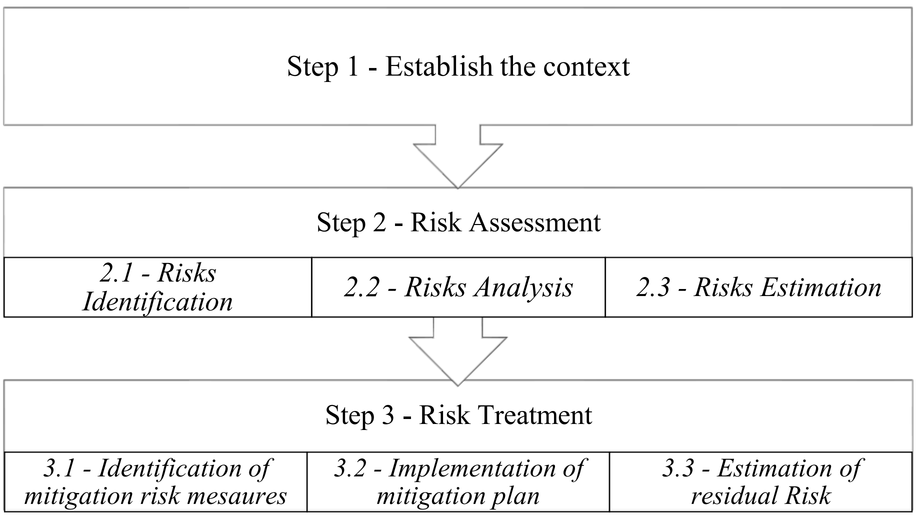


Figure 1. Steps of the Risk Management Process (source: own elaboration)

2.2.2. The ALARP principle for risk assessment

The ALARP logic aims at informing about the tolerability of the risk if it is "As Low As Reasonably Practicable", meaning that it is convenient to reduce the level of risk to the point where further action to reduce it is too costly (French, Bedford, & Atherton, 2007; Aven & Abrahamsen, 2007; Jones-Lee & Aven, 2011).

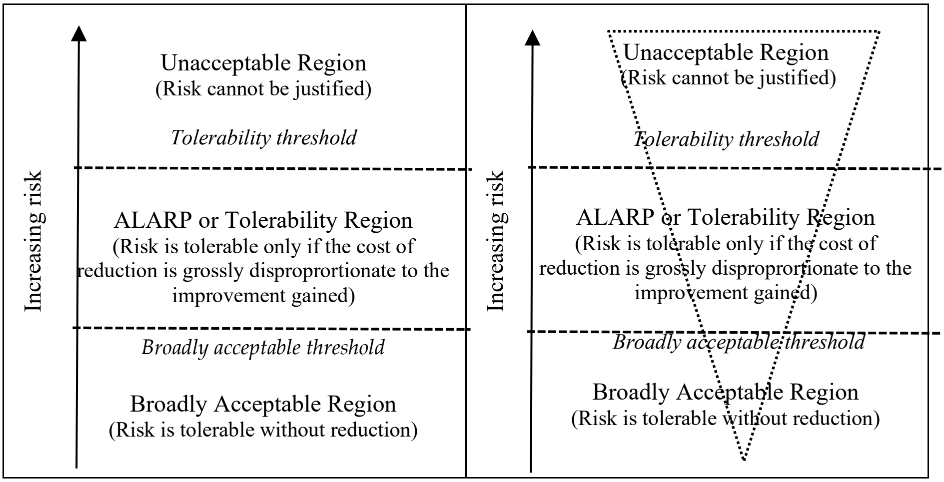
Already set out in the regulations of the Health and Safety Executive (2001; 2014), this approach goes back a long way, appearing in English documents such as the Salmon Fishery Act of 1861, the Self-acting Mules Regulations of 1905 or the Electricity Regulations of 1908.

Since the 1950s, the concept of As Low As Practicable (ALAP) has been introduced in the US in the field of radiation protection, prescribing that radiation exposure be kept within certain limits. In 1979, ALAP was replaced by ALARA (As Low As Reasonably Achievable). The difference between the two concepts lies in the different meanings of "Practicable" and "Achievable": an intervention can be defined as "practicable" if its technical feasibility can be demonstrated; on the other hand, "achievable" implicitly assumes that an intervention is always possible, even if its practical feasibility has not been demonstrated. Substantial is also the meaning of the term "reasonable". To understand its meaning, reference is made to 'Best Available Technology' (BAT) in a specific sector regardless of costs. In mitigation, BAT can reduce the risk to ALAP, but it is not necessarily the "reasonably practicable" techniques. In fact, 'reasonableness' implies the need to consider extra-monetary aspects such as social, cultural, environmental. In other words, any ALARP risk reduction intervention must be "reasonably" feasible and sustainable in a broad sense (Ale & Hartford, ALARP and CBA all in the same game, 2015). It is with this in mind that the Health and Safety at work etc. It is precisely this meaning that the Health and Safety at work etc. ACT 1974 (HSWA), the English statute that regulates and protects safety at work, requires that the risk be reduced to 'So Far As is Reasonably Practicable' (SFAIRP). It should be noted that the concepts of SFAIRP and ALARP are interchangeable, with the difference that the former is used more in health and safety regulations and legislation, while the latter is used mainly by risk specialists. While the HSWA offers no prescription on how the acceptability threshold should be determined, the HSE defines - precisely through the ALARP principles - a guide for dealing with the decision-making process on risk tolerability understood as «the willingness to live with a risk in a way that provides some benefits» (Ale, 2005).

Figures 2.a and 2.b show two different representations of the ALARP principle. The simplest is Fig. 2.a, in which the risk increases along the vertical axis. Fig. 2.b, on the other hand, represents the “carrot” model defined by the HSE, which makes explicit the obvious criterion that as the risk increases, the mitigation costs to make it tolerable are progressively higher. In both cases, two horizontal lines delimit three regions of risk: the lower line represents the “broadly acceptable” threshold, up to which the risk does not need to be reduced; the upper line defines the “limit of tolerability” threshold, which separates the zone of risk tolerability from that of unacceptability.

The ALARP principle implicitly recognises that “zero” risk is not a viable option, so that in the context of “safety risk” the “broadly acceptable” threshold is often regarded as a “safe level”. Similarly, the ‘limit of tolerability’ threshold is not an indicator of certain catastrophe but represents the beginning of an ‘unsafe’ area.

It should be noted that the absence of specific numerical values for the thresholds suggests the need to calibrate the model according to the areas of application. For example, the HSE recommends a “broadly acceptable” threshold of 10^{-6} deaths per year (one in a million) for the nuclear industry and a “tolerable limit” value of 10^{-3} to 10^{-4} deaths per year.



a. Representation of the ALARP principle, simple model

b. Representation of the ALARP principle, carrot model

Figure 2. Representation of the ALARP principle (source: own elaboration)

It should be noted that in ALARP the disproportion between costs and benefits obtained is reflected in the estimated Implied Cost of Averting one Fatality (ICAF). This indicator, which represents the cost or investment made to save an additional life, is given by the ratio between the cost of the investment the investment divided by the decrease in expected number of fatalities due to the action:

$$\text{ICAF} = \frac{\text{Cost of mitigation measure}}{\text{Reduction in Potential Loss of Life}} \tag{2.1}$$

By comparing the estimated ICAF for the proposed option with sector-specific ICAF reference values, it is verified whether there is a disproportion between the costs of risk mitigation and the benefits brought. The risk is tolerable if it falls within the ALARP area, as further costs to bring the risk to the acceptable threshold would be excessive.

In the light of the above, several important aspects are highlighted:

- ALARP principles recognise that zero risk is not a viable option. Thus, ensuring that risks are reduced to ALARP does not mean that harmful events will not occur, but that the specific risk is tolerable within certain limits;
- ALARP does not necessarily imply that measures must be taken to mitigate the risk. The latter need not involve disproportionate costs;

– at the heart of the ALARP logic is the concept of tolerable risk, i.e. that risk which, in the absence of benefits, cannot be considered acceptable;
– when implementing ALARP principles, the assessment cannot disregard extra-monetary issues.

While the approach has been criticised on ethical grounds, i.e. related to the difficulty of assigning the correct value to human life, it has also found wide acceptance in practice, as it provides analysts with a guide to assess the acceptability and tolerability of the risk of loss of human life, considering both economic and social aspects. In fact, the ALARP approach, which originated in the nuclear sector, is increasingly being used in other areas, such as land use planning in the immediate vicinity of industries or dams, landslide risk management, risk assessment in tunnels, etc. (Morgenstern, 1995; Porter, Jakob, & Holm, 2009). And, more generally, it can have highly relevant applications in all cases where the primary objective is the triangular balancing of risks, costs to reduce them and potential benefits to be achieved. According to Redmill (2010, p. 5) «The ALARP Principle is not difficult to understand (…), but its application is non-trivial (…), often due to ignorance or uncertainty of the likelihood or consequences of supposed risks, and always because risk-tolerability decisions depend on circumstances, which may change».

2.3. The risk management in the economic evaluation of investment projects

Risk management is closely integrated with decision theory. In this regard, Althaus, Bridgman & Davis (2007) and Aven (2016) show not only that the phases of the decision-making process are in line with those of the risk analysis process, but also that the risk field provides useful inputs to support analysts in their decisions, among others: the conceptualisation and characterisation of the problem in terms of objectives, criteria, risks, uncertainty, knowledge and priorities; the hierarchization of the problem in order to understand its key principles; the analysis of statistical data to identify the elements of risk; the risk assessment, also quantitative, of the potential alternatives; the perception of risk by the different actors involved in the decision-making process.

It can be deduced that risk management becomes essential when it is necessary to make an economic judgement on investments. This is particularly true when the uncertainty related to the sensitive variables of the project makes it difficult to express the result of the Cost-Benefit Analysis (CBA) in deterministic terms, as in the case of large-scale interventions or when the data necessary for the analysis are incomplete or difficult to find (European Commission, 2014). This leads the evaluator to implement the analysis in stochastic terms. In fact, the investment risk is closely related to the probability that the investor will fail, i.e. that the most probable value of the profitability indicator of the project will be below a certain threshold value.

It follows that, in the context of investment risk assessment, phase (1) of context analysis translates into the study of: the type of project under consideration; the relative investment sector; the socio-economic characteristics in which the intervention is located; the type of investor (public or private) and his propensity to take risks.

Following the context analysis, the most complex phase must be implemented, i.e. phase (2) of Risk Assessment. In other words, it is necessary to:

- identify the riskiness of the project which, in economic terms, translates into the identification of the sensitive (or risky) variables of the system. These are the variables that significantly influence the final value of the profitability indicator of the investment, since even small variations in them lead to a significant variation in the value of the NPV or IRR;
- carry out risk analysis, which consists in the statistical characterisation of the quantities under examination. There are several risk analysis techniques generally used in practice, which are discussed in paragraph 2.4 below.
- estimating the investment risk by predicting the probability of failure of the investor and then studying what consequences the assigned probability distributions have on the outcome of the intervention.

The output of the Risk Assessment allows to understand if and how to implement the phase (3) of Risk Treatment, i.e. it allows to: plan the possible risk mitigation strategies; re-estimate the investment risk, taking into account the proposed mitigation actions, i.e. estimate the residual risk that remains despite the mitigation actions undertaken.

2.3.1. Techniques for uncertainty analysis

Before analysing the main risk analysis techniques, it is necessary to focus on the approaches useful for expressing judgements on the feasibility of projects under conditions of uncertainty.

Two approaches are suggested by the literature, namely:

- sensitivity analysis;
- scenario analysis.

The objective of the sensitivity analysis is to detect the effects of the uncertainty related to the parameters that significantly affect the results of the evaluation. To this end, the variation of the initiative's performance index is recorded when the measurement of one parameter changes, leaving the others unchanged. By repeating the operation for the main factors involved, it is possible to recognise to which of them the project is most sensitive. The criteria to be adopted for the choice of critical variables are a function of the specific project and must be carefully evaluated case by case. According to the European Commission's Guide to Cost-Benefit Analysis (2014), "critical" variables are those for which a change of ±1% in the estimated value results in a change of more than ±1% in the Net Present Value (NPV).

According to the Guide to the Cost-Benefit Analysis of Investment Projects (European Commission, 2003), there are five steps to be followed to implement sensitivity analysis:

a) to identify all the variables used for estimating inputs and outputs in the financial and economic analyses, grouping them into homogeneous categories;
b) to carry out an analysis of the listed parameters in order to identify any deterministically dependent variables that would give rise to biases in the results;
c) to implement a qualitative analysis of the impact of the variables, so as to select those that have a low elasticity, so as to limit the subsequent quantitative analysis to the most significant variables only;
d) to evaluate the elasticity of the selected variables. Operationally, it is necessary each time to assign a new value to each variable and re-estimate the IRR or NPV, noting the variation (absolute and percentage) with respect to the base case. Since in general there is no guarantee that

the elasticity of the variables is always a linear function, a check should be carried out;

e) to identify the critical variables, applying the chosen criterion.

The main limitation of the procedure concerns the range of variation of the variables, which is often established subjectively by the analyst, without having data on the probability of occurrence of the events. Furthermore, in sensitivity analysis a linear relationship is assumed between the individual variable and the result of the evaluation, which cannot always be considered true. Finally, the procedure requires that the analysis be developed separately for each variable, thus not considering the joint effect of uncertainty on several factors.

Therefore, a scenario analysis must be added to the procedure described above, which generally refers to various scenarios: optimistic, maximum likelihood and pessimistic.

For each scenario, plausible combinations of parameters are assumed, to reduce the spectrum of different cases that may arise.

The combined consideration of certain ‘optimistic’ and ‘pessimistic’ values of a group of variables can be useful for demonstrating different scenarios under certain assumptions. An exactly specified probability distribution is not necessary - but if it can be deduced - to define optimistic or pessimistic scenarios, the extreme values of the probability distribution must be chosen for each critical variable. Project performance indicators are then calculated for each hypothesis. Scenario analysis does not replace sensitivity and risk analysis but is merely a shorter procedure.

Here again, the evaluator has a wide margin of discretion when the probability distribution of the variables is not available, and that it is difficult to make decisions when there are multiple solutions, from optimistic to pessimistic scenarios. In summary, there are two main limitations of scenario analysis:

1) the wide spectrum of solutions, ranging from the pessimistic to the optimistic hypothesis, is so broad that it may not be very effective for the final decision orientation;
2) the substantial subjective component left to the decision-maker.

2.3.2. Techniques for risk analysis

Regarding the estimates to be made under risk conditions, there are many criteria that can be applied. In fact, it is possible to:

- reflecting the risk in one of the terms making up the present value of the project, i.e. implementing the decision approaches based on the "classic" NPV (section 2.3.2.1);
- adopt probabilistic analyses, including Monte Carlo simulation and Decision Tree Analysis (section 2.3.2.2);
- use statistical tools such as mean-variance or stochastic dominance (Section 2.3.2.3);
- looking at the intervention as a function of its "real options", i.e. as the source of a range of opportunities it can generate (section 2.3.2.4).

The technique is chosen from time to time by the analyst either in relation to the characteristics of the project initiative, or according to the availability of data and information needed to implement the analysis tool. However, the reliability of the data is in turn a function of several factors. These certainly include the possibility of finding elements of comparison in projects similar to the one under study and falling within the same territorial system of reference; but they also include the socio-economic peculiarities of the context in which the intervention is located, which define a more or less transparent market and a static or dynamic economic framework (Nesticò, 2019).

In the following sections we examine the single analysis techniques, but it is necessary to point out that all the methodologies have two main critical points in common. The first one is that they all support the CBA, which imposes to transform in monetary terms all the Cash-Flows that the intervention generates, leading to considerable difficulties in the cases where it is necessary to evaluate environmental and social externalities. The second critical point is the absence of objective criteria to establish whether the investment risk and the residual risk, i.e. the risk that remains despite the proposed mitigation measures, are acceptable for the investor or for the community.

2.3.2.1. Approaches to decision-making based on the "classical" NPV

Assessing the performance of an investment by estimating the Net Present Value (formulae 1.1 and 1.2) may be an inadequate method if the assessment is carried out under conditions of risk or uncertainty. In such cases, the literature proposes alternative methods to decision-making, still based on NPV estimation, but which allow filtering out project risk components. These methods include:

- the Equivalent-Certainty Method;
- the Discount Rate Adjustment Method (Dallocchio & Salvi, 2011a; 2011b).

In the first case, i.e. through the certainty-equivalent method, the risk components related to the venture are filtered out by replacing the so-called "at risk" cash flows with smaller "certainty-equivalent" flows. Alternatively, under the discount rate adjustment method, risk is accounted for by increasing the representative rate of non-risky assets with a term that expresses the premium for investment risk.

Certainty Equivalent Method. According to this method, the values of annual cash flows, expressed in terms of the expected value of a probabilistic distribution of cash flows, are "corrected" through a coefficient, called the Equivalent Certainty Coefficient (ECC).

The ECC allows the degree of risk associated with the estimated distribution of cash flows to be incorporated into the valuation. It has a value between 0 and 1: in particular, the higher its value, the lower the uncertainty related to the distribution of cash flows.

With the method of the certain equivalent, the goodness of a project is assessed in a similar way to that seen with NPV, i.e. investments with a certain equivalent less than zero are not economically viable. (Dallocchio & Salvi, 2011a). It follows that the Expected Certain Equivalent (CE) and the related $NPV_{(CE)}$ are respectively worth:

$$CE = \sum_{t=0}^{n} \frac{\alpha_t \cdot CF_t}{(1+r)^t} \tag{2.2}$$

$$NPV_{(CE)} = -C_0 + \sum_{t=0}^{n} \frac{\alpha_t \cdot CF_t}{(1+r)^t} \qquad (2.3)$$

Where:

- α_t = risk premium;
- FC_t = expected cash flow at period t;
- r = risk-free rate of return;
- n = project lifetime;
- C_0 = initial investment cost.

The value of certainty-equivalent flows, the nature of which is such as to impose their discounting at the foreseeable rate for uses of money with zero risk, can be derived in various ways. Two are the best known: the one based on the construction of the decision-maker's utility function; and the one using the Capital Asset Pricing Model (CAPM) theory, analysed in the following section.

Due to the difficult mathematical derivation of the utility functions, the first method is scarcely used. On the contrary, the second method has proven validity and is easier to use, given its characteristic of finding the information needed to implement the calculation model in the market (Nesticò, 2019).

Discount rate adjustment method. This method consists in adding to the rate r_f able to remunerate risk free money allocations a premium *p* for the risk of the specific investment. This affects the denominator of the NPV formula, leaving the random cash flows in the numerator unchanged. In practice, the rate *p* is often set subjectively by the valuer, either based on his own experience or with the intention of setting a minimum profitability threshold below which the project should be abandoned. In this case, however, no concrete and objective risk analysis process is implemented. Again, an objective approach to adjusting the discount rate to the riskiness of the initiative is based on the CAPM theory.

The Capital Asset Pricing Model (CAPM) was introduced in financial economics by Sharpe (1964) and Lintner (1965) to explain how the risk of a financial investment affects its expected return. This is an extension of the market portfolio model proposed by Markowitz (1952) who argue that investors are risk averse investors and will choose a portfolio by trading off between risk and return for one investment period (Elbannan, 2015). This means that investors will choose efficient portfolios that minimise the variance of the portfolio return for a specific level of expected return, or maximise the expected return, given the specific level of variance. According to this theory, in a "perfect" financial market and in conditions of equilibrium, the return on each security is equal to the sum of the interest rate and a "premium" for systematic risk. The higher the premium, the less the yield of the security itself can fluctuate in harmony with the market. The random risk component, which can be eliminated by means of appropriate portfolio diversification, has no influence on the rate under consideration. In fact, the risk is costed by two different rates: the diversifiable (or non-systematic) component is eliminated by the operators themselves, with the formation of the market-optimal portfolio; the non-diversifiable (or systematic) component, on the other hand, is linked to the greater or lesser discrepancies that may occur between the fluctuations in the yields of the particular security under consideration, on the one hand, and the optimal portfolio, on the other.

The CAPM assumptions are specified below. They are the same as in the Markowitz portfolio model, plus assumptions 2 and 3 added by Sharpe (1964) and Lintner (1965):

1) all investors select efficient portfolios in order to maximise the utility of their investments. In other words, investors are risk-averse, so they maximise utility and focus only on their return (mean) and relative risk (variance). It follows that the portfolio of investments that traders choose will depend on their utility function and a trade-off between risk and return;
2) investors can borrow or lend funds at the risk-free rate of return;
3) all investors have homogeneous expectations, which means that they estimate the same distributions for future rates of return;
4) all investors hold investments for the same period of time;
5) investors are able to buy or sell shares in any security or portfolio they hold;
6) there are no taxes or transaction costs on the purchase or sale of assets;
7) there is no inflation or any change in interest rates;
8) capital markets are in equilibrium, and all investments are fairly priced, i.e. investors cannot influence prices (Reilly & Brown, 2003).

The CAPM equation according to the assumptions of Sharpe and Lintner can be expressed as follows:

$$E(r_i) = r_f + \beta \cdot [E(r_m) - r_f] \quad (2.4)$$

Where $E(r_i)$ is the expected return of investment, r_i and r_m represent respectively the gross return of the security in question and the return of the market portfolio. r_f is the return on a risk-free investment. The difference between the market return and the risk-free return gives the market risk premium, i.e. the remuneration for the risk taken by the investor. The β coefficient gives a measure of the systematic - i.e. non-diversifiable - risk of a firm and expresses the expected percentage change in the excess return of an investment initiative for a 1% change in the excess return of the market portfolio. In other words, beta measures the sensitivity of the investment return to the change in the market return, whereby if:

- $\beta = 0$, the investment is risk-free and its return is r_f;
- $\beta = 1$, the investment has the same risk as the market and its return is equal to r_m;
- $\beta < 0$, the investment is risky but its level of risk moves “against the trend” of the general average;
- $0 < \beta < 1$, the venture is risky but less than the market and its level of risk moves “in the same direction” as the market;
- $\beta > 1$, the risk level of the project still moves “in the same direction” as the market but is higher than the average.

Analytically, β is expressed by the following formula:

$$\beta = \frac{\text{cov}\,(r_i, r_m)}{\text{var}\, r_m} \quad (2.5)$$

That is, β is given by the ratio of the covariance between the return r_i of the generic investment and the market return r_m and the variance of the market return r_m.

Graphically, β corresponds to the slope of the line that best interpolates the excess returns of the investment with respect to the excess returns of the market in an x-y Cartesian diagram:

$$r_i = \alpha + \beta \cdot r_m + \varepsilon \quad (2.6)$$

Whit $\alpha = (1 - \beta) \cdot r_f$ and ε statistical error measuring the reliability of the estimate made (Rosenberg & Guy, 1976; Black, 1993).

2.3.2.2. Probabilistic approaches

Monte Carlo simulation. Probabilistic approaches have been extensively tested to interpret investment-related risk and return the probability law of the profitability indicator.

The probabilistic risk analysis is expressed in the stochastic description of the critical variables of the project and in the subsequent estimation of the probability distribution of the profitability indicator.
Thus, having identified the critical variables, it is necessary to derive the relative probability distributions. The main probability distributions reported in the literature include:

- discrete distribution;
- continuous distribution.

The random variable X is said to be discrete if it assumes a finite number or a numerable infinity of values $\{x_1, x_2, ..., x_n\}$.

The probability distribution of a discrete random variable X assigns a probability $P(X = x_i)$ – or P(x) – at every possible value x.

For each x, the probability P(x) is between 0 and 1. The sum of the probabilities for all possible realisations x is 1:

$$\sum_{i=1}^{n} P(X = x_i) = 1 \quad (2.7)$$

A continuous random variable takes on all values that fall in a certain interval. Its probability distribution is represented by a curve that allows us to determine the probability that the random variable takes on each value falling in the interval. The interval that contains all possible values of the random variable has a probability of 1. It follows that the total area under the probability distribution curve is 1.

The probability that the random variable X does not exceed a certain value x is called the distribution function, and represents the cumulative probabilities:

$$F(x) = P(X \leq x) \quad (2.8)$$

Let a and b be two possible realisations of the variable X, such that $a < X < b$. The probability that X takes values between a and b is given by:

$$P(a \leq X \leq b) = F(b) - F(a) \tag{2.9}$$

Among the continuous probability distributions, the most widely used in risk analysis are the Gaussian distribution, the triangular distribution, and the uniform distribution.

The normal distribution depends on two parameters, the mean μ and the variance σ^2, and is traditionally denoted by N ($\mu; \sigma^2$), where:

- μ represents the mean or expected value $E[X]$[3];
- σ^2 provides a measure of the variability of the values taken by the variable itself; namely, a measure of how far they deviate quadratically from the arithmetic mean or the expected value respectively $E[X]$.

The normal distribution, also called Gauss curve or Gaussian distribution, is characterised by the following probability density function:

$$f(x)= \frac{1}{\sqrt{2\pi\sigma^2}} \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \text{with } x \in R \tag{2.10}$$

Triangular distributions, on the other hand, are often used when there is no detailed information about the trend of the variable. This distribution is in fact described by a maximum value, a minimum value, and the modal value of the probability distribution.

The triangular distribution is typically used as a subjective description of a population of data for which only a limited number of sampled values are

[3] In general, the expected value of a discrete random variable is given by the sum of the possible values of this variable, each multiplied by the probability that each of them has of occurring, i.e. it is the weighted average of the possible outcomes. In other words, in the case of a discrete random variable that admits probability function p_i, then its expected value is:

$$E[X] = \sum_{i=1}^{\infty} x_i \cdot p_i$$

In the case of a continuous random variable admitting a probability density function f(x), we have that:

$$E[X] = \int_{-\infty}^{+\infty} x \cdot f(x)dx$$

available, and especially in cases where the relationship between the variables is known but the data are few. The analytical and graphical description of a triangular distribution may vary considerably according to the "weight" given to the modal value with respect to the values of the extreme points of the distribution.

In a symmetrical triangular distribution, the interval between the modal value and the minimum value is equal to that between the modal value and the maximum value.

In an asymmetric distribution, on the other hand, the modal value divides the distribution into two unequal parts.

Finally, if in a distribution each value has the same probability of occurring, then the distribution is called uniform.

It is also extremely important to understand how to derive the probability distribution of each variable. One possible approach is reference forecasting, which consists of adopting an "external point of view" by fitting the project into a statistical distribution of results from a class of similar projects. It consists of three steps:

- identification of a reference class of projects large enough to be statistically significant;
- determination of a probability distribution of the reference class for the chosen variable;
- comparison with the reference class distribution and derivation of the predicted result (European Commission, 2014).

In addition, the probability distribution for each variable can also be derived from experimental data or from consultations with experts.

Once the probability distributions of the sensitive variables of the system have been defined, the transition from these distributions to that of the design IRR takes place through Monte Carlo analysis. In short, the random extraction of the probable values for each critical variable allows the derivation of the respective value of the performance indicator. By repeating the procedure for a sufficiently high number of extractions, the probability distribution of the economic performance indicator is derived.

If one considers the Internal Rate of Return (IRR) as the financial performance indicator, then:

$$\sum_{t=0}^{n} \frac{B_t - C_t}{(1 + IRR_p)^t} = 0 \qquad (2.11)$$

I.e.:

$$\sum_{t=0}^{n} \frac{f(B_{p1}, \ldots B_{pn}; B_{d1}, \ldots B_{dn}) - f(C_{p1}, \ldots C_{pn}; C_{d1}, \ldots C_{dn})}{(1 + TIR_p)^t} = 0 \qquad (2.12)$$

Where:

- B_t represents the benefits at time t and are a function of both probabilistic terms $(B_{p1}, \ldots B_{pn})$ che deterministici $(B_{d1}, \ldots B_{dn})$;
- C_t are the costs at time t, which are also described both in probabilistic terms $(C_{p1}, \ldots C_{pn})$ than deterministic $(C_{d1}, \ldots C_{dn})$;
- IRR_p is the Internal Rate of Return expressed in terms of the cumulative probability curve.

From the reading of the probability distribution of the IRR, it is possible to derive important information about the project risk, e.g. the expected value and the variance of the expected profitability index E(TIR).

If we consider IRR as an indicator of economic performance and if p(IRR) is a continuous random variable with probability density, the expected value (mean value or mathematical expectation) of the variable is defined as the integral extended throughout $\mathbb{R}$ of the product between IRR and the density function p(IRR):

$$E(IRR) = \int_{-\infty}^{+\infty} IRR \cdot p\,(IRR) \qquad (2.13)$$

Discretizing the probability density function of IRR, then the expected value of the discrete random variable E(IRR) is the sum of the products of the IRR_i values and the respective probability $p(IRR_i)$, i.e.:

$$E(IRR) = \sum_{i=1}^{n} IRR_i \cdot p(IRR_i) \qquad (2.14)$$

With n number of discretisation intervals of the probability distribution of the random variable IRR.

The comparison between E(IRR) and the performance limit values allows a judgement to be made on the project risk. In this sense, however, regulatory guidelines do not provide clear indications on the levels of acceptability of design risk.

In addition, there are two other critical issues inherent in Monte Carlo simulation, which often limit its implementation in the business environment. The first is that it is assumed that economic factors are uncorrelated, an assumption that is not always true. The second is that the probability distribution of the project's risk variables must be specified.

On the other hand, Monte Carlo simulation, due to the relative immediacy of its implementation and the goodness of the results that can be obtained if sufficient data are available to define the probability distributions of the critical variables, is the most widely used approach for assessing the risk of investments – also in the civil field – as suggested by European and non-European standards (section 2.3.4).

Decision Tree Analysis. These analyses can be considered as a dynamic version of the NPV method, as they make it possible to predict the evolution of the project based on different scenarios that could occur and their probability of occurrence.

Thus, Decision Tree Analyses schematise a complex decision problem in graphic form, i.e. by means of a flow chart or decision tree. This decision tree summarises both the activities related to the investment and the possible project alternatives. By means of the diagram, it is possible to visualise the interdependence between the activities and to isolate the various decision-making moments.

In practice this technique is used to analyse the initial complex and articulated problem, which may involve several temporally divided decisions, and then break it down into a series of simpler sub-problems.

The diagrams are made up of square nodes, i.e. the points at which decisions are made. Branches lead from the square nodes to the circular nodes representing the various scenarios that can be realised with respect to the scenario hypotheses. Each branch is associated with a value corresponding to the probability of that event occurring.

The tree is constructed from left to right but in order to calculate the probability linked to the nodes and above all to the starting node, it is necessary to apply the roll back method, i.e. to go from right to left.

The main advantage of implementing Decision Tree Analysis is to highlight the critical phases of a project and the interdependencies between the different phases. However, the approach is rather rigid. In fact, to be able to apply it, it must always be possible to understand the interrelationships that may occur and their consequences. Figure 3 schematises the structure of a decision tree.

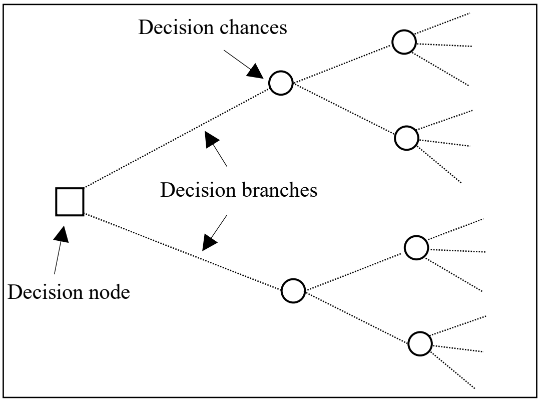


Figure 3. Structure of a decision tree (source: own elaboration)

2.3.2.3. Statistical approaches

Among the statistical approaches to risk analysis, the mean-variance approach and the stochastic dominance approach should be mentioned. Both approaches are feasible as soon as it is possible to associate a probability distribution with the investment performance index.

Mean-variance approach. According to this approach, it is assumed that the flows related to a certain investment project are not known with certainty, but it is possible to define their probability distribution. As is well known, the meaning of a probabilistic curve is clear in the light of the corresponding mean value and variance, which respectively define the average trend value of the project's return and its "quality" in terms of dispersion of values around the central trend value, which instead summarises the project risk.

In statistical terms, the formula for the expected return R – estimated by means of the NPV or IRR or other indicator best suited to interpreting the results of the analysis – is expressed as the weighted average of the various returns R_s (s = *1*, …, *n*) that the intervention is expected to generate under different scenarios, where the weighting factor P_s is given by the probabilities associated with each of the *n* scenarios:

$$R = \sum_{s=1}^{n} P_s \cdot R_s \tag{2.15}$$

The variance σ^2 is the mean of the square of the deviations of the returns R_s associated with the initiative from the mean value R:

$$\sigma^2 = \sum_{s=1}^{n} P_s \cdot (R_s - R)^2 \tag{2.16}$$

The square root of the variance is the standard deviation, also called the mean square deviation. Although variance and standard deviation give the same information about the dispersion of returns around the mean, the latter gives the measure of risk in the same unit as the expected or observed values and their mean.

Evidently, one initiative is to be preferred over another if it expresses a higher average value of the valuation index and a lower dispersion. This can be assessed by estimating the coefficient of variation (CV), which expresses the amount of risk per unit of return. It represents a fundamental indicator of riskiness and is given by the ratio between standard deviation and expected return of a generic investment:

$$CV = \frac{\sigma}{R} \tag{2.17}$$

CV estimation allows the ranking of different initiatives according to a risk minimisation criterion. In fact, according to the “mean-variance” decision rule, a project will be preferred to another if one of the following two statements is true:

1. the expected value of one investment is higher and the dispersion measure is lower than (or at most equal to) that of the other project;
2. the expected value is greater than or equal to that of the other project and the measure of dispersion is smaller.

This choice criterion is applicable to all risk-averse decision-makers.
However, the limitation of this type of analysis is clear in the case where a choice must be made between projects that present both different risks and

returns. In such cases, the mean-variance approach is feasible if the following two conditions are met:

1. the NPV values follow a normal distribution: this allows the project to be fully described by means of mean and variance;
2. the utility function (which describes the degree of risk aversion) is of the second degree or quadratic, i.e. of the type: $U(x) = ax^2 + bx + c$. To define the investor's degree of risk aversion, it is necessary to introduce the concept of the indifference curve, given by the set of points identifying risk-return combinations that provide the investor with the same utility. In fact, the slope of the indifference curves expresses the investor's degree of risk aversion and, as the slope of the curve increases, the investor will be willing to take on more and more risk on condition that he receives proportionally higher returns.

Stochastic dominance approach. The difficulties related to the mathematical derivation of utility functions required by the mean-variance approach can be overcome by resorting to the concept of stochastic dominance. Using this concept, investments are assumed to behave as random variables. Thus, based on the information available from their probability distributions, investments can be divided into efficient (i.e. not dominated) and inefficient (i.e. dominated). It follows that the investor, according to his preferences, will be able to choose the best alternative within the efficient set.

To define stochastic dominance criteria, we need to introduce the distribution function, which expresses the probability that the random variable X is less than or equal to a certain level k, $\forall k \in \mathbb{R}$.

In other words, in the context of investment evaluation, it is necessary to construct the cumulative probability function of the NPV for each of the projects to be compared. This function returns on the y-axis the probability that the NPV is equal to or less than the corresponding value read on the x-axis.

Two main criteria for stochastic dominance are distinguished: first degree stochastic dominance and second-degree stochastic dominance (Cardin, 1987).

First-degree stochastic dominance assumes that investors prefer high returns over low returns, whatever their attitude towards risk.

Thus, there is first-degree stochastic dominance of variable X over variable Y when it occurs that:

$$\text{Prob}\ (X \leq k) \leq \text{Prob}\ (Y \leq k) \tag{2.18}$$

I.e.:

$$F_x(k) \leq F_y(k) \tag{2.19}$$

and if there is at least one k_0 value at which the inequality is strictly valid.

Thus, to have first-order dominance, the distribution function F_X must not exceed the distribution function F_Y at any point. From a graphical point of view, the function F_X must always be below F_Y, with no intersection between the two. If the F_X and F_Y distribution functions intersect, it must be checked whether there is second-order dominance, which also includes risk aversion on the part of the investor.

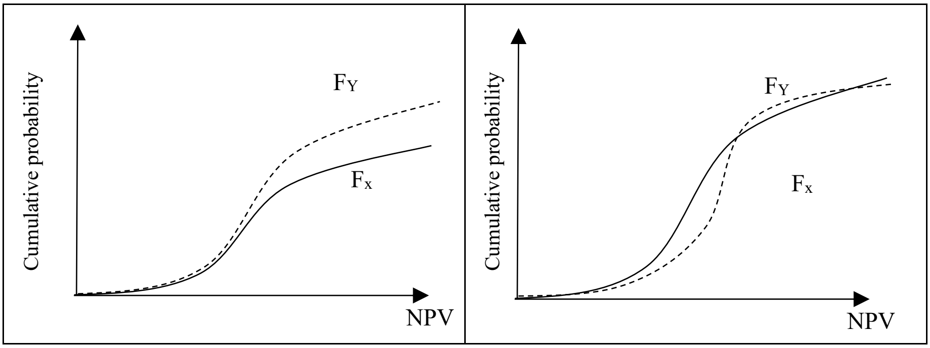
Second-degree stochastic dominance occurs if and only if $\forall\ k \in \mathbb{R}$, in the interval $[a,t]$, it is verified that:

$$\int_a^k [F_X(t)]\, dt - \int_a^k [F_Y(t)] dt \leq 0 \tag{2.20}$$

I.e.:

$$\int_a^k [F_X(t) - F_Y(t)]\, dt \leq 0 \tag{2.21}$$

and if there is at least one k_0 value at which the inequality holds in the strict sense. Thus, in this case, dominance depends on the size of the area in which one function dominates the other. More specifically, F_X can be said to dominate F_Y if the area in which F_X lies below F_Y has a larger amplitude than the area in which the opposite situation occurs. Figure 4 shows two examples: one of first-degree stochastic dominance (Fig. 4.a) and one of second-degree dominance (Fig.4.b).



a. First-degree stochastic dominance **b.** Second-degree stochastic dominance

Figure 4. Examples of stochastic dominance (source: own elaboration)

It is important to emphasise that the applicability of statistical criteria depends on the availability of objective data and the ability to process them. In this regard, Dallocchio (1995, p. 311-312) underlines: «The attribution of a probability distribution to the returns of a project therefore implies a certain degree of subjectivity on the part of the decision-maker. To reduce the uncertainty that characterises the process of formulating estimates, an analysis is often carried out on the historical performance of projects that present a level of risk similar to that of the project to be evaluated».

2.3.2.4. Real Options Analysis

Real Options Analysis (ROA) emphasises the problem of the reciprocal influence existing between current decisions and future opportunities and, consequently, the possibilities of modifying the terms of the project initiative at a time after its actual launch, according to changes in the economic, political, social, and environmental reference framework (Nesticò, 2019).

The objective of ROA is not to identify the exact price of a real option but rather to consider the value of managerial flexibility, otherwise ignored, which could change the fate of an investment.

More specifically, when both the uncertainty surrounding an investment and the flexibility are contained, then the project can be evaluated using the NPV method. Conversely, when the project uncertainty is not negligible and management has the flexibility to make changes to the project cost, then it may be useful to implement the ROA approach.

While NPV provides a measure of the expected return from the individual investment project, ROA provides a strategic map showing possible alternatives. However, it should be emphasised that ROA does not replace the NPV method but supports and complements traditional evaluation tools. In other words, there is no point in implementing ROA if the NPV of the project is less than zero or not sufficiently high.

In accordance with Amram and Kulatilaka (1999), four steps are necessary to implement the real options approach:

1) *Identification of the relevant aspects of the decision problem*. This phase consists first in the analysis of all sources of uncertainty, distinguishing between market and private uncertainties; then in the definition of the decision rule through simple mathematical equations and of the optimisation objective (in terms of profit maximisation or risk minimisation); finally, in the retrieval of available market data useful to estimate the parameters involved and the relative uncertainty.
2) *Implementation of an option pricing model*. This step consists in: defining the inputs; estimating the output, i.e. the value of the options in a specific situation using the risk neutrality approach.
3) *Verification of the result*. The results obtained from the real options model should be reviewed not only to draw insights and conclusions, but also to evaluate the model and recalibrate it if necessary.
4) *Redesign* (if necessary). If the quality of the model is not satisfactory, it should be improved iteratively. The results of option evaluation models include critical values that can support the analyst in making decisions.

In summary, the implementation of Real Option Analysis makes it possible to:

- identify project alternatives, which the decision maker can select given the highly uncertain market conditions;
- Assess each possible strategy and its economic feasibility;
- Prioritise these strategies on the basis of a series of qualitative and quantitative metrics;
- identify the optimal timing for investment execution;
- Managing project alternatives, including developing new ones for possible future opportunities (Mun, 2002).

2.3.3. Critical issues

It has been said that the choice of the risk analysis technique to be implemented may depend on the availability of data and information or even on the specific characteristics of the decision problem. For example, the analyst may prefer to use one technique if the riskiness of a single investment is to be assessed and another if the objective is to compare the riskiness of alternative projects. Furthermore, some techniques may be inappropriate if the assessment is conducted from the point of view of the public operator. Take, for example, a risky project where the main benefits accrue in the long term. In such a case, the use of approaches based on the adjustment of the discount rate would lead to an excessive contraction of the cash-flow value progressively more distant in time. Thus, there would be a risk of not considering environmental and socio-cultural externalities in the economic analyses, thus reducing their weight on the performance indicators. This is a crucial issue that requires the use of methods and techniques that allow these benefits, costs, and risks to be considered jointly in the relevant analyses. This issue will be further explored in section 2.3.4 below.

In Table 1 below, critical issues are summarised for each technique analysed in the previous section. However, it should be emphasised that all techniques are supportive of traditional evaluation based on Cost-Benefit Analysis. Therefore, a common difficulty concerns the assessment of environmental and social externalities. In addition, a further critical issue is the lack of shared criteria and objective data that can offer more detailed guidance to the analyst who must make a judgement on the acceptability of the investment risk.

Table 1. Critical issues in risk analysis techniques (source: own elaboration)

Method		*Formula*	*Critical Issues*
Methods based on classical NPV	Certainty-equivalent method	$NPV(CE) = \sum_{t=0}^{n} \frac{\alpha_t \cdot CF_t}{(1+r)^t}$ (formula 2.2)	– Difficulties in evaluating cash flow equivalent-certainty, especially when using the utility function of the decision-maker
	Discount rate adjustment method	$E(r_i) = r_f + \beta \cdot [E(r_m) - r_f]$ (formula 2.3)	– Excessive discounting of the present value of cash flows, especially in the case of projects with long-term effects
Probabilistic methods	Monte Carlo simulation	$E(IRR) = \int_{-\infty}^{+\infty} IRR \cdot p(IRR)$ (formula 2.13)	– It is assumed that there are no correlations between the sensitive variables – Difficulties in inferring probability distributions of variables
	Decision Tree Analysis	(il riferimento è in Figura 3)	– Rigidity of approach. So it is necessary to detect the interrelationships that may occur and their consequences
Statistical methods	Mean-Variance	$CV = \frac{\sigma}{R}$ (formula 2.17)	– Need for objective data and ability to process them – The attribution of probability distributions to the returns of a project implies a certain degree of subjectivity on the part of the decision-maker
	Dominance-Stochastic	$F_x(k) \leq F_y(k)$ (formula 2.19) $\int_a^k [F_X(t) - F_Y(t)]\, dt \leq 0$ (formula 2.21)	– Need for objective data and ability to process them – The attribution of probability distributions to the returns of a project implies a certain degree of subjectivity on the part of the decision-maker
Real Option Analysis (ROA)		(section 2.3.2.4)	– ROA does not replace the NPV method, but supports and complements traditional valuation tools – The prioritisation of these strategies based on qualitative and quantitative metrics implies a certain degree of subjectivity on the part of the decision-maker

2.3.4. Risk assessment in inter-generational projects

Evaluating investment risk is particularly challenging from a theoretical and operational point of view when projects are subjected to a cost-benefit test and their effects are felt over a long-time horizon. In fact, the longer the period of analysis, the more difficult it is to estimate with certainty the costs and benefits that the project generates. As seen in the previous section, the risk components related to the project initiative can be filtered by replacing the so-called “risky” cash flows with “certainty- equivalent” flows of lesser magnitude. Alternatively, the risk can be considered by increasing the rate with a term expressing the premium for the investment’s aleatory. On the other hand, however, taking risk into account by increasing the discount rate in the analysis would lead to contracting the present values of cash flows even further away from the time of valuation, thus strongly reducing their weight on the performance ratios.

To meet this challenge, two issues need to be considered together:

1) the choice of the discount rate to be used in the analyses, in order to give proper weight to progressively more distant costs and benefits over time;
2) the assessment of the riskiness of cash flows, since it is even more complex to estimate them with certainty in the long run.

In the next two sections, we first review the literature on the choice and methodologies of estimating the Social Discount Rate (SDR) to be used in the economic analysis of projects with long-term extra-financial impacts. Then a focus on risk assessment of public projects is proposed.

2.3.4.1. The social discount rate in the CBA of inter-generational projects: a literature review

Recent concerns about climate change increasingly lead analysts to focus on the proper valuation of environmental externalities. One of the most important issues is discounting, as the discount rates commonly used in economic analysis tend to underestimate environmental benefits and damages that are progressively more distant in time (Gollier, 2010). This is because conventional discounting procedures, i.e. conducted with time-invariant discount rates, cause a pronounced and sometimes unacceptable contraction in the values of the cash flows produced for future generations (Nesticò & Maselli, 2019).

Some authors suggest solving the problem by using hyperbolic discounting procedures (Newell & Pizer, 2003; Arrow, Cropper, Gollier, Groom, & al., 2013; Weitzman M. , 2001). This leads to the exclusion of the use of time-invariant rates in favour of time-declining assays, which are able to give more weight to events with long-term effects. Two approaches are proposed in the literature for the estimation of time-declining rates: the Consumption-Based Approach, which makes use of the Ramsey formula; the Expected Net Present Value Approach (ENPV). For both, the theoretical assumption defining the declining trend consists in the inclusion of an uncertainty factor in the time structure of the social discount rate. If for the Consumption-Based Approach the uncertainty concerns the growth rate of consumption, in the ENPV it is the discount rate itself that is modelled as uncertain.

Other scholars, however, propose to adopt a double discount rate in the cost-benefit analysis for projects with substantial environmental impacts (Price, 2003; Hasselmann, Hasselmann, Giering, Ocana, & von Storch, 1997; Yang, 2003; Weikard & Zhu, 2005; Viscusi, Huber, & Bell, 2008; Gollier, 2012; Almansa & Martínez-Paz, 2011):

– a discount rate for strictly financial cash flows;
– another discount rate, with a lower value, for the evaluation of environmental externalities (Kula & Evans, 2011).

Usually, the discount rate coincides with the rate at which society is willing to postpone a unit of current consumption to obtain more consumption later. That is, future generations are assumed to be richer than the present ones, so that, due to the principle of diminishing marginal utility, an incremental unit of consumption is worth more today than tomorrow. However, today's policy actions increasingly lead to greater impacts on the environment – greenhouse gas emissions, rising temperatures, reduced biodiversity, among others – than on future consumption. Hence, there is a need to define an ecological discount rate that considers the correlation between environmental and consumption goods (Gollier, 2010; 2012).

The approaches for estimating the declining discount rate. The literature proposes two approaches for estimating the DDR:

1. *Consumption-Based Approach*;

2. *Expected Net Present Value Approach*.

The first valuation approach assumes that in economic analyses the costs and benefits of the project are discounted at the consumption discount rate, i.e. that rate r_t at which society is willing to postpone a unit of current consumption in order to obtain more consumption later.

The assumption underlying the SRTP approach is that the welfare of society is a function of the utility U(c) of income or consumption alone. Consider then the inter-temporal social welfare function W as the sum of the utilities of consumption for each time instant:

$$W = \int_{t=0}^{\infty} U(c_t)\ e^{-\rho t} dt \qquad (2.22)$$

Where: $U(c_t)$ is the utility function of consumption at time t, while ρ is the utility discount rate, also called the pure time preference rate.

It follows from formula (2.22) that the present value of utility from consumption decreases over time. It follows that a positive value of the utility discount rate means giving more importance to choices that are sustainable today, since this is the only way to ensure sustainable choices tomorrow. Furthermore, (2.22) relates the utility discount rate to the change in time of a unit of consumption. This variation is expressed through the consumption discount rate, also known as the Social Discount Rate (SDR), since it is used to evaluate the effects – financial and extra-financial – that public projects generate on the community.

Thus, the consumption discount rate is the rate at which the value of a small increment of consumption falls as time changes. So, if $U_c = \mathrm{d}U(c_t)/\mathrm{d}c_t$, then:

$$r = \frac{\frac{\mathrm{d}}{\mathrm{d}t}\left(U_c \cdot e^{-\rho t}\right)}{U_c \cdot e^{-\rho t}} \qquad (2.23)$$

Hence the well-known Ramsey formula (1928):

$$r = \rho + \eta \cdot g \qquad (2.24)$$

Where:

- ρ is the rate of time preference;
- η represents the elasticity of marginal utility with regard to consumption;

– *g* is the expected growth rate of consumption.

Ramsey formula makes clear the correlation between the utility discount rate ρ and the consumption discount rate r and shows that if $\rho \geq 0$, $\eta > 0$, $g > 0$, then the consumption discount rate r is positive and future goods are worth less than current goods.

It is precisely the uncertainty related to the growth rate of consumption g that leads to write the extended Ramsey formula. In particular, if we assume that *g* is approximated by a sequence of normally, independently and identically distributed random variables with mean μ and variance σ^2, then (2.24) becomes:

$$r_t = \rho + \eta \cdot \mu_g - 0{,}5\, \eta^2 \cdot \sigma_g^2 \tag{2.25}$$

The last term in (2.24), called "precautionary", summarises the uncertainty about the growth rate of consumption and leads to a reduction in the value of the discount rate rt. This rate is, however, constant in time.
According to Gollier (2008; 2012), to obtain a declining function of the discount rate is to introduce some uncertainty parameters in (2.25). In fact, the absence of a sufficiently large data set concerning the growth process of the economy in the long run implies that the parameters μ and σ can be treated as uncertain (Weitzman, 2001). It is then assumed that the consumption register follows a Brownian motion with trend $\mu(\theta)$ and volatility $\sigma(\theta)$. These values depend on a parameter θ, which is uncertain at time 0. In particular, two cases are made explicit:

1. the mean μ growth rate of the economy is uncertain, i.e. $\mu = \mu(\theta)$. Then:

$$r_t = \rho - \frac{1}{t} \ln \sum_{\theta=1}^{n} q_\theta e^{(-\eta\mu_\theta)t} - 0{,}5\eta^2\sigma^2 \tag{2.26}$$

where $\sum q_\theta = 1$, with q_θ probability that the parameter μ associated with the uncertainty has of occurring;

2. the volatility σ of the economy's growth rate is uncertain, i.e. $\sigma = \sigma(\theta)$. In this case we have that:

$$r_t = \rho + 0{,}5\eta\mu - \frac{1}{t} \ln \sum_{\theta=1}^{n} q_\theta e^{(0{,}5\eta^2\sigma_\theta^2)t} \tag{2.27}$$

where $\sum q_\theta = 1$, in which q_θ is the probability that the parameter σ associated with the uncertainty has to occur.

The ENPV approach, on the other hand, takes the discount rate as an uncertain parameter. Weitzman (2001) shows that estimating ENPV with an uncertain but constant discount rate is equivalent to calculating Net Present Value (NPV) with a certain rate but decreasing with an "certainty-equivalent" until it reaches the minimum possible value at time $t = \infty$.

If we do not consider the uncertainty related to the rate r, the discounting of future costs and benefits occurring at time t takes place by means of the well-known discount factor P_t:

$$P_t = \exp\left(-\sum_{i=1}^{t} r_i\right) \tag{2.28}$$

When r is a stochastic variable, the expected net present value of €1 after t years is worth:

$$E(P_t) = E(\exp(-\sum_{i=1}^{t} r_i) \tag{2.29}$$

Formula (2.29) represents the "certainty equivalent" discount factor. Thus, the corresponding "certainty equivalent" discount rate, understood as the exchange rate of the expected discount factor, is worth:

$$\frac{E(P_t)}{E(P_t+1)} - 1 = \tilde{r}_t \tag{2.30}$$

$\tilde{r}_t$ s therefore the rate of progression from t to $t + 1$ or also marginal discount rate.

Economic-environmental discounting. Recent contributions to the debate on discounting the returns from investments with significant environmental impacts concern the use of two different discount rates, useful for assessing consumption and environmental quality separately (Price, 2003; Hasselmann, Hasselmann, Giering, Ocana, & von Storch, 1997; Yang, 2003; Weikard & Zhu, 2005; Viscusi, Huber, & Bell, 2008; Gollier, 2012; Almansa & Martínez-Paz, 2011). Growing population and per capita consumption levels are placing increasing stress on the environment, with the consequent risk of exceeding the regenerative capacity of the ecosystem. In such a context, conventional discounting procedures fail to adequately assess the utility of ecosystem goods and services, so using a different discount rate for environmental impacts may be a solution to this problem. Discounting environmental impacts separately from economic impacts becomes a way of guiding the decision-maker towards more sustainable choices (Kula & Evans, Dual discounting in cost-benefit analysis for environmental impacts., 2011; Almansa & Martínez-Paz, 2011).

Several studies have been conducted in this direction. Some authors analyse the issue of dual discounting from a theoretical perspective, reaching the general conclusion that environmental goods should be discounted at a lower rate than consumer goods (Echazu, Nocetti, & Smith, 2012). Other authors instead conduct empirical studies on environmental discounting. In this respect, Richards and Green (2015) estimate a hyperbolic discount rate for environmental goods that is lower than the financial rate. Using the Ramsey growth model at global level, Baumgärtneret et al. (2015) propose a discount rate for Ecosystem Services (ESs) that is 0.9% lower than for consumer goods. Drupp (2018) reaches such conclusions by implementing a based on a constant elasticity of substitution utility specification and on global metadata on willingness to pay for different ESs. Again, Vazquez-Lavín et al. (2019) highlight the importance of estimating a declining discount rate for eco-system services, with particular attention to projects aimed at preserving biodiversity in marine protected areas in Chile.

Under this dual discounting approach, Net Present Value (NPV) is estimated using the following equation:

$$\text{NPV} = \sum_{t=0}^{n} \frac{F_t}{(1+r_c)^t} + \sum_{t=0}^{n} \frac{E_t}{(1+r_q)^t} \tag{2.31}$$

Where: F_t indicates annual economic cash flows; E_t expresses annual environmental benefits net of costs; r_c is the discount rate of consumption, which for simplicity we also call the economic discount rate; r_q is the discount rate of environmental quality which we also define as the ecological discount rate di r_c.

To estimate r_c and r_q it is necessary that the utility function, already defined in section 2.1, no longer depends only on consumption c_t but also by environmental quality q_t, i.e. $U_t = U(c_t, q_t)$. In addition, the following assumptions are introduced (Gollier, 2012):

1. the environment deteriorates over time, so an incremental improvement in environmental quality will be more valuable to future generations than to current ones;

2. the availability of consumption c_t and environmental quality q_t varies over time;
3. the utility function $U(c_t, q_t)$ is of the Cobb-Douglas type, increasing and concave;
4. environmental quality grows less rapidly than consumption;
5. it is assumed that consumption is a substitute to the quality of the environment, economic growth has a positive impact on the ecological discount rate, thereby potentially counterbalancing the effect of the deterioration of the environment. The possibility to substitute the deteriorating environment quality by other goods is at the core of the notion of sustainable development. If the substitutability is limited, the environmental deterioration effect dominates the economic growth effect, and the ecological discount rate should be small or negative, thereby inducing us to preserve environmental assets;
6. people change as well as needs and expectations, causing some factors to become less or more important.

Under these conditions, the inter-temporal social welfare function W becomes the sum of the utilities derived from both consumption c_t and environmental quality q_t:

$$\mathrm{W} = \int_{t=0}^{\infty} U(c_t, q_t) \cdot \mathrm{e}^{-\rho t} \mathrm{d}t \tag{2.32}$$

If parameters c_t and q_t are known, if they follow a geometric Brownian motion, and if they are related to each other by a deterministic function of the type $q_t = \mathrm{f}(c_t)$, then deriving $U(c_t, q_t)$ with respect to consumption c_t the equation describing the economic discount rate r_c is:

$$r_c = \rho + \left[\eta_1 + \delta \cdot (\eta_2 - 1)\right] \cdot \left[g_1 - 0.5 \cdot (1 + \eta_1 + \delta \cdot \left(\eta_2 - 1\right)\right] \cdot \sigma_{11} \tag{2.33}$$

Deriving instead $U(c_t, q_t)$ with respect to environmental quality q_t we have the function of the environmental quality discount rate r_q:

$$r_q = \rho + \left[\left(\delta \cdot \eta_2 + \eta_1 - 1\right)\right] \cdot \left[g_1 - 0.5 \cdot \left(\delta \cdot \eta_2 + \eta_1\right)\right] \cdot \sigma_{11} \tag{2.34}$$

With reference to (2.33) and (2.34):

- ρ is the rate of time preference;

- η_1 the risk aversion parameter of income inequality;
- η_2 the degree of environmental risk aversion;
- g_1 the growth rate of consumption;
- σ_{11} the uncertainty of the consumption growth rate in terms of the mean square deviation of the variable;
- δ the elasticity of environmental quality to changes in the growth rate of consumption g_1.

Under the specified assumptions, as equations (2.33) and (2.34) show, we obtain a time-invariant (or flat structure) of the two economic discount rate r_c and ecological discount rate r_q. Considering, instead, uncertain the parameters that govern the economic growth and the environmental quality, then we obtain a time-invariant structure for the economic and ecological discount rates.

2.3.4.2. Approaches to risk assessment of public projects with long-term effects

In Section 2.3.4.1 it was stated that in a deterministic world Cost-Benefit Analysis would assess the social desirability of a project in terms of the Social Welfare Function (SWF), expressed by 2.22.

When the consumption and net benefits of the project cannot be assessed deterministically, the welfare function must take uncertainty into account as shown by 2.35:

$$V = \int_{t=0}^{\infty} E[U(\widetilde{c_t})]\ e^{-\rho t} dt \qquad (2.35)$$

where consumption $(\widetilde{c_t})$ is now a random variable, while the value of the undiscounted expected utility is valid:

$$[U(\widetilde{c_t})] = \int_{c_{min}}^{c_{max}} U(c_t) f(c_t)\ dc_t \qquad (2.36)$$

where $f(c_t)$ is the probability density function of consumption and c_{min} to c_{max} are the maximum and minimum values of $\widetilde{c}_t$.

Thus, according to the OECD (2018), one way to incorporate risk into the net benefits of a project is to assess the certainty equivalent of those net benefits. This equivalent includes: (i) the uncertainty inherent in the benefits themselves, due to the impossibility of predicting them deterministically; (ii) the macroeconomic uncertainty in the level of growth. Once the net certainty equivalent benefits are estimated, they can be treated as if they were certain and, consequently, discounted at a risk-free rate to estimate the performance indicator.

Assume that a project provides an uncertain net benefit NB. Assume also that the income level Y is uncertain, i.e. it is not known how rich the society will be when the net benefits arrive. According to OECD (2018), the change in welfare for a small value of NB, measured in terms of units of consumption/income, is given by:

$$\Delta W = \mu_{NB} - \frac{1}{2\bar{Y}} \eta \sigma_{NB}^2 - \frac{1}{\bar{Y}} \eta \sigma_{Y,NB} \qquad (2.37)$$

where $\eta = \frac{U''(\bar{Y})}{U'(\bar{Y})} \bar{Y}$ and $\bar{Y}$ = E $[\bar{Y}]$. In the case of a public project, Y represents the national income, or sometimes, the portfolio of public projects. Equation (2.37) shows that the change in welfare in terms of consumption is essentially equivalent to the sum of three terms:

1. the expected value of the change in net benefits, μ_{NB};
2. a risk premium associated with the pure variance of the project's net benefit, σ_{NB}^2;
3. a risk premium reflecting the covariance of the net benefit with national income, $\sigma_{Y,NB}$.

In the context of public project appraisal, the latter two components can be considered as diversifiable and non-diversifiable sources of risk. In essence, (2.37) represents the equivalent certainty value of the uncertain net benefit, NB, measured in units of consumption. If it is greater than zero, then the project is sustainable.

It follows that $\frac{1}{2\bar{Y}} \eta \sigma_{NB}^2$ measures the willingness to pay to avoid the change in net benefits only. For a risk-averse agent this term will be positive. $\frac{1}{\bar{Y}} \eta \sigma_{Y,NB}$ is the second component of the risk premium and reflects how net benefits may be related to national income, which is uncertain.

Thus, in the case of public projects, risk can be treated by transforming future cash flows into certainty equivalents and thus treat the problem as "certain".

In addition, Gollier (2011) shows that if it is assumed that both project cash flows and consumption follow a Brownian motion, then the theory of the Consumption Capital Asset Pricing Model (CCAPM) can also be used.

According to this theory, the project risk can be incorporated into the discount rate, whereby in addition to the risk-free rate, the risk premium proportional to the project beta is considered.

The Consumption Capital Asset Pricing Model (CCAPM) is an extension of the Capital Asset Pricing Model (CAPM) that uses a consumption beta instead of a market beta to explain the expected return premiums on the risk-free rate. The beta component of both the CCAPM and CAPM formulae represents a risk that cannot be diversified. The CCAPM predicts that the return premium of an asset is proportional to its consumption beta. According to the CCAPM theory, initially developed by Lucas (1978):

$$r(\beta) = r_f + \pi(\beta) = r_f + \eta \cdot \beta \cdot \sigma_c^2 \qquad (2.38)$$

Where: r(β) is the risk-adjusted discount rate, which can be interpreted as the minimum expected rate of return of an investment project with risk profile β, is specific to each project through the estimation of each project's β; η is the marginal utility elasticity of consumption, while σ_c^2 represents the standard deviation of the consumption growth rate.

2.3.5. The legislative landscape

At European level, the regulatory guidelines highlight the importance of risk analysis in the *ex-ante* evaluation of investments in the civil field. In this regard, Regulation 1303/2013 of the European Commission specifies that the risk analysis may be required either because of the complexity or size of the project or because of the availability of data necessary for the assessment (European Commission, 2013). It is compulsory in the case of major projects, defined as «works, activities or services intended to accomplish an indivisible task of a precise economic and technical nature, with clearly identified aims and a total eligible cost exceeding €50 million».

The European Commission (EC) Guide to Cost-Benefit Analysis for the 2014-2020 programming period describes the four main steps for investment risk assessment (European Commission, 2014).

1) sensitivity analysis;
2) qualitative risk analysis;
3) probabilistic risk analysis;
4) definition of risk prevention and/or mitigation actions.

Step 1. CBA allows to express a judgement on the economic performance of the investment and to choose between alternative projects. This technique consists in: forecast of costs and benefits that the project initiative generates in the analysis period; the subsequent discounting of Cash Flow (CF); then estimation of performance indicators, Net Present Value (NPV), Internal Rate of Return (IRR), Benefit/Cost ratio, Payback Period.

In the implementation of the CBA, the sensitivity analysis allows the identification of the "critical" variables of the project, i.e. those which have the greatest impact on the evaluation result. The sensitivity analysis is conducted by changing the values associated with each variable and assessing the effect of this change on the project's profitability indicators. A guiding criterion may be to consider as "critical" those variables for which a variation of ± 1% of the value adopted in the base case determines a variation of more than 1% in the value of the economic performance indicator. To study the impact on the project caused by the simultaneous variation of the critical variables, the sensitivity analysis can be completed with the scenario analysis. The estimation of the profitability indicators in optimistic and pessimistic scenarios allows a preliminary judgement to be made on the project risks.

Step 2. The qualitative risk analysis consists of:

- in the identification of possible events with negative implications on the execution of the project;
- in the consequent definition of a risk matrix for each adverse event, from which it is possible to read the probability of occurrence (P) and severity of impact (S);
- in the interpretation of the risk matrix in order to assess the risk levels associated with the project (P-S);
- in the planning of mitigation interventions for the main risks according to the estimated risk level.

About the definition of the risk matrix, each adverse event is assigned a probability (P) of occurrence. The classification recommended by the EC is given below, although in principle other classifications are possible:

A. Very unlikely (probability 0-10%);
B. Unlikely (probability 10-33%);
C. As unlikely as probable (probability 33-66%);

D. Probable (probability 66-90%);
E. Very likely (probability 90-100%).

Each effect is then assigned an impact severity (S) from I (null effect) to V (catastrophic), based on the costs and/or social welfare losses generated. These values make it possible to define a classification of risks, associated with their probability of occurrence.

Step 3. The probabilistic risk analysis is expressed in the stochastic description of the critical variables of the project and the subsequent estimation of the probability distribution of the profitability indicator. The transition from the cumulative probability curve of the risky variables to that of the project IRR takes place through Monte Carlo analysis. In a nutshell, the random extraction of probable values for each critical variable allows the derivation of the respective value of the profitability indicator. By repeating the procedure for a sufficiently high number of extractions, the probability distribution of the IRR is derived, as described in par. 2.5.2.

By reading the probability distribution of the IRR, it is possible to derive important information about the project risk, e.g. the expected value and variance of the profitability ratio E(IRR).

The comparison between E(TIR) and the return limit values allows to express a judgement on the project risk. However – it was said – regulatory guidelines do not provide clear guidance on acceptable levels of project risk.

Step 4. The definition of an effective risk mitigation and/or prevention strategy is a direct consequence of the outcomes of the previous phases. This phase includes: the selection of mitigation measures; the implementation of the prepared plan; the analysis and evaluation of the residual risk, i.e. the risk that remains despite the undertaken mitigation strategy. In other words, it is necessary to re-estimate the probability distributions of the risky variables of the project, resulting from the implementation of the mitigation measures and, consequently, that of the economic performance indicator. Table 2 summarises the steps necessary for the risk management activity referring strictly to the investment risk, following what suggested by the EC.

Table 2. Investment risk assessment according to European Commission guidelines (2014) (source: own elaboration based on EC information)

<table>
<tr><td>Sensitivity analysis</td><td>Sensitivity analysis to identify ‘critical’ variables:
A variable is critical if:
± 1 % variation of CV → % variation of NPV > 1 %
<table>
<tr><th>Variable</th><th>Variation of the NPV due to a ± 1 % variation</th><th>Criticality judgement</th></tr>
<tr><td>Total investment cost</td><td>0.6%</td><td>Non critical</td></tr>
<tr><td>Yearly maintenance cost</td><td>2%</td><td>Critical</td></tr>
</table></td></tr>
<tr><td>Qualitative Risk analysis</td><td>– a list of adverse events to which the project is exposed;
– a risk matrix for each adverse event indicating:
1. the (ranked) levels of probability of occurrence (P)
2. the (ranked) level of the severity of impact (S)
3. the risk level (P·S)
<table>
<tr><th>Severity / Probability</th><th>I</th><th>II</th><th>III</th><th>IV</th><th>V</th></tr>
<tr><td>A</td><td>Low</td><td>Low</td><td>Low</td><td>Low</td><td>Moderate</td></tr>
<tr><td>B</td><td>Low</td><td>Low</td><td>Moderate</td><td>Moderate</td><td>High</td></tr>
<tr><td>C</td><td>Low</td><td>Moderate</td><td>Moderate</td><td>High</td><td>High</td></tr>
<tr><td>D</td><td>Low</td><td>Moderate</td><td>High</td><td>Very High</td><td>Very High</td></tr>
<tr><td>E</td><td>Moderate</td><td>High</td><td>Very High</td><td>Very High</td><td>Very High</td></tr>
</table></td></tr>
<tr><td>Probabilistic Risk assessment</td><td>– Estimate of the probability distribution of the risk variables
– Generation of the cumulative frequency distribution of the performance indicator to verify the feasibility of the project</td></tr>
<tr><td>Risk treatment</td><td>Individuation of strategies and measure for risk prevention and mitigation and evaluation of residual risk in qualitative terms (low, medium, high ...)</td></tr>
</table>

The Asian Development Bank also emphasises the extreme importance of risk analysis in the ex-ante evaluation of projects.

In “*Cost-Benefit Analysis for development: A practical guide*” (2013) is specified which approaches to implement depending on the type of investment.

Specifically, if the decision-maker is risk-neutral, probabilistic approaches such as Monte-Carlo analysis can be implemented, since the estimation of expected values of performance indicators is the basis for decision-making.

Risk neutrality implies that the risk of failure can be ignored; for example, if a government or large investor can pool risks across a large number of projects, an unfavourable outcome on one is offset by a favourable outcome on another. Thus, risk neutrality can be accepted as the correct risk response for all projects, except for non-marginal or pro-cyclical projects, where the failure of one project may affect the whole portfolio.

If the expected return and risk are positively correlated, then higher return assets are generally riskier. This implies that for large or pro-cyclical projects, the decision criterion for acceptability has two dimensions: the expected return and its variance (i.e. the risk of failure).

In "*Guidelines for the economic analysis of projects*" (2017), The ADB describes the steps necessary to implement Monte Carlo analysis. These steps concern:

i. the identification of key factors, i.e. those that significantly influence the result of the analysis;
ii. the construction of the probability distributions of these key variables;
iii. the random selection of the values of these variables from their probability distributions;
iv. the estimation of the ENPV or EIRR by combining the random values of the sensitive variables with the certain values of the variables considered as non-risky;
v. the re-iteration of steps (iii) and (iv) several times to provide reliable estimates of the ENPV and EIRR and establish their probability distributions;
vi. the estimation of the probability that the EIRR will fall below the acceptable discount rate.

In addition, it is specified that quantitative risk analysis should be considered for large projects that have a potentially large impact on a particular target group within the borrowing country and for investments where there is significant uncertainty about key issues such as the probability of flooding.

The "*Handbook for integrating Risk Analysis in the economic analysis of the project*" (ADB, 2002) analyses the principles to be applied in practical applications, so that quantitative risk assessment is treated as transparently as possible. Table 3 summarises these principles.

Table 3. Principles to apply in Data Handling for Probabilistic Risk Analysis (Source: ADB, 2002)

1	Identify those variables for which future values are unknown and which are likely to affect project returns (i.e., the 'key' variables)
2	Fully explain the general nature of the data set which is used for modeling those variables' values (its origin—i.e., from objective or subjective sources, whether it is based on historical observations or forecasted projections, the number of observations the data set contains, its extent of completeness/any missing data points, etc.)
3	If the data derives from subjective sources, explain the method by which it was elicited (e.g., from visual techniques, from subjective questioning, from an expert-based 'Delphic' process, etc.)
4	Explain the statistical nature of those variables' assigned probability distributions (i.e., whether these distributions are triangular, uniform, normal, logarithmic, exponential, etc.)
5	Make clear the goodness of fit of the distribution to the data set (if one has been fitted using specific software), and quote appropriate statistical measures (e.g., Chi-square, Kolmogorov-Smirnov, Anderson-Darling statistics, etc.)
6	Make explicit any correlation thought to exist between variables used in the risk analysis (i.e., its extent, and the technical, real-world basis for the assumption, etc.), and (based on this)
7	Explain and justify the extent of any variable disaggregation

3. Setting thresholds of risk acceptability with the As Low As Reasonably Practicable approach

Summary

Assessing is a crucial issue when the object of the evaluation is “major works”, for which the riskiness due mainly to the scarce availability of certain data makes it difficult to express with certainty a forecast judgment on the financial performance of these investment projects. Even if the community and extra-European normative guidelines provide indications to implement the risk analysis (the reference is paragraph 2.3.4), there is a lack of objective criteria that can guide the analyst in expressing a judgement on the acceptability of the investment risk and on the residual risk, that is, the risk that remains despite the planned mitigation strategies. The objective is therefore to define an innovative risk management model that can support the investor in the decision-making process by basing the assessment of project risk on shared criteria and objective data. There are two main new elements in the model: the first concerns the definition of minimum levels of acceptance of investment risk; the second concerns the characterisation of the methodology for estimating these threshold values.

With reference to the first element, thresholds of risk acceptability and tolerability are borrowed from the *As Low As Reasonably Practicable* (ALARP) logic. According to this principle, which is widely used in safety risk, a risk is defined as ALARP if it falls between these thresholds or if the costs for its mitigation appear disproportionate compared to the achievable benefits.

As regards the methodology for estimating the threshold values, the theoretical framework of reference is the Capital Asset Pricing Model (CAPM) which defines how to assess the minimum return expected from an investment project with a given risk profile. Thus, the joint use of the CAPM and statistical survey tools makes it possible to estimate limit values of risk that can be specified according to both the investment sector and the territorial context in which the project is located. The comparison between the expected

return of a civil project and the estimated risk limit values can effectively guide the analyst in the evaluation of investments.
This section is structured in five sub-sections. First, the ALARP principle for risk acceptance (Section 3.1.1) and the risk analysis techniques used in the model (section 3.1.2) are recalled. We then describe the stages of the model (section 3.1.3) with a focus on the methodology for estimating the acceptability and tolerability thresholds useful for expressing an opinion on investment risk.
In the last paragraph of this section, the described methodology is implemented for different investment sectors and for different economic contexts. Specifically, application to the "Engineering/Construction", "Environmental & Waste Services" and "Green & Renewable Energy" sectors, both with reference to stable economies, such as Europe, and emerging economies, such as China, makes it possible to analyse how the investment risk depends both on the sector of reference of the project and on the socio-economic context in which the civil work is located.

3.1. The ALARP principle for the assessment of investment risk

Risk assessment is widely used in the field of safety where human life must be protected from the consequences of carrying out dangerous activities. It has been said that in such approaches the Quantitative Risk Assessment (QRA) is increasingly used, so much so that numerous regulatory agencies are requiring the use of quantitative methods in their published regulations and guidelines and clients are aiming to improve the economic efficiency of their risk management decision-making (Vanem, 2012; Macciotta & Lefsrud, 2018). Consider, for instance, the guidelines of *ERM-Hong Kong Ltd* (1998) for landslide risk management and the regulations of the *Association of Professional Engineers and Geoscientists of British Columbia* (2010) which also considers the application of quantitative assessments for land-use planning.

However, when risk is assessed in terms of the probability of loss of life, it becomes complex to establish acceptable levels of risk of death as legal, political, social and economic issues need to be included in the assessment (Aven T. , 2016; Fell, 1994; Ho, Leroi, & Roberds, 2000). For this reason, policymakers often employ quantitative methods in conjunction with criteria to assess the tolerability/acceptability of risk. In 1992, the UK Health and

Safety Executive (HSE) agency, in response to the need to manage the hazard inherent in industrial processes, defined some general principles of risk acceptance:

- *The accountability principle*. The definition of risk acceptance criteria must be clear and transparent, based on quantitative definitions and objective assessments;
- *The principle of equivalency*. The risk must be compared with limit thresholds which derive from the analysis of activities or systems similar to the one to be assessed and which are widely recognised as acceptable or tolerable;
- *The holistic principle*. Security decisions must be based on a holistic view of all risks. Only when the overall risk to which one is exposed has been properly assessed, can mitigation measures be proposed;
- *The ALARP principle.* Risks must be reduced to As Low As Reasonably Practicable. In other words, all mitigation measures must be implemented if the costs do not appear disproportionate to the achievable benefits. In ALARP, threshold values are defined for 'acceptable' and 'tolerable' risks. Risks below the tolerable threshold must be reduced because they are unacceptable; risks between the tolerable and acceptable thresholds are in the ALARP zone, i.e. they must be mitigated as far as is reasonably practicable; risks above the acceptable threshold are "broadly acceptable", i.e. they do not need to be mitigated.

The relevant literature also distinguishes between individual and societal risk.

Individual risk is defined as the «frequency at which an individual is expected to be subjected to a certain level of harm as a result of an accident in a major hazard industry» (Health and Safety Executive, 2001). In other words, it can be defined as the risk of death to which an individual in an unsafe location is subjected at a given time. This risk gives a value of annual probability of death for a given location.

Social risk, on the other hand, is given by the frequency with which a certain number of people are subjected to a certain level of damage as a result of a specific accidental event.

This risk is well represented by F-N curves, which relate the number of deaths (N) on the horizontal axis to the frequency (F) of having one or more deaths on the vertical axis. These curves were originally developed to assess nuclear risks based on tolerance thresholds, which reflected social aversion to more deaths during a single catastrophic event.

In these graphs, the two thresholds of risk acceptability and tolerability are a function of parameters such as slope and anchor point. A first important indication of the development of the social risk curves is given by the historical accident curves in a given area, which provide important indications on the slope and the starting point to be associated with the limit lines. The first parameter, the anchor point, represents the cumulative frequency (F) limit for a certain number of deaths. The slope, always negative and generally ranging between -1 and -2, is instead a function of risk aversion towards accidents involving a progressively increasing number of fatalities (Health and Safety Executive (HSE), 1992; 2001; Morgenstern, 1995; Ho, Leroi, & Roberds, 2000).

Fig. 5 shows a generic F-N diagram, divided into four areas. In the unacceptable region, the risk should be reduced regardless of the investment. It follows that if the investment is unsustainable, those exposed should be removed. In the intense security region, the probability of the catastrophic event occurring is very low but should always be kept under control. In the broadly acceptable region, no investment is reasonably necessary to further reduce the risk. Finally, in the tolerable region, the risk should be reduced further if the ALARP principle is practicable, i.e. cost-benefit approaches are used to assess the cost-effectiveness of a mitigation option or to compare different possible interventions.

In other words, the costs of implementing risk reduction measures are compared with the reduced risks assessed in monetary terms, thus assigning an economic value to life. Various estimates of the economic value of life appear in the literature, in which people are regarded as a resource in economic activities. However, equally relevant are the ethical criticisms of the approach. Thus, in order to avoid assigning a cost to human life, cost-effectiveness analysis is often used (Skjong, Vanem, & Øyvind, 2005). According to this method, the ratio between the cost of risk reduction measures and the risk reduction itself is assessed, avoiding giving life an economic value. In this case, indicators such as the gross-cost-of-averting-a-fatality (GCAF) and the net-cost-of-averting-a-fatality (NCAF) are estimated:

$$GCAF=\frac{\Delta C}{\Delta R} \tag{3.1}$$

$$NCAF=\frac{\Delta C\text{-}\Delta B}{\Delta R} \tag{3.2}$$

Where: ΔC is the cost of the risk mitigation intervention; ΔB is given by the benefits resulting from the implementation of the mitigation strategy; ΔR is the reduction of risk resulting from the implementation of the planned intervention.

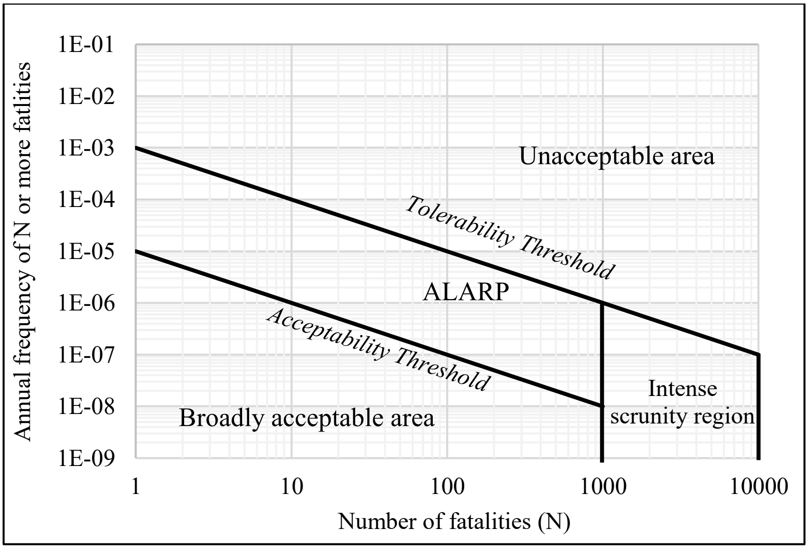


Figure 5. Societal risk evaluation criteria: example of a risk curve on the F-N plane (source: own elaboration)

These aspects show how ALARP logics can be integrated with the criteria of Cost-Benefit Analysis (CBA), typical of economic-evaluation disciplines, to manage investment risk. In fact, if up to now it has been generally applied to evaluate the security risk linked to the safeguard of human life, it is believed that the ALARP criterion of risk acceptance may represent a general thinking way (Redmill, 2010). For this reason, it can also find original application in the assessment of the riskiness of investments in the civil field, where a triangular balancing of risk, mitigation costs and achievable benefits is still required. In this case, a critical aspect concerns the estimation of the threshold values of acceptability and tolerability useful to circumscribe the region in which the investment risk for the economic operator is reasonably practicable because ALARP.

3.2. The steps of the investment risk management process

Investment risk management is closely integrated with decision theory. This is particularly so when the uncertainty related to the sensitive variables of the project makes it difficult to express the result of the Cost-Benefit Analysis (CBA) in deterministic terms, as in the case of large-scale interventions or when the data necessary for the analysis are incomplete or difficult to find (EC 2014). This leads the evaluator to conduct the analysis in stochastic terms. In this case, it is necessary to:

1. Identify the sensitive variables of the system, i.e. those that significantly influence the final value of the return on investment indicator. According to the European Commission's Guide to Cost-Benefit Analysis (2014), "critical" variables are defined as those for which a change of ±1% in the estimated value results in a change of more than ±1% in the Net Present Value (NPV);
2. Describe in stochastic terms the sensitive variables, i.e. derive the probability distribution of the risky parameters of the analysis, identified in point (1);
3. Estimate the probability distributions of the investment performance indicators. This step returns the stochastic description of the profitability indicator, according to the probability distribution associated to the risky parameters in point (2). In fact, from the reading of the probability distribution of the IRR and of the cumulative probability distribution of the IRR, it is possible to derive important information on the project's riskiness.

   From the probability density function of the profitability indicator, which is depicted in Fig. 6, it is possible to read all the possibilities of the index and the probability that each of them has of occurring. Therefore, the expected or mean value of the variable is also derived from this distribution. Let IRR be a continuous random variable with probability density f(IRR), the expected value (mean value or mathematical hope) of the variable IRR is defined as the integral extended throughout $\mathbb{R}$ of the product between IRR and the density function f(IRR):

$$E(IRR)= \int_{-\infty}^{+\infty} IRR \cdot f(IRR) \tag{3.3}$$

If we discretize the probability density function of IRR, then the expected value of the discrete random variable EIR is the sum of the products of the IRR_i values and the respective probability $f(IRR_i)$:

$$E(IRR)= \sum_{i=1}^{n} IRR_i \cdot f(IRR_i) \tag{3.4}$$

With *n* number of discretisation intervals, the probability distribution of the random variable IRR.

The cumulative distribution finction $F_{(IRR)}$, also provides important information on project risk. It allows us to check the probability of having an IRR above or below a critical value.

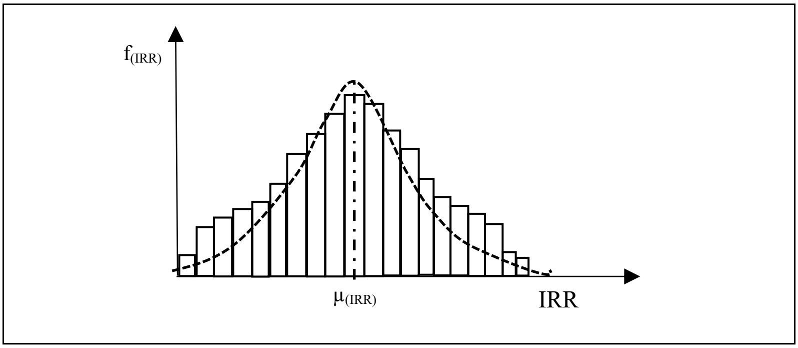


Figure 6. Example of probability density function of IRR (source: own elaboration)

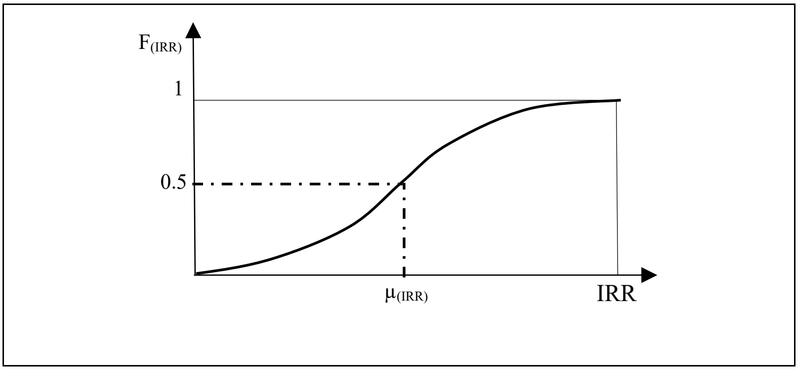


Figure 7. Example of cumulative distribution function of IRR (source: own elaboration)

The main limitation of the approach is, however, the absence of objective criteria to establish whether the investment risk and the residual risk, i.e. the risk that remains despite the proposed mitigation measures, are "sufficiently acceptable" for the investor. Thus, in the following section an innovative model of investment risk assessment is characterised, which shows how this criticality can be overcome by resorting to the ALARP principle, from which the concepts of risk acceptability threshold and risk tolerability threshold are borrowed.

Figure 8 summarises the three main steps of risk analysis.

Identification of sensitive system variables
A variable X is critical if X ± (1% X) → ΔNPV ≥ ± 1%

⇩

Stochastic description of sensitive variables

$$(B_{p1}, B_{p2}, \dots B_{pn})$$
$$(C_{p1}, C_{p2}, \dots C_{pn})$$

⇩

Estimation of probability distributions (probability density function and cumulative distribution function) of investment profitability indicators

$$\mathrm{E(TIR)} = \sum_{i=1}^{n} \mathrm{TIR_i} \cdot \mathrm{f}\,(\mathrm{TIR_i})$$

Figure 8. Risk Analysis steps in the economic evaluation of the projects (source: own elaboration)

3.3. ALARP and CAPM. A novel model for the financial risk management

In order to characterise the model, it is first necessary: (1) to establish objective criteria for assessing the acceptability of investment risk; (2) to define a methodology for estimating the acceptance limit values. To solve point 1, we refer to the As Low As Reasonably Practicable (ALARP) logic. According to this principle, risk assessment is related to two thresholds: the acceptability threshold and the tolerability threshold.

Another crucial step is step 2, which concerns the definition of a methodology for estimating the limit values of acceptability and tolerability of the project risk. In this case, the novelty consists in the joint use of the Capital Asset Pricing Model (CAPM) and statistical survey tools, thus making it possible to assess risk thresholds according to both the investment sector and the territorial context in which the project is located.

The following paragraph 3.1.3.1 describes the steps of the risk assessment protocol; 3.1.3.2 details the methodology for estimating the risk acceptance thresholds.

3.3.1. Phases of the risk assessment model

The proposed investment risk management model follows the logical and operational steps of the risk management process described in Figure 1.

Step 1: Establish the context. In this first phase, it is necessary to define the objective that the economic operator intends to achieve, i.e. to avoid the failure of the investment. To this end, it is necessary to estimate the costs and revenues of the project, define the period of analysis and assess the profitability of the investment, using financial performance indicators, such as the Internal Financial Rate of Return (FIRR), the Financial Net Present Value (FNPV), the Payback Period and the Revenue to Cost ratio.

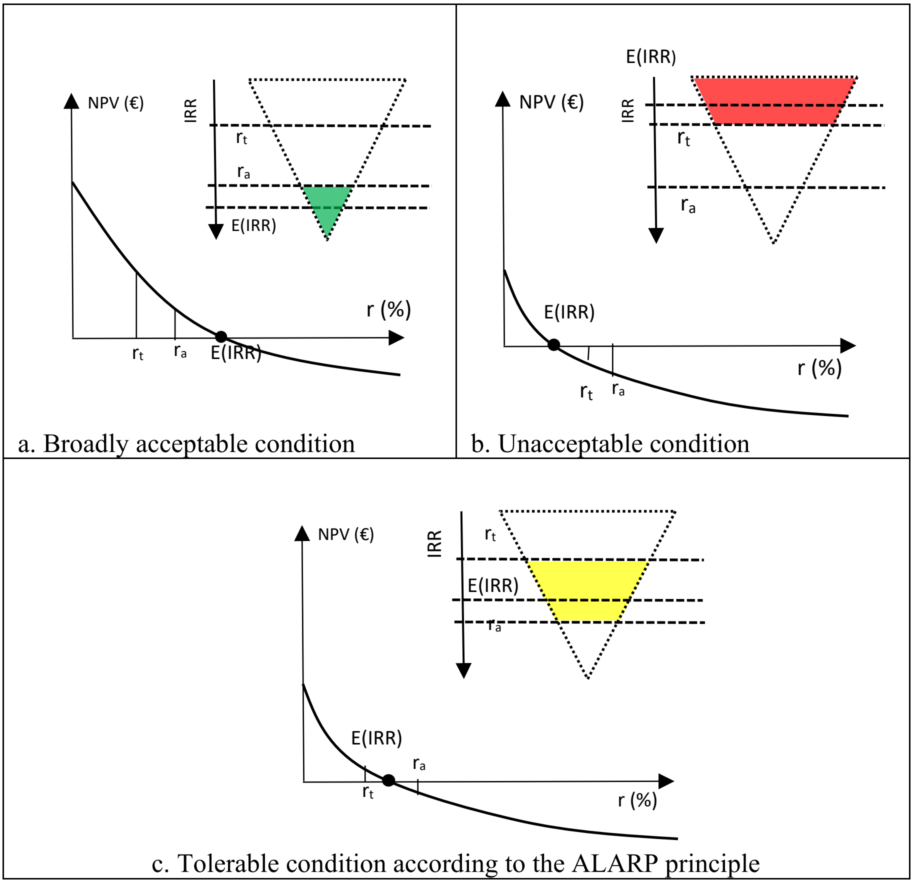
Step 2: Risk assessment. This phase consists of the following three steps: identification of risky variables; risk analysis; risk estimation.

- *Step 2.1. Identification of risky variables*. This can be done by implementing a sensitivity analysis that allows the identification of those project variables whose variations (positive or negative) have a greater impact on the financial performance of the initiative.
- *Step 2.2. Risk analysis*, first qualitative then quantitative. The qualitative risk analysis includes a list of the adverse events to which the project is exposed and the consequent definition of the risk matrix. From this matrix it is possible to read, for each adverse event, the relative level of risk based on the probability of occurrence and the severity of impact. The quantitative risk analysis first requires the attribution of the probability distribution for each risk variable. Implementing Monte Carlo analysis, using specific software, the probability density function and the cumulative probability distribution of the financial performance indicator are then derived.
- *Step 2.3. Risk estimation*, in which the acceptability of the investment risk is verified. This is the phase in which the main novelty of the model takes shape. In fact, from the ALARP logic – widely used for the assessment of the risk of loss of human life in industrial engineering – the concepts of acceptability threshold and risk tolerability have been changed.

The tolerability threshold separates the region of unacceptable risk from the region where the risk is ALARP tolerable. Therefore, we assume that an investment whose return is equal to the return expected from a project with an average risk profile, i.e. one that is representative of civil enterprises operating in a given area, is barely tolerable. Or, an investment whose probability of having a rate of return at least equal to that expected from a project with an average risk profile is 75% is barely tolerable.
The acceptability threshold, on the other hand, separates the ALARP risk region from the region where the risk is broadly acceptable to the investor. Given that as the investment risk increases, the expected return on the project increases, we assume that an investment is acceptable to the investor if its average return is at least equal to the return expected from a project with a high risk profile, i.e. one that is representative of the first-quartile civil enterprises – i.e. those with the lowest returns and therefore the riskiest – operating in a given area. Or, an investment is acceptable if the probability of having a rate of return at least equal to that expected from a project with a high risk profile is 75%.
Having conceptually defined the thresholds of acceptability and tolerability, it is possible to assess the riskiness of the project estimating Expected IRR, i.e. E(IRR).
As shown in Figure 9, we have that:

- the project initiative is largely acceptable to the investor if $E(IRR) > r_a$, i.e. the average IRR of the project is higher than the return expected from a project with an average risk profile. In such a case, no risk mitigation measures need to be defined in order to increase the project return (Fig. 9.a);
- the project initiative is unacceptable to the investor if $E(IRR) < r_t$ or the average IRR of the project is lower than the return expected from a project with a high risk profile. In this case, the project is unsustainable, so that it is necessary to define improvement measures capable of decreasing the risk of failure or increasing the profitability of the initiative (Fig. 9.b);
- the project initiative is tolerable, if $r_a < E(IRR) < r_t$, i.e. the average IRR of the project is between the return expected from a project with a medium risk profile and between the return expected from a project with a high risk profile. In such a case, mitigation measures should be

implemented that do not have disproportionate costs compared to the achievable benefits (Fig. 9.c).



a. Broadly acceptable condition

b. Unacceptable condition

c. Tolerable condition according to the ALARP principle

Figure 9. Acceptability and tolerability of the investment risk (source: own elaboration)

Step 3: Risk treatment. If the risk is unacceptable or tolerable for the investor (cases 9.b-9.c), it is first necessary to define changes to the project, then to assess the residual risk, i.e. the risk which remains despite the containment strategy undertaken. Then, the riskiness of the project is assessed again in terms of expected IRR (Fig. 9).
Specifically, consider that the pre-mitigation intervention is in a tolerable condition (represented in Fig. 9.c). In this case, the following scenarios may occur:

- the post mitigation design initiative is in a condition of broad acceptability (Fig. 9.a). The mitigation measures should be implemented;
- the design initiative post mitigation interventions is in an unacceptable or tolerable condition for the investor (Fig. 9.b). The pre-mitigation project is tolerable according to the ALARP principle, i.e. it has been shown that the improvement measures have disproportionate costs compared to the achievable benefits.

Consider, instead, the case in which the pre-mitigation intervention is in an unacceptable condition (Fig. 9.b). It may be that:

- the post-mitigation design initiative is in a condition of broad acceptability (Fig. 9.a). Mitigation measures should be implemented;
- the project initiative after mitigation still falls into an unacceptable condition (Fig. 9.b). The project is still risky and the planned interventions cannot be implemented;
- the project initiative after mitigation is in a tolerable condition (Fig. 9.c). The investment risk is now tolerable according to the ALARP principle, i.e. if any other improvement intervention does not result in greater benefits at lower costs.

To compare two or more mitigation strategies, the risk assessment described above can be combined with the estimation of an indicator similar to the net-cost-of-averting-a-fatality (NCAF), i.e. the net-cost-of-preventing-a-failure (NPAF):

$$\mathrm{NPAF} = \frac{\Delta \mathrm{C}}{\Delta \mathrm{R}} \tag{3.5}$$

Where: ΔC is the cost of the risk mitigation intervention net of benefits; ΔR is the risk reduction resulting from the implementation of the planned intervention. ΔR is given by the difference between the cumulative probability of r_a pre-intervention mitigation and the cumulative probability of r_a post-intervention mitigation. Once a maximum cost is set that the investor is willing to bear to make the project initiative widely acceptable, the higher the ΔR, the better the planned mitigation strategy performs.

3.3.2. A statistical methodology for the estimation of the tolerability and acceptability thresholds of the investment risk

Estimating investment risk thresholds is essential for the characterisation of the model described in the previous section.The objective is to define a methodology to establish the minimum tolerable return and the minimum acceptable return for the investor. These returns depend on factors such as: the investment sector of the project; the investor's risk appetite; and the specific socio-economic conditions of the area in which the intervention is located.

Thus, the theoretical reference to establish these limit values is the Capital Asset Pricing Model, as it allows to evaluate the risk-adjusted discount rate r(β), which can be interpreted as as the minimum expected rate of return of an investment project with risk profile β , is specific to each project through the estimation of each project's β (Gollier 2011). n order to define the meaning of the minimum tolerable return rt and the minimum acceptable return ra for the investor on which the model is based, it is necessary to briefly recall the theoretical framework of the CAPM (already introduced in section 2.3.2.1)

The main equation of the CAPM can be expressed as follows:

$$E(r_i) = r_f + \beta \cdot [E(r_m) - r_f] \tag{3.6}$$

Where $E(r_i)$ is the expected return on investment *i*, r_i and r_m are the gross return on the security in question and the return on the market portfolio respectively. r_f is the return on a risk-free investment. The β coefficient gives a measure of the systematic risk of a firm and expresses the expected percentage change in the excess return of an investment initiative for a 1% change in the excess return of the market portfolio.

β is also expressed by the:

$$\beta = \frac{\text{cov}\ (r_i, r_m)}{\text{var}\ r_m} \tag{3.7}$$

That is, β is given by the ratio of the covariance between the return r_i of the generic investment and the market return r_m and the variance of the market return r_m.

Graphically, β corresponds to the slope of the straight line that best interpolates in an x-y Cartesian diagram the investment returns with respect to the market returns:

$$r_i = \alpha + \beta \cdot r_m + \varepsilon \tag{3.8}$$

With $\alpha = (1 - \beta) \cdot r_f$ and ε statistical error measuring the reliability of the estimate made (Rosenberg and Guy 1976, Black 1993).

On the basis of this premise, we can then define the minimum tolerable return r_t and the minimum acceptable return ra for the investor.
Specifically, we define r_t as equal to the return expected from a project with an average risk profile, i.e. one that is representative of civil enterprises operating in a given area. It follows that:

$$r_t = re_t = r_f + \beta_t \cdot ERP \tag{3.9}$$

With: r_f risk-free rate of return; β_t "tolerable" systematic risk, which corresponds to the average industry risk; ERP is the equity risk premium, calculated as the difference between r_f and r_m.

Given that as the investment risk increases, the expected return on the project increases, we assume that an investment whose average return is at least equal to the return expected from a project with a high risk profile, i.e. representative of first-quartile civil enterprises – i.e. those with the lowest returns and consequently the riskiest - operating in a given territorial context, is acceptable to the investor.

Thus:

$$r_a = re_a = r_f + \beta_a \cdot ERP \tag{3.10}$$

In which β_a represents the "acceptable" systematic risk and corresponds to the average representative risk of the "worst" firms in the industry, i.e. those whose beta is highest. In other words, having defined the panel of firms useful to determine the industry beta, β_a is obtained as the average of the systematic risk of the 25% of the panel firms with the highest β.

In order to estimate the expected return considering both equity and all the capital invested by the firms, it is necessary to evaluate the tolerable Weighted Average Cost of Capital ($WACC_t$) and acceptable Weighted Average Cost of Capital ($WACC_a$):

$$WACC_t = ke_t \cdot re_t + (1 - t) \cdot kd_t \cdot rd_t \tag{3.11}$$

$$WACC_a = ke_a \cdot re_a + (1 - t) \cdot kd_a \cdot rd_a \tag{3.12}$$

Dove:

- re_t is the expected tolerable rate of return on equity, estimated with the (3.9);
- ke_t is the weight of equity, given by the ratio $\frac{E}{D+E}$ where E is the market value of the average net assets of the sector and D is the market value of the average debt of the sector;
- rd_t is the average sector cost of debt;
- kd_t is the debt weight, given by the ratio $\frac{D}{E+D}$;
- T is the marginal tax rate;
- re_a is the expected acceptable rate of return on equity, estimated with the (3.10);
- ke_a is the weight of average equity representative of the "worst" sector companies, i.e. those whose beta is highest;
- rd_a is the average sector cost of debt of the "worst" sector companies;
- kd_a is the average debt weight of the "worst" companies in the sector.

3.4. Estimation of the threshold values for the investment risk. Applications to different sectors in Europe and China

The methodology described in section 3.1.3.2 is implemented in order to estimate the expected tolerable return re_t and the expected acceptable return:

(i) Engineering – Construction;
(ii) Environmental & Waste Services;
(iii) Green & Renewable Energy.

For each sector, the two thresholds will be estimated with reference to both the European and Chinese economies. Thus, it is necessary to estimate the following parameters: r_f, ERP, β_a, β_t.

The risk-free rate rf represents the minimum return that a shareholder expects for investing in a company, so it can approximate the return on government bonds. While it is true that risk-free investments do not exist in reality, in sufficiently stable markets it can be assumed that an investment in such bonds tends to be risk-free. In the case of the European market, r_f is given by the average yield of government bonds in Europe with 10-year maturity. The data analysed refer to the time period September 2004-November 2020 (source: European Central Bank, https://www.ecb.europa.eu/stats/financial_markets_and_interest_rates/euro_area_yield_curves/html/index.en.html; Bloomberg).

With reference to the Chinese market, r_f is given by the average of the China Government Bond 10Y yields for the period 2005-2020 (source: Trading Economics, https://tradingeconomics.com/china/government-bond-yield).

The equity risk premium ERP measures the expected return that investors require in addition to the risk-free rate to compensate for the risk of an investment, so it is equal to the is equal to the spread between the stock market return rm and the risk-free bond return r_f (Damodaran, 2020).

For the estimation of the beta variable, a preliminary step is the definition of the panel of companies useful to estimate the systematic risk of the sector. Table 4 summarises the panel of companies on which the study was conducted, divided by sector and by territorial context of reference. For more information on the companies analysed, please refer to Appendix 1.

Table 4. Panel of companies analysed by sector and territorial context

Sector	**N. European Industry for sector**	**N. Chinese Industry for sector**
Engineering/Construction	139	222
Environmental & Waste Services	49	78
Green & Renewable Energy	48	34

For each of the selected civil firms in each sector and in each territorial context, the firm's beta is estimated using (3.7) and (3.8). In fact, beta can be estimated as: the ratio between the covariance between the expected returns of the stock and those of the market and the variance of the expected return of the market (formula 3.7); slope of the line interpolating the returns of the investment with respect to the returns of the market (formula 3.8).

Specifically, we analyse the weekly returns over a time period of three and five years for both the stock and the market. Then, from the implementation of the linear regression of the weekly return of the listed firm against the local index - which coincides with the most followed index of that market - we obtain the beta of the firm over 2 years $\beta_{x(2y)}$ and over five years $\beta_{x(5y)}$ of data. Finally, the beta of company x is calculated by weighing ⅔ the estimated beta over two years and ⅓ the estimated beta over five years (Damodaran A., 2020):

$$\beta_x = \tfrac{2}{3} \cdot \beta_{x(2y)} + \tfrac{1}{3} \cdot \beta_{x(5y)} \qquad (3.13)$$

It follows that the "tolerable" systematic risk β_t is obtained by averaging the β_x of the *n* firms in each panel sector:

$$\beta_t = \frac{\sum_{i=1}^{n} \beta_{xi}}{n} \qquad (3.14)$$

The "acceptable" systematic risk β_a, on the other hand, is derived from the average of the 25% highest betas in the panel. In other words, if the reference is the household sector in Europe, sorting the betas in ascending order, β_a is given by the average of the 35 highest betas, i.e. betas ranging from firm 112 to firm 149.

$$\beta_a = \frac{\sum_{i=104}^{139} \beta_{xi}}{35} \qquad (3.15)$$

Table 5 and Table 6 give the results of the processing, i.e. the values of the parameters r_f, ERP, β_t, β_a, r_t e r_a for each of the three sectors, for Europe and China respectively.

Table 5. r_t and r_a estimation for Europe

Sector	Variable	Value	Source
	r_f	2.31%	European Central Bank; Bloomberg
	ERP	7.51%	Damodaran A., Stern School of Business
Engineering/Construction	β_t	1.13	YahooFinance; Damodaran, Stern School of Business
	β_a	1.36	YahooFinance; Damodaran A., Stern School of Business
	$\boldsymbol{r_t}$	**10.82%**	**(formula 3.9)**
	$\boldsymbol{r_a}$	**12.49%**	**(formula 3.10)**
Environmental & Waste Services	β_t	0.97	YahooFinance; Damodaran, Stern School of Business
	β_a	1.18	YahooFinance; Damodaran A., Stern School of Business
	$\boldsymbol{r_t}$	**9.59%**	**(formula 3.9)**
	$\boldsymbol{r_a}$	**11.17%**	**(formula 3.10)**
Green & Renewable Energy	β_t	0.92	YahooFinance; Damodaran, Stern School of Business
	β_a	1.15	YahooFinance; Damodaran A., Stern School of Business
	$\boldsymbol{r_t}$	**9.24%**	**(formula 3.9)**
	$\boldsymbol{r_a}$	**10.91%**	**(formula 3.10)**

Table 6. r_t and r_a for China

Sector	Variable	Value	Source
	r_f	3.30%	Trading Economics
	ERP	7.30%	Damodaran A., Stern School of Business
Engineering/Construction	β_t	1.61	YahooFinance; Damodaran, Stern School of Business
	β_a	1.88	YahooFinance; Damodaran A., Stern School of Business
	$\boldsymbol{r_t}$	**15.07%**	**(formula 3.9)**
	$\boldsymbol{r_a}$	**17.04%**	**(formula 3.10)**
Environmental & Waste Services	β_t	1.68	YahooFinance; Damodaran, Stern School of Business
	β_a	1.93	YahooFinance; Damodaran A., Stern School of Business
	$\boldsymbol{r_t}$	**15.53%**	**(formula 3.9)**
	$\boldsymbol{r_a}$	**17.39%**	**(formula 3.10)**
Green & Renewable Energy	β_t	1.43	YahooFinance; Damodaran, Stern School of Business
	β_a	1.66	YahooFinance; Damodaran A., Stern School of Business
	$\boldsymbol{r_t}$	**13.73%**	**(formula 3.9)**
	$\boldsymbol{r_a}$	**15.38%**	**(formula 3.10)**

In order to estimate the expected return considering both equity and all the capital invested by the firms, it is necessary to evaluate the tolerable Weighted Average Cost of Capital ($WACC_t$) and the acceptable Weighted Average Cost of Capital ($WACC_a$), implementing respectively (3.11) and (3.12).

The cost of debt r_d is estimated by adding the risk-free rate rf and the default spread of the country in which the firm operates. In this case, the Average Default Spread (ADF) coincides with the average of the spreads of the

European countries. This is an acceptable approximation, as estimating the average cost of debt of the panel companies is not an easy task, due to the difficulty of finding the data needed for analysis (Damodaran, 2020). Therefore, it can be considered consistent that $rd_t \cong rd_a \cong \mathrm{r}d = r_f + \mathrm{ADF}$.

The coefficients ke_t and kd_t are estimated as a function of the value of equity E and the value of debt D, which represent on average that of the companies in each panel. ke_a and kd_a, on the other hand, are assessed on the basis of the average equity value E and debt value D of the 'worst' companies in each panel, i.e. those with the highest beta market risk.

As the cost of capital is valued in US dollars, the expected inflation rate in local currency (euro or yuan) has to be taken into account when converting them into local currenc ($\mathrm{EIR}_{€/¥}$) and the expected inflation rate in US dollars ($\mathrm{EIR}_{\$}$). It follows that:

$$\mathrm{WACC}_{t(€/¥)}=(1+\mathrm{WACC}_t)\cdot\frac{(1+\mathrm{EIR}_{€/¥})}{(1+\mathrm{EIR}_{\$})}-1 \qquad (3.16)$$

$$\mathrm{WACC}_{a(€/¥)}=(1+\mathrm{WACC}_a)\cdot\frac{(1+\mathrm{EIR}_{€/¥})}{(1+\mathrm{EIR}_{\$})}-1 \qquad (3.17)$$

Table 7 gives the WACC_t and WACC_a estimated for the three investment sectors in Europe. Table 8 shows the estimated WACCt and WACC_a for each of the three sectors under analysis with reference to the Chinese financial environment.

The elaborations carried out show the following main results.

- WACC_t and WACC_a values in China are significantly higher than those estimated for Europe. This is due to the higher beta and cost of equity values, i.e. the systematic risk for each sector is higher in China than in Europe.
- In Europe, the Engineering/Construction investment sector is slightly riskier than the Green & Renewable Energy and Environmental & Waste Services sectors. However, the financial structure of the target company leads to lower tolerable and acceptable WACC values for the "Green & Renewable Energy" sector, medium for the "Engineering/Construction" investments and higher for the "Environmental & Waste Services" sector.

– In China, on the other hand, the Environmental & Waste Services investment sector is less risky than the Engineering/Construction and Green & Renewable Energy sectors. In this case, the financial structure of the target company leads to lower tolerable and acceptable WACC values for the "Engineering/Construction" sector, medium for the "Green & Renewable Energy" investments and higher for the "Environmental & Waste Services" sector.

Table 7. Estimation of $WACC_t$ $WACC_a$ for the three investment sectors in Europe

Sector	Variable	Value	Variable	Value	Source
Engineering/ Construction	ke_t = E/(D+E)	56.00%	kd_a= E/(D+E)	60.00 %	Damodaran, 2020; Orbis database
	re_t = Cost of Equity	10.82%	re_a= Cost of Equity	12.49 %	(see Table 1)
	kd_t = D/(D+E)	44.00%	kd_a= D/(D+E)	40.00 %	Damodaran, 2020; Orbis database
	r_f	2.31%	r_f	2.31%	(see Table 1)
	ADF	1.22%	ADF	1.22%	Damodaran, 2020
	rd_t = Cost of Debt	3.53%	rd_t = Cost of Debt	3.53%	-
	t = *tax-rate*	22.62%	t = *tax-rate*	22.62 %	Damodaran, 2020
	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.73%	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.73%	Damodaran, 2020
	$WACC_t$	7.26%	$WACC_a$	8.58%	(formula 3.11 e formula 3.12)
	$EIR_€$	0.20%	$EIR_\$$	1.50%	Damodaran, 2020
	$WACC_t$ (Euros)	**5.89%**	***$WACC_a$ (Euros)***	**7.19%**	(formula 3.16 e formula 3.17)
Environmental & Waste Services	ke_t = E/(D+E)	73.39%	kd_a= E/(D+E)	82.50 %	Damodaran, 2020; Orbis database
	re_t = Cost of Equity	9.59%	re_a= Cost of Equity	13.21 %	(see Table 1)
	kd_t = D/(D+E)	13.03%	kd_a= D/(D+E)	17.50 %	Damodaran, 2020; Orbis database
	r_f	2.31%	r_f	2.31%	(see Table 1)
	ADF	1.22%	ADF	1.22%	Damodaran, 2020
	rd_t = Cost of Debt	3.53%	rd_t = Cost of Debt	3.53%	-

	t = tax-rate	22.62%	*t = tax-rate*	22.62 %	Damodaran, 2020
	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.73%	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.73%	-
	$WACC_t$	7.76%	$WACC_a$	9.69%	(formula 3.11 e formula 3.12)
	$EIR_€$	0.20%	$EIR_\$$	1.50%	Damodaran, 2020
	$WACC_t$ (Euros)	**6.38%**	***$WACC_a$ (Euros)***	**8.29%**	(formula 3.16 e formula 3.17)
Green & Renewable Energy	ke_t = E/(D+E)	55.11%	kd_a= E/(D+E)	44.89 %	Damodaran, 2020; Orbis database
	re_t = Cost of Equity	9.24%	re_a= Cost of Equity	10.91 %	(see Table 1)
	kd_t = D/(D+E)	44.89%	kd_a= D/(D+E)	39.78 %	Damodaran, 2020; Orbis database
	r_f	2.31%	r_f	2.31%	(see Table 1)
	ADF	1.22%	ADF	1.22%	Damodaran, 2020
	rd_t = Cost of Debt	3.53%	rd_t = Cost of Debt	3.53%	-
	t = tax-rate	22.62%	*t = tax-rate*	22.62 %	Damodaran, 2020
	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.73%	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.73%	-
	$WACC_t$	6.32%	$WACC_a$	7.66%	(formula 3.11 e formula 3.12)
	$EIR_€$	0.20%	$EIR_\$$	1.50%	Damodaran, 2020
	$WACC_t$ (Euros)	**4.95%**	***$WACC_a$ (Euros)***	**6.28%**	(formula 3.16 e formula 3.17)

Table 8. Estimation of $WACC_t$ $WACC_a$ for the three investment sectors in Europe

Sector	Variable	Value	Variable	Value	Source
Engineering/ Construction	ke_t = E/(D+E)	39.30%	kd_a= E/(D+E)	45.00%	Damodaran, 2020; Orbis database
	re_t = Cost of Equity	15.07%	re_a= Cost of Equity	17.04%	(see Table 1)
	kd_t = D/(D+E)	60.70%	kd_a= D/(D+E)	55.00%	Damodaran, 2020; Orbis database
	r_f	3.30%	r_f	3.30%	(see Table 1)
	ADF	0.59%	ADF	0.59%	Damodaran, 2020
	rd_t = Cost of Debt	3.89%	rd_t = Cost of Debt	3.89%	-
	t = tax-rate	25.00%	*t = tax-rate*	25.00%	Damodaran, 2020
	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.92%	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.92%	Damodaran, 2020
	$WACC_t$	7.69%	$WACC_a$	9.27%	(formula 3.11 e formula 3.12)
	$EIR_¥$	3.00%	$EIR_\$$	3.00%	Damodaran, 2020
	$WACC_t$ (Yuan)	**9.29%**	***$WACC_a$ (Yuan)***	**10.89%**	(formula 3.16 e formula 3.17)
Environmental & Waste Services	ke_t = E/(D+E)	65.70%	kd_a= E/(D+E)	73.40%	Damodaran, 2020; Orbis database
	re_t = Cost of Equity	15.53%	re_a= Cost of Equity	17.39%	(see Table 1)
	kd_t = D/(D+E)	34.30%	kd_a= D/(D+E)	26.60%	Damodaran, 2020; Orbis database
	r_f	3.30%	r_f	3.30%	(see Table 1)
	ADF	0.59%	ADF	0.59%	Damodaran, 2020
	rd_t = Cost of Debt	3.89%	rd_t = Cost of Debt	3.89%	-
	t = tax-rate	25.00%	*t = tax-rate*	25.00%	Damodaran, 2020
	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.92%	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.92%	Damodaran, 2020
	$WACC_t$	11.20%	$WACC_a$	13.54%	(formula 3.11 e formula 3.12)
	$EIR_¥$	3.00%	$EIR_\$$	1.50%	Damodaran, 2020
	$WACC_t$ (Yuan)	**12.85%**	***$WACC_a$ (Yuan)***	**15.22%**	(formula 3.16 e formula 3.17)

Green & Renewable Energy	ke_t = E/(D+E)	54.03%	kd_a= E/(D+E)	61.40%	Damodaran, 2020; Orbis database
	re_t = Cost of Equity	13.73%	re_a= Cost of Equity	15.38%	(see Table 1)
	kd_t = D/(D+E)	45.97%	kd_a= D/(D+E)	38.60%	Damodaran, 2020; Orbis database
	r_f	3.30%	r_f	3.30%	(see Table 1)
	ADF	0.59%	ADF	0.59%	Damodaran, 2020
	rd_t = Cost of Debt	3.89%	rd_t = Cost of Debt	3.89%	-
	t = tax-rate	25.00%	*t = tax-rate*	25.00%	Damodaran, 2020
	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.92%	$rd_{t\ (tax\text{-}rate)}$ = After-tax Cost of Debt	2.92%	Damodaran, 2020
	$WACC_t$	8.76%	$WACC_a$	10.57%	(formula 3.11 e formula 3.12)
	$EIR_¥$	0.20%	$EIR_\$$	1.50%	Damodaran, 2020
	$WACC_t$ (Yuan)	**10.36%**	***$WACC_a$ (Yuan)***	**12.20%**	(formula 3.16 e formula 3.17)

4. The Social Discount Rate in the assessment of extra-financial risks

Summary

The assessment of investment risk becomes an even more complex issue in the case of intergenerational public projects. Here the challenge is to be able to consider two antithetical problems in the relevant analyses: (1) the riskiness of investment costs and benefits, which tends to increase over time. In fact, as one moves further away from the moment of valuation, it becomes more and more complex to estimate Cash-Flows with certainty; (2) the need to give due weight to environmental and social impacts, especially if they occur in the long term. In fact, while it is true that these terms are not known with certainty, the combined "risk-discounting" effect would lead to underestimating significant environmental and social effects.

Consider, for instance, investments aimed at the sustainable development of the urban and built environment: from urban forestation interventions to projects for green/smart cities, whose investment costs are high while the greatest benefits occur in the long term; to interventions on water resources, which also generate multiple effects over a long-time horizon. Thus, for such projects, considering both the risk effect and the effect of the contraction of the current values of Cash-Flow over time, linked to the use of time-invariant discount rates, would lead to an underestimation of environmental benefits and damages that are progressively more distant in time.

In the literature, the two issues are rarely dealt with together.

About question (1), it has been shown that in the case of public interventions, project risk can be filtered out by replacing so-called "risky" cash flows with smaller "certainty-equivalent" flows, and then discounting the cash flows with a risk-free rate, highlighting its main operational and computational problems.

With reference to question (2), instead, it has been said that, from a theoretical point of view, discounting procedures different from the traditional ones, i.e. based on constant discount rates, have been proposed. One thinks of hyperbolic discounting, i.e. using time-declining discount rate functions, or of

dual discounting based on the use of an economic discount rate different from the discount rate for discounting net environmental benefits. However, there are few instances where such discounting procedures are commonly used by governments in the cost-benefit analysis of investment projects.

Thus, with this research we intend to define a project risk management model able to direct analysts towards more sustainable investment choices. The aim is to be able to include in risk assessments all the possible effects – including those in the long term – that initiatives may generate, avoiding a preference for investments with high initial revenues over those with considerable intergenerational environmental and social benefits, which are often underestimated. This will have an impact on the entire process of allocating public resources, directing decision-making towards projects that are also capable of pursuing the UN's sustainable development objectives, aimed at promoting social welfare and protecting the environment.

The chapter is structured in four main Sections. Section 4.1 highlights the rationale and main innovations of the model. Section 4.2 defines the logical-operational steps on which the risk/discounting model for intergenerational projects is based. Section 4.3 details the innovative methodology for estimating the economic discount rate and the environmental discount rate. In Section 4.4 the methodology is implemented to estimate the discount rates for both Italy and China.

4.1. Concept and novelties of the model

The objective of the model to be defined is to assess the risk of public projects with long-term environmental and social impacts. This means considering the difficulty of estimating costs and benefits progressively further away from the time of the assessment and at the same time avoiding that intergenerational environmental effects are underestimated or not assessed at all.

The model aims to overcome some of the limitations of the risk analysis techniques found in the literature and set out in section 3.2. while at the same time being simple to implement in practice.

Two main novelties of the model are:

1) the riskiness of cash flows is treated separately from the macroeconomic riskiness. This means that costs and benefits that

cannot be treated as deterministic variables are modelled stochastically, i.e. each risky variable is assigned a probability distribution. Macroeconomic risk is incorporated into the assessment of the discount rate, as the macroeconomic variable on which the estimate of the Social Discount Rate is based – the growth rate of consumption – is also modelled as a stochastic variable;
2) the discounting of cash flows is based on the joint use of Declining Discounting and Dual Discounting. In other words, a novel model is defined for the estimation of the economic discount rate and the environmental discount rate, both with a declining structure over time.

4.2. The steps of the model

Like the financial risk management model presented in section 3.1, the economic risk management model follows the logical and operational steps described in Figure 1.

Step 1: Establish the context. In this first phase it is necessary to analyse the costs and benefits of the project, to define the period of analysis and to assess the profitability of the investment, through economic performance indicators, such as the Economic Internal Rate of Return (EIRR), the Economic Net Present Value (ENPV), the Payback Period, the benefit-cost ratio.

Step 2: Risk assessment. This phase consists of the following three steps: identification of risky variables; risk analysis; risk estimation.

- *Step 2.1. Identification of risky variables*. This phase consists of a sensitivity analysis that makes it possible to identify those variables that significantly affect the financial and/or economic performance of the initiative.
- *Step 2.2. Risk analysis*, first qualitative then quantitative. The qualitative risk analysis includes a list of the adverse events to which the project is exposed and the consequent definition of the risk matrix. Quantitative risk analysis allows us to estimate the probability distribution of the economic performance indicator, implementing Monte Carlo analysis. It is important to underline that for the estimation of the ENPV probability distribution, a double declining discount rate is used: an economic discount rate, for the discounting of the strictly financial cash-flows and an environmental discount rate, for the discounting of the extra-financial net benefits. For the

definition of the model and the estimation of the discount rates for Italy and China, see section 3.2.3.

- *Phase 2.3. Risk estimation*, in which the acceptability of the investment risk is verified. Also in this phase, the reference is the ALARP logic, as the investment risk is evaluated with reference to acceptability and tolerability thresholds. However, the result will not be expressed in terms of a "tolerable" and "acceptable" expected return, but will be expressed in terms of the probability that the investment will fail or return a positive Economic Net Present Value (ENPV). This is essentially for two reasons. Firstly, because public interventions generally tend to have a greater social and cultural impact on the territory than the financial revenue from the planned activities. In other words, these are initiatives which must be economically sustainable but which do not necessarily have to produce high profit margins.
  Secondly, because discounting will take place through the use of declining discount rates. Therefore, it is easier to express the result of the economic performance of the investment in terms of ENPV rather than EIRR.

Thus, in the case of public projects, the following acceptability criteria are defined:

- the intervention is largely acceptable if the probability of having a ENPV ≥ 0 is 75% (Fig. 10.a). In this case, there is no need to define risk mitigation measures in order to increase project performance;
- the intervention is not tolerable if the probability of having a ENPV ≥ 0 is less than or equal to 50% (Fig. 10.b). In such a case, the project is not sustainable, therefore it is necessary to define improvement interventions able to decrease the risk of failure or to increase the profitability of the initiative;
- The project is in an ALARP area if the probability of having a ENPV≥ 0 is between 50% and 75% (Fig. 10.c). In such a case, mitigation measures should be implemented that do not have disproportionate costs compared to the benefits to be obtained.

This results in the following limit values:

1) Tolerability threshold with probability of not less than 50% of having an ENPV ≥ 0;

2) Acceptability threshold with a probability of not less than 75% of having an ENPV ≥ 0.

In other words, it has been established that an investment whose probability of having a positive ENPV is 50% is barely tolerable. Thus, it was assumed that the public funding body has a "neutral" attitude to risk, which is legitimate as a matter of risk pooling, since the public sector is able to pool the risks of a large number of projects.

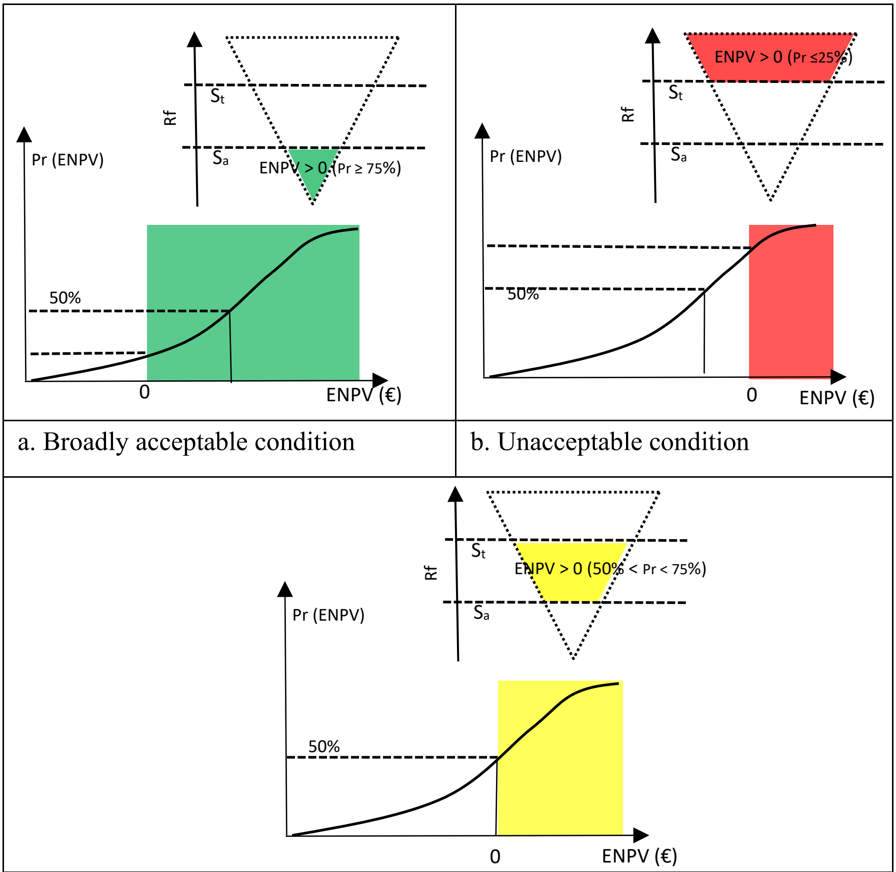
On the other hand, an investment whose probability of failure is less than 25% (i.e. the probability of having a positive ENPV is at least 75%) is largely acceptable.

This second acceptability limit was derived from *ex-post* evaluation studies conducted by the Asian Development Bank (2017a) which reveal that the average failure rate of public investment on the existing project portfolio is about 25%. This second limit can be updated from time to time by estimating the average probability of failure of sector investments in a given territorial context by analysing ex post feasibility studies.

Step 3: Risk treatment. If the risk is unacceptable or tolerable for the investor (cases 10.b and 10.c), it is necessary first to define changes to the project, then to assess the residual risk, i.e. the risk which remains despite the containment strategy undertaken. Thus, the riskiness of the project is again assessed in terms of the probability that the ENPV is positive or negative.

Specifically, consider that the pre-mitigation intervention is in an ALARP condition. In this case, it can be verified that:

- the post mitigation design initiative is in a condition of broad acceptability. The mitigation measures should be implemented;
- the post-mitigation project initiative is in an unacceptable or tolerable condition for the investor. The pre-mitigation project is tolerable according to the ALARP principle, i.e. it has been demonstrated that the improvement measures have disproportionate costs compared to the achievable benefits.



a. Broadly acceptable condition

b. Unacceptable condition

c. Tolerable condition according to the ALARP principle

Figure 10. Acceptability and tolerability of the investment in terms of cumulative probability of ENPV (source: own elaboration)

Consider, on the other hand, the case where the pre-mitigation intervention is in a condition of unacceptability:

– if the design initiative post mitigation falls into a condition of broad acceptability, then the mitigation interventions must be implemented;
– if the design initiative post mitigation interventions is still in a condition of unacceptability, then the project is still risky and the planned interventions cannot be implemented;
– if the project initiative post mitigation interventions is in a tolerable condition, then the investment risk is now tolerable according to the ALARP principle.

Again, in order to compare two or more mitigation strategies, the risk assessment can be combined with the estimation of an indicator similar to the net-cost-of-averting-a-fatality (NCAF), namely the net-cost-of-preventing-a-failure (NPAF), described by the formula (3.2).

4.3. An innovative methodology to estimate the economic discount rate and environmental discount rate

It has been argued that with increasing environmental stress, conventional discounting procedures are increasingly inadequate, especially when intergenerational environmental issues are to be considered in *ex-ante* assessments (Kula & Evans, 2011). In such a context, the joint use of declining discounting and dual discounting can support decision making, guiding the analyst towards the selection of sustainable investment alternatives. Therefore, it is intended to outline a novel model for the estimation of the economic discount rate and the ecological discount rate, both with a declining discounting structure over time.

The proposed model is based on Ramsey formula, but assumes that the utility function U depends not only on consumption c_t but also on environmental quality q_t. Therefore, the value of the economic discount rate r_c and of the environmental discount rate r_q are estimated respectively with the formulas (2.33) and (2.34), described in paragraph 2.3.4.1 and re-proposed here:

$$r_c = \rho + [\eta_1 + \delta \cdot (\eta_2 - 1)] \cdot [g_1 - 0.5 \cdot (1 + \eta_1 + \delta \cdot (\eta_2 - 1))] \cdot \sigma_{11} \qquad (2.33)$$

$$r_q = \rho + [(\delta \cdot \eta_2 + \eta_1 - 1)] \cdot [g_1 - 0.5 \cdot (\delta \cdot \eta_2 + \eta_1)] \cdot \sigma_{11} \qquad (2.34)$$

Where:

- ρ is the rate of time preference;
- η_1 the risk aversion parameter of income inequality;
- η_2 the degree of environmental risk aversion;
- g_1 the growth rate of consumption;
- σ_{11} the uncertainty of the consumption growth rate in terms of the mean square deviation of the variable;
- δ the elasticity of environmental quality to changes in the growth rate of consumption g_1.

There are two main innovations in the model. The first is the introduction of environmental quality, expressed in terms of the Environmental Performance Index (EPI). Proposed by the Center for Environmental Law & Policy at Yale University and the Center for International Earth Science Information Network at Columbia University, the EPI is used to determine how close countries are to achieving the UN's 2015 Sustainable Development Goals (EPI, 2018).

The second novelty concerns the modelling of the growth rate of consumption g1 which appears in formula (2.33) and (2.34). This is a crucial parameter for the evaluation. In fact, since $q_t = f(c_t)$, both the value of the economic discount rate r_c and the value of the environmental discount rate r_q depend on g_1. The growth rate of consumption g_1 is an uncertain parameter, so it is modelled as a stochastic variable. This means that from the analysis of the historical trend of g_1, we first estimate a probability function to be associated with the parameter itself. Then, from the probability function obtained in this way, implementing the Monte Carlo analysis, we obtain a series of probable values to associate with the rate g1 and, consequently, with the unknowns r_c and r_q.

Once the logic of the probabilistic model has been defined, the Environmental Performance Index is described below; the logical-operational steps required to estimate the economic and environmental DDR are then detailed.

4.3.1. The Environmental Performance Index to estimate the environmental quality

In the proposed model, environmental quality q_t is expressed through the Environmental Performance Index (EPI). With the UN's 2015 Sustainable Development Goals, governments are increasingly being asked to measure their environmental performance through quantitative metrics. This is because the use of empirical approaches makes it easier to identify problems, track trends, highlight policy successes and failures, identify best practices, and optimise the returns on investments in environmental protection (Wendling, et al., 2018). This is the context for the EPI, which provides a measure of a nation's environmental sustainability and performance, allowing us to understand which countries implement policies to reduce environmental pressures.

The EPI is a composite index of 24 individual metrics of environmental performance, which are aggregated into a hierarchy of ten issue categories: air quality, water and sanitation, heavy metals, biodiversity and habitats, forests, fisheries, climate and energy, air pollution, water resources and agriculture. These problem categories converge into two policy objectives: environmental health and ecosystem viability. The final EPI value falls in the range 0-100, where 0 indicates the worst and 100 the best performance. Table 9 shows the hierarchical organisation of the EPI, its constituent indicators and their weights.

In summary, EPI provides important information about a country's environmental performance that can help refine policy choices, understand the determinants of environmental progress and maximise the return on government investment (Wendling, et al., 2018). Thus, alongside strictly financial parameters, EPI will also influence the estimation of SDR, and consequently, environmental investment choices.

Table 9. The Environmental Performance Index (Source: Wendling et al. 2018)

POLICY OBJECTIVE	*WEIGHT*	ISSUE CATEGORY	*WEIGHT*	INDICATOR	*WEIGHT*
Environmental Health	*40%*	Air Quality	*26%*	Household Solid Fuels	*10.4%*
				$PM_{2.5}$ Exposure	*7.8%*
				$PM_{2.5}$ Exceedance	*7.8%*
		Water & Sanitation	*12%*	Drinking Water	*6.0%*
				Sanitation	*6.0%*
		Heavy Metals	*2%*	Lead Exposure	*2.0%*
Ecosystem Vitality	*60%*	Biodiversity & Habitat	*15%*	Marine Protected Areas	*3.0%*
				Biome Protection (National)	*3.0%*
				Biome Protection (Global)	*3.0%*
				Species Protection Index	*3.0%*
				Representativeness Index	*1.5%*
				Species Habitat Index	*1.5%*
		Forests	*6%*	Tree Cover Loss	*6.0%*
		Fisheries	*6%*	Fish Stock Status	*3.0%*
				Regional Marine Trophic Index	*3.0%*
		Climate & Energy	*18%*	CO_2 Emissions – Total	*9.0%*
				CO_2 Emissions – Power	*3.6%*
				Methane Emissions	*3.6%*
				N_2O Emissions	*0.9%*
				Black Carbon Emissions	*0.9%*
		Air Pollution	*6%*	SO_2 Emissions	*3.0%*
				NO_X Emissions	*3.0%*
		Water Resources	*6%*	Wastewater Treatment	*6.0%*
		Agriculture	*3%*	Sustainable Nitrogen Management	*3.0%*

4.3.2. The operational phases for estimating the economic declining discount rate and declining environmental discount rate

Figure 11 illustrates the sequence of logical and operational steps on which the model is based. This paragraph details the assumptions and elaborations to be carried out for each step.

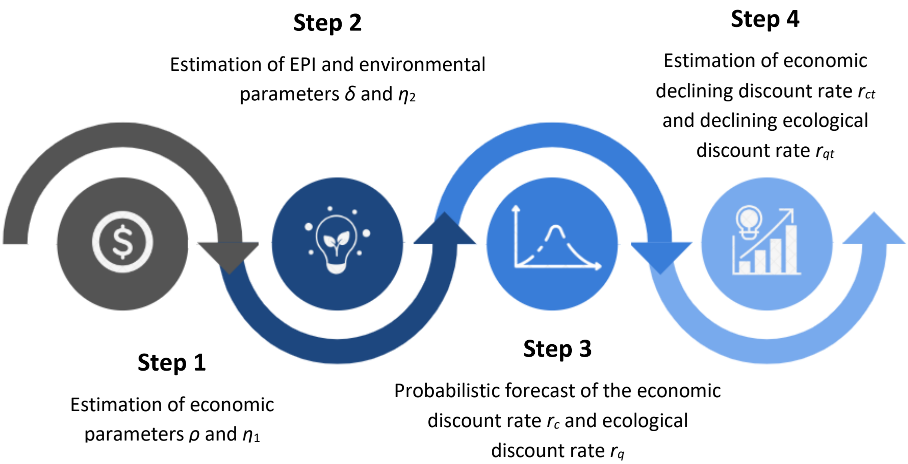


Figure 11. The phases of the model (source: own elaboration)

Step 1. *Estimation of economic parameters* ρ *and* η_1

The time preference rate ρ is also called the "inter-generational discrimination rate". It reflects the importance that society attaches to the well-being of the current generation over the well-being of the future generation (Heal, 2009). Some authors believe that ρ should have a very low value but not zero, both because the possibility of natural disasters or catastrophes must be taken into account (Stern, 2007), either because individuals naturally tend to prioritise the well-being of their own family members over the future well-being of strangers (Nordhaus, 2008). According to these authors, ρ can be estimated through the relation:

$$\rho = l + r \tag{3.18}$$

where l is the estimated discount rate as a function of mortality and is given by the ratio of the number of deaths in the country to the total population in the reference year (Florio & Sirtori, 2013); r is the pure time preference rate, related to the so-called "myopia" or "irrationality" factor. Some authors believe that the value of r should be 0 (Kula, 2004; Evans, 2006; Percoco, 2008). According to others, the value of r cannot be zero, since individuals do not always behave rationally, but tend to give more weight to current well-being in an "unreasoned" way. The literature suggests that r values are generally between 0 and 0.5% (Pearce & Ulph, 1999; Evans & Kula, 2009; Nesticò & Maselli, 2020).

Elasticity η_1 marginal utility of consumption represents the percentage change in marginal utility resulting from a unit change in consumption: «η is the percentage by which marginal utility decreases when consumption increases by 1%» (Heal, 2009). The revealed social values approach, also known as the "equal absolute sacrifice approach", is proposed for estimating this parameter, with η_1 as a parameter of the social planner's, or more generally the government's, aversion to income inequality. Cowell and Gardiner (1999) argue that tax decisions are decisive for equalisation purposes, even in discounting or for the determination of welfare weights. Therefore, the estimate of η_1 based on the analysis of the country's progressive tax structure is able to express the government's behaviour towards the unequal distribution of incomes (Nesticò & Maselli, 2020). η_1 is estimated by implementing the formula proposed by Cowell and Gardiner (1999):

$$\eta_1 = \frac{\log\ (1-t)}{\log\ (1-\frac{T}{Y})} \tag{3.19}$$

where t is the marginal tax rate; T/Y is the average tax rate, which is the ratio of the total amount of income tax to the taxable income before tax.

Step 2. *Estimation of EPI and environmental parameters* η_2 *and* δ

The degree of environmental risk aversion η_2 is not easy to assess. Gollier (2010; 2012) notes that the share of consumption expenditure to be allocated to environmental quality is given by the following formula:

$$\eta^* = \frac{\eta_2 - 1}{\eta_1 + \eta_2 - 2} \tag{3.20}$$

Hoel and Sterner (2007) and Sterner and Persson (2008) suggest deriving the value of η_2 in (3.20) considering that $10\% < \eta^* < 50\%$. Gollier (2010), for instance, assume $\eta* = 30\%$, from which a value of $\eta_2 = 1.4$.

Finally, the calibration of the parameter δ depends on how environmental quality is defined. Indeed, δ expresses the sensitivity of environmental quality q to changes in consumption c, the latter approximated to GDP per capita (Gollier, 2010).

Consider c as the GDP per capita of a country and q as the relative EPI, as defined in step 0. From the correlation between the two parameters we derive the value δ, which represents the inclination of the line:

$$c = x + \delta \cdot q + \varepsilon \tag{3.21}$$

In (3.21) x is the intercept of the line on the y-axis and ε is the statistical error of the regression.

Step 3. *Probabilistic forecast of economic discount rate and ecological discount rate*

The novel idea is to assume the growth rate of the consumption g_1 in the (2.33) and in the (2.44) as an uncertain and constant variable in the period of analysis. In other words, it is necessary to associate to the uncertain future value of g_1 a probability distribution deduced from the analysis of the historical trend g_t in a sufficiently wide past time span. Once the distribution of the probable values of g_1 has been predicted based on the historical trend analysis, it is possible to obtain the probability distribution of the consumption discount rate r_c and the environmental quality discount rate r_q. This can be done by implementing Monte Carlo analysis, a stochastic simulation method based on random sampling. By means of this method, it is possible to pass from the probability distribution of the uncertain variable, i.e. the growth rate of consumption g_1, to the probability distribution of the economic discount rate r_c and the environmental discount rate r_q. In fact, the two discount rates are correlated to the growth rate of consumption through the (2.33) and the (2.34).

Step 4. *Estimation of economic and ecological declining discount rates*

From the probability distributions identified in the previous step, we now determine the values of the rates r_c and r_q for each of the *n* years of the analysis period.

The reference is to the logic of the ENPV Approach, according to which estimating the ENPV with an uncertain but constant discount rate is equivalent to computing the NPV with a certain rate but decreasing with a "certainty equivalent" until it reaches the minimum possible value at time t = ∞. According to this approach, we move from the two uncertain and constant discount rates r_c and r_q, which coincide with the expected value of the probability distributions at step 2, to certain but decreasing rates with a "certainty equivalent". The transition from the uncertain and constant discount rate to the certain but decreasing rate with an "certainty equivalent" requires first of all to estimate the economic discount factors $E_c(P_t)$ and ecological $E_q(P_t)$ for every future instant *t*. $E_c(P_t)$ and $E_q(P_t)$ are expressed respectively by the relations:

$$E_c(P_t) = E_c\left[\sum_{i=1}^{m} p_{rci} \cdot e^{(-r_{ci} \cdot t)}\right] \tag{3.22}$$

$$E_q(P_t) = E_q\left[\sum_{i=1}^{m} p_{rqi} \cdot e^{(-r_{qi} \cdot t)}\right] \tag{3.23}$$

Where:

r_{ci} = value of the i-*th* economic discount rate, as resulting from the probability distribution of r_c derived from formula (2.33) with g_1 as uncertain variable;
p_{ci} = the probability that the i-*th* economic rate value r_c has of occurring;
r_{qi} = value of the i-*th* ecological discount rate, as resulting from the probability distribution of rq derived from formula (2.34) with g_1 as uncertain variable;
p_{qi} = the probability that the i-*th* ecologicalrate value r_q has of occurring;
t = time variable;
m = number of intervals in which the probability functions of r_c and r_q are discretized.

At this point, from the time sequences obtained from (3.22) and (3.23), we estimate the declining economic discount rate r_{ct} and the declining ecological discount rate r_{qt}:

$$r_{ct} = \frac{E_c(P_t)}{E_c(P_t+1)} - 1 \tag{3.24}$$

$$r_{qt} = \frac{E_q(P_t)}{E_q(P_t+1)} - 1 \tag{3.25}$$

4.4. The estimation of the DDRs for Italy and China

The proposed model is implemented to estimate the economic DDR and the ecological DDR for Italy and China, with the aim of discounting financial cash flows and net environmental benefits generated by intergenerational investment projects. The elaborations follow the operational steps in Figure 11.

Step 1. *Estimation of economic parameters ρ and η_1*

According to (3.19), δ is the sum of two contributions: the mortality-based discount rate *l* and the pure time preference rate *r*. The first parameter, *l*, coincides with the time average of the mortality rate, given by the ratio between the number of deaths in the reference year and the average number of residents. Since the mortality rate varies little over time, it is considered correct to use data from the last 30 years. *l* is estimated based on mortality rates for the period 1991-2020 provided by ISTAT for Italy and by the World Bank for China (see Table 10).

Table 10. Mortality rates for Italy and China over the 30-year period 1991-2020

Year	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*Decade average rate*
Death rate Italy (%)	0.97	0.96	0.97	0.97	0.98	0.97	0.98	1.00	0.98	0.98	0.98
Death rate China (%)	0.67	0.66	0.66	0.64	0.66	0.66	0.65	0.65	0.65	0.65	0.66
Year	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*Decade average rate*
Death rate Italy (%)	0.96	0.98	1.02	0.95	0.98	0.96	0.98	0.99	1.00	0.99	0.98
Death rate China (%)	0.64	0.64	0.64	0.64	0.65	0.68	0.69	0.71	0.71	0.67	0.67
Year	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*Decade average rate*
Death rate Italy (%)	1.00	1.03	1.00	0.98	1.07	1.00	1.04	1.05	1.05	1.06	1.03
Death rate China (%)	0.71	0.72	0.72	0.72	0.71	0.71	0.71	0.71	0.73	0.74	0.62
Thirty-year average rate Italy (%)											**1.00**
Thirty-year average rate China (%)											**0.68**

This results in Italy $l = 1.00\%$, a result in line with that obtained by Percoco (2008) and by Florio and Sirtori (2013).

China has $l = 0.68\%$. The lower value compared to Italy is the effect of lower mortality rates over the 30-year period.

The pure time preference rate r is positive and reflects the irrational behaviour of individuals in making choices about the distribution of resources over time. As suggested by both Evans & Kula (2009) and by Pearce & Ulph (1999), $0 < r < 0.5\%$ and is assumed to be 0.3. It follows that:

$$\rho_{\text{Italy}} = 1.00\% + 0.3\% = 1.30\%;$$

$$\rho_{\text{China}} = 0.68\% + 0.3\% = 0.98\%.$$

Elasticity η_1 of the marginal utility of consumption is estimated by implementing the formula (3.19) proposed by Cowell & Gardiner (1999). The Organization for Economic Cooperation and Development Countries (OECD) database provides the marginal t and average T/Y individual income tax rates for various multiples (67%, 100%, 133%, 167%) of the average wage. Using these data, it is straightforward to calculate log $(1 - t)$, log $(1 - T/Y)$ and its ratio. From the average of the results obtained for each multiple of average wage, we derive the final value of η1 for Italy, which is equal to 1.34.

The analysis of average and marginal tax rates by income bracket in China, on the other hand, gives a value of η_1 = 1.14 (source: https://taxsummaries.pwc.com/peoples-republic-of-china/individual/taxes-on-personal-income).

In summary, the elaborations return the following values:

$$\eta_{1\ \text{Italy}} = 1.34;$$

$$\eta_{1\ \text{China}} = 1.14.$$

This means that both the Italian and Chinese governments place equal importance on the issue of intergenerational inequality. It also shows that the results of the estimates are consistent with known values from the literature, where the social values approach leads to $1 < \eta < 2$.

Step 2. *Estimation of EPI and environmental parameters η_2 and δ*

Since it has been assumed that environmental quality is related to consumption through a deterministic function of the type $q_t = f(c_t)$, it is important to analyse the correlation between EPI and a country's relative GDP per capita. This analysis shows that generally the achievement of sustainability goals is related to the economic capacity to invest in the infrastructure needed to protect both human health and ecosystems. In a rapidly urbanising world, it is important to build facilities to provide better sources of drinking water, manage wastewater and mitigate pollution. On the other hand, however, the inherent tension in sustainable development is that income growth too often comes at the expense of the environment, particularly through the exploitation of natural resources and uncontrolled industrialisation (Wendling, et al., 2018). Figure 12 shows for 140 countries that higher values of GDP per capita tend to correspond to higher values of EPI. This is true for Italy which has an EPI of 76.96 and a GDP per capita of USD 34,715.34. Whereas for China, the EPI is 50.74, with a GDP per capita of USD 14,399.44. This shows how much further China is from reaching the UN Sustainable Development Goals than Italy. In other words, China should be investing much more in green projects than Italy. In terms of the discount rate, this translates for China into a function for the two rates that decreases much faster, to give more weight to environmental damages and benefits.

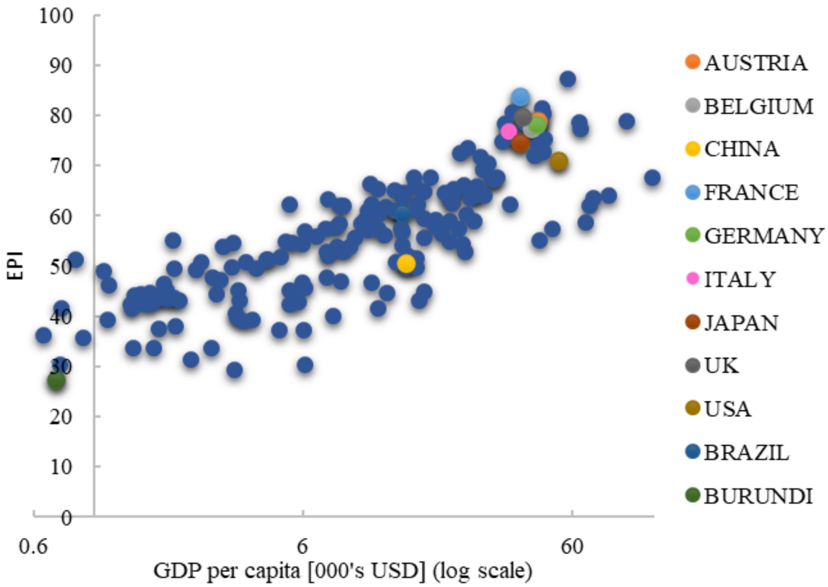


Figure 12. The relationship between EPI and GDP per capita (source: own elaboration)

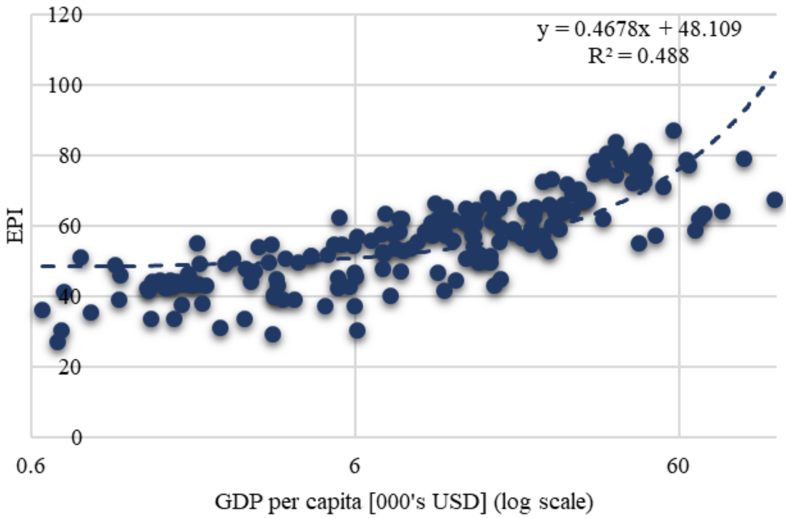
As far as the estimation of the two environmental parameters is concerned, the value of η_2 is obtained from (3.20) assuming $\eta^* = 30\%$, according to Hoel and Sterner (2007), Sterner and Persson (2008) and Gollier (2012). Hence, we have that:

$$\eta_{2\ \text{Italy}} = 1.15;$$

$$\eta_{2\ \text{China}} = 1.06.$$

δ, on the other hand, summarises the sensitivity of environmental quality q, expressed through the EPI, to changes in consumption c, with c approximated to GDP per capita. For 140 countries, the most recent values of the index, i.e. those of 2018, are correlated with the respective GDP per capita of the year 2018. Figure 13 summarises the result of the regression analysis carried out based on formula (3.21), where δ, a parameter common to both countries, is equal to 0.49.

Figure 13. The relationship between EPI and GDP per capita to estimate δ (source: own elaboration)



Step 3. *Probabilistic forecast of economic and ecological discount rates for Italy and China*

In accordance with literature data, g_t is estimated based on the growth rate of GDP per capita (Percoco, 2008; Florio & Sirtori, 2013). From the economic analysis on the trend of the per capita GDP growth rate for Italy, it is considered consistent to select data from the last forty years, i.e. from 1980 to 2019. In fact, if from a statistical point of view, it is established that the more data there are, the more correct and truthful the final information is. However, when analysing the historical trend of the last 150 years from an economic point of view, it is also objectionable to take into consideration GDP growth rates relative to historical-economic scenarios that cannot be compared with the current one or even likely future ones. In other words, the GDP growth rates recorded, for example, in the historical period of Italian unification or during the two world wars, are the reflection of situations that can no longer be traced back either to the current or to the foreseeable future economic, social and cultural context of the country.

To forecast the probable values to be associated with the growth rate of consumption, it is first necessary to identify the probability distribution that best approximates the starting historical series, which in the case under consideration is the Weibull curve, chosen on the basis of the Anderson-Darling test[4]. Then, the likely values of the GDP growth rate are predicted by implementing the Monte Carlo analysis, calibrated on 10,000 random draws. The simulation was conducted using Oracle Crystall Ball software. Having defined the probability distribution of the consumption growth rate g_1, we also obtain the probability distributions of the economic discount rate r_c and the ecological discount rate r_q. This is done by applying formulae (2.33) and (2.34). Figure 14 shows the probability distributions of g_1, r_c and r_q derived from the Monte Carlo simulation, while Table 11 shows the values of the statistical indices correlated to the forecast. From the elaborations we deduce that: g1 has values between -11.72% and 5.08% and after 10,000 simulations the standard error of the mean is 0.02%; r_c and r_q have values between -15.46% and 8.26% and between -9.19% and 5.53% respectively. In both simulations, after 10,000 trials the standard error of the mean is 0.02%, which is acceptable. Since negative discount rates have no economic significance, only positive values are considered in the definition of the declining structure of the two rates.

[4] The Anderson-Darling statistic measures how well the data follow a particular distribution. For a specified data set and distribution, the better the distribution fits the data, the smaller this statistic will be.

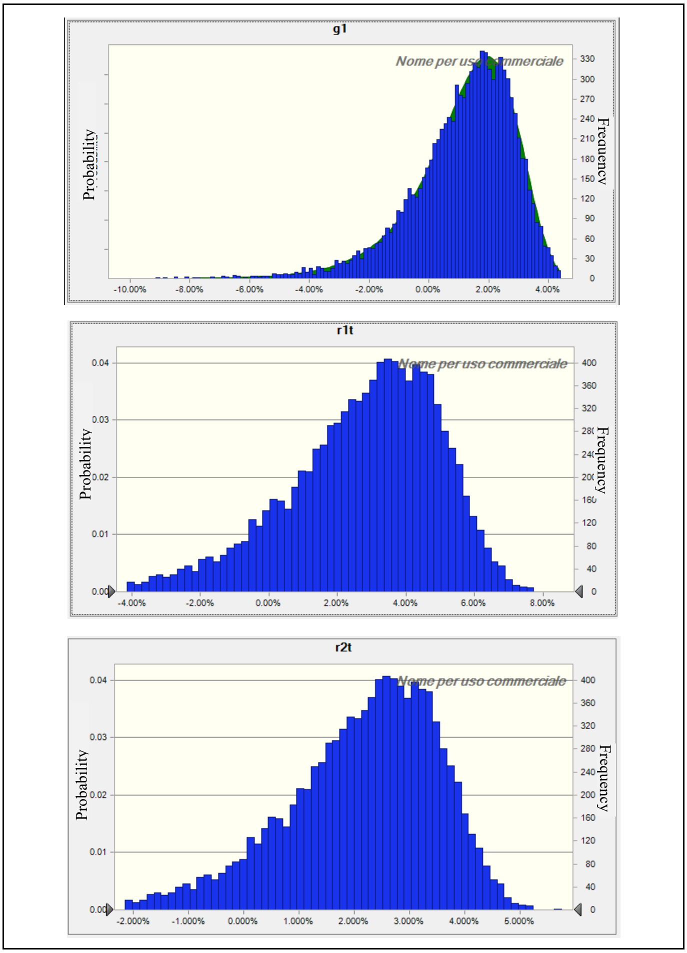


Figure 14. Probability distribution for g_1, r_c and r_q for Italy (source: own elaboration)

Table 11. Statistical indices for g_1, r_c and r_q for Italy

	Hypothesis: g_1	Forecast: r_c	Forecast: r_q
Tests	10,000	10,000	10,000
Base Case	1.17%	2.69%	2.10%
Mean	1.20%	2.74%	2.13%
Median	1.50%	3.15%	2.38%
Standard Deviation	1.72%	2.42%	1.50%
Variance	0.03%	0.06%	0.02%
Kurtosis	5.13	5.13	5.13
Minimum	-11.72%	-15.46%	-9.194%
Maximum	5.08%	8.20%	5.53%
Mean standard error	0.02%	0.02%	0.02%

In analysing the historical trend of China's consumption growth rate, a time span of the last 60 years is considered. In fact, in the period 1960-2020, the economic growth of the country is quite evident. In short, except for a few shocks, the trend is upward. In this case, the Anderson-Darling test showed that the curve that best approximates the historical data is the logistic curve. Again, we predict the likely values of the GDP growth rate by implementing the Monte Carlo analysis, based on 10,000 random draws. Figure 15 returns the point probability distribution of g_1 and the cumulative probability curves of r_c and r_q. Table 12 shows the values of the statistical indices correlated with the forecast. From the calculations we deduce that: g_1 has values between -23.22% and 45.23% and after 10,000 simulations the standard error of the mean is 0.06%. Even in the case of the simulations of r_c and r_q, the standard error is acceptable because it is 0.07% for the first variable and 0.04% for the second. Again, only positive values of the two discount rates are considered. This assumption is acceptable because it is almost certain that there are positive values for the two discount rates. In particular, there is a 95.06% probability of having a positive discount rate r_c and a 95.96% probability of having a discount rate r_q greater than 0. For details of the calculations, see Appendix 2.

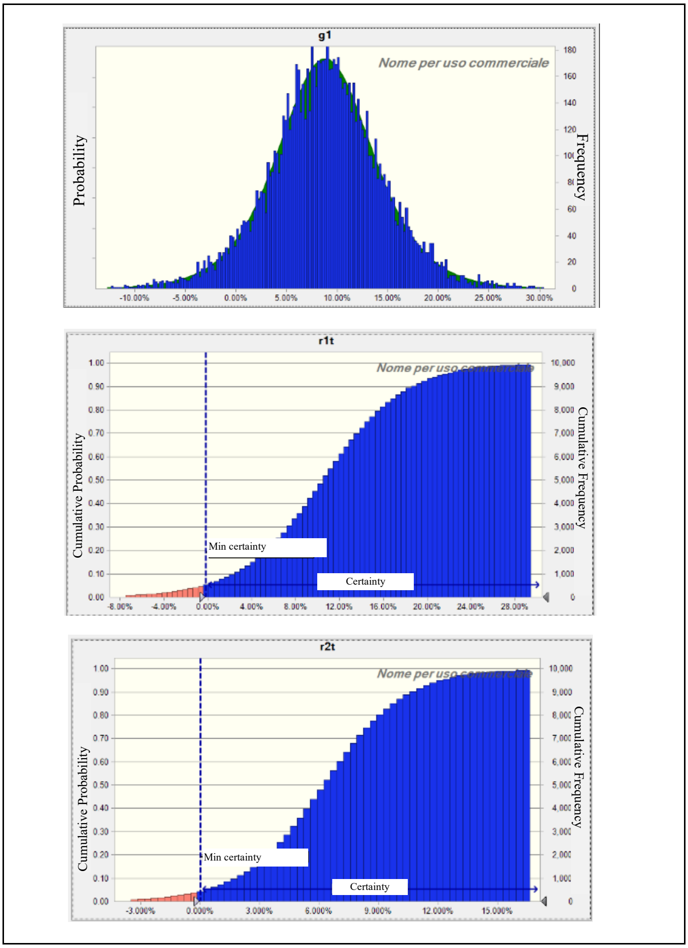


Figure 15. Probability distribution for g_1, r_c and r_q for Italy (source: own elaboration)

Table 12. Statistical indices for g_1, r_c and r_q for China

	Hypothesis: g_1	Forecast: r_c	Forecast: r_q
Tests	10,000	10,000	10,000
Base Case	8.17%	9.97%	5.97%
Mean	8.84%	10.75%	6.39%
Median	8.84%	10.75%	6.40%
Standard Deviation	5.71%	6.69%	3.65%
Variance	0.33%	0.45%	0.134%
Kurtosis	4.26	4.26	4.26
Minimum	-23.22%	-26.82%	-14.12%
Maximum	45.23%	53.41%	29.68%
Mean standard error	0.06%	0.07%	0.037%

Step 4. *Estimation of economic and ecological declining discount rates for Italy and China*

The probability distributions of r_c and r_q obtained in step 3 are first discretized into 100 intervals. Then, for each of the two distributions, we estimate the probability that the average rate in each interval has of occurring. Given the set of values to associate with the discount rates r_c and r_q and their probabilities, the equivalent certainty discount factors are estimated $E_c(P_t)$ and $E_q(P_t)$ through the formulas (3.22) and (3.23). Finally, the implementation of (3.24) and (3.25) for each instant t leads to the result of the analysis, i.e. the estimate of the time sequence of the declining economic discount rate r_{ct} and the declining ecological discount rate r_{qt}. These are declining functions along the time horizon, assumed to be 300 years. Figures 16 and 19 show the term-structure of the economic and environmental discount rates for Italy and China respectively.

Figures 17 and 18 show the step functions (with solid lines) that approximate the functions (dashed lines) of the economic and ecological declining rates for Italy. Figures 20 and 21 show the same step functions of r_c and r_q for China.

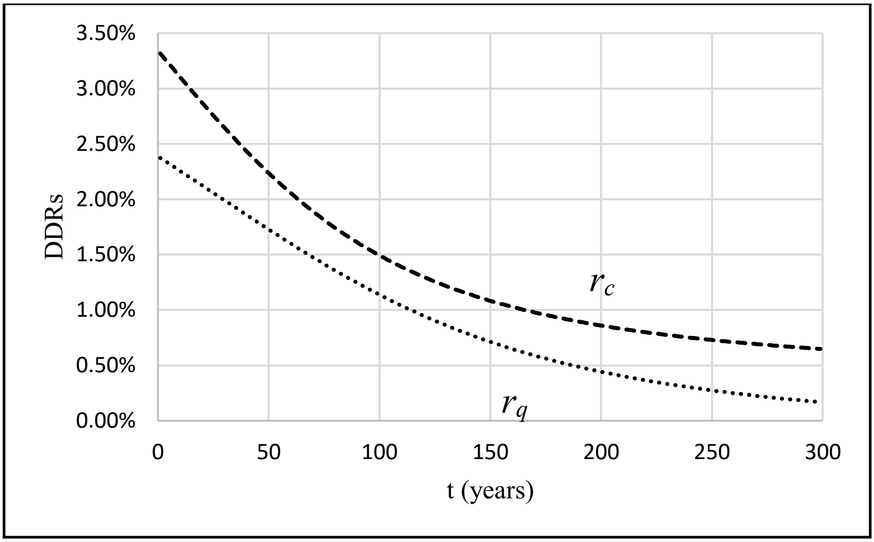


Figure 16. Term structure of economic discount rate r_{ct} and ecological discount rate r_{qt} for Italy (source: own elaboration)

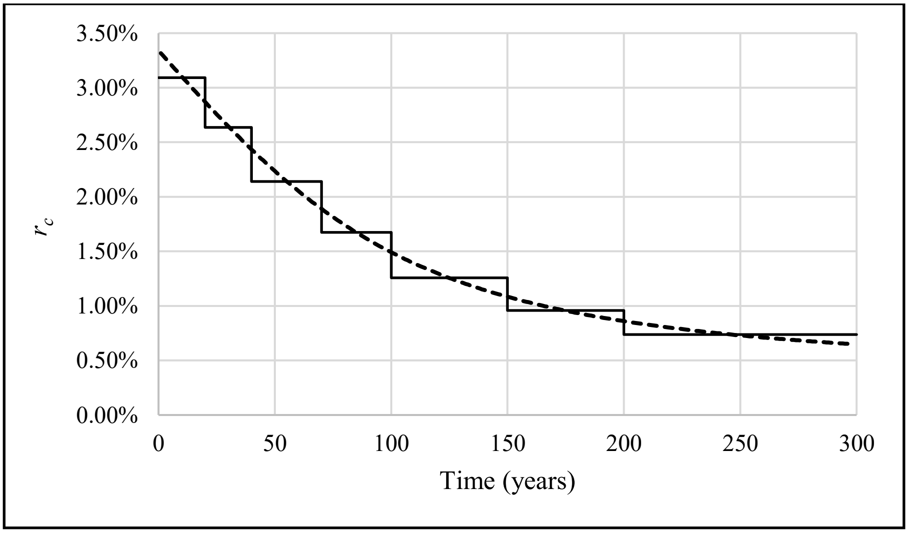


Figure 17. Step structure of economic discount rate r_{ct} for Italy (source: own elaboration)

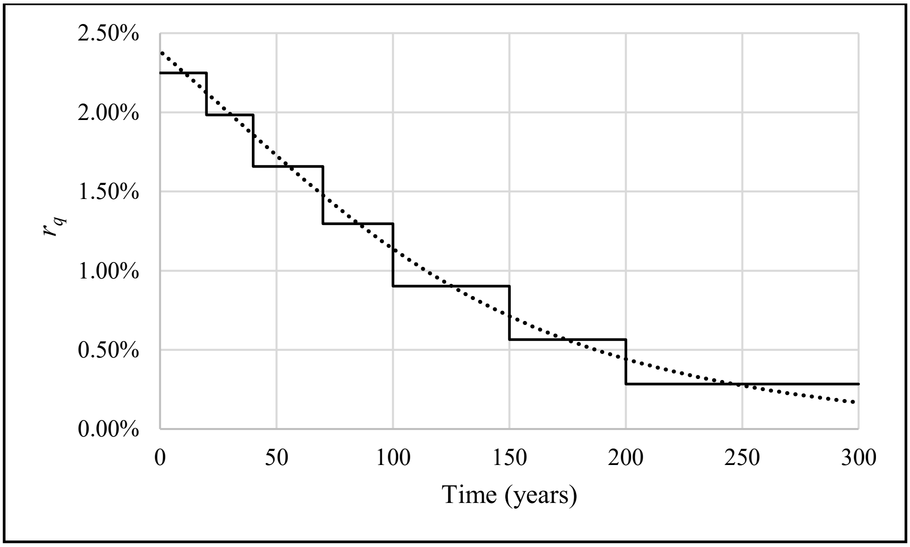


Figure 18. Step structure of environmental discount rate r_{qt} for Italy (source: own elaboration)

The following results emerge from the calculations carried out:

- the economic discount rate function r_{ct} for Italy starts from an initial value of 3.32% to reach after 300 years the value of 0.65%, thus decreasing by about 2.6%;
- the environmental discount rate r_{qt}, on the other hand, assumes values that are markedly more contained than r_{ct}, starting from a value of 2.37% and reaching that of 0.17% after 300 years;
- the average economic discount rate for the first 20 years is about 3.1%, a result consistent with the value of the discount rate suggested by the European Commission (2014) for economic analyses, which is 3.0%;
- the average environmental discount rate for the first 20 years is 2.2%, highlighting how from the beginning of the assessment more weight is given to the damage and benefits that the investment generates on the environment.

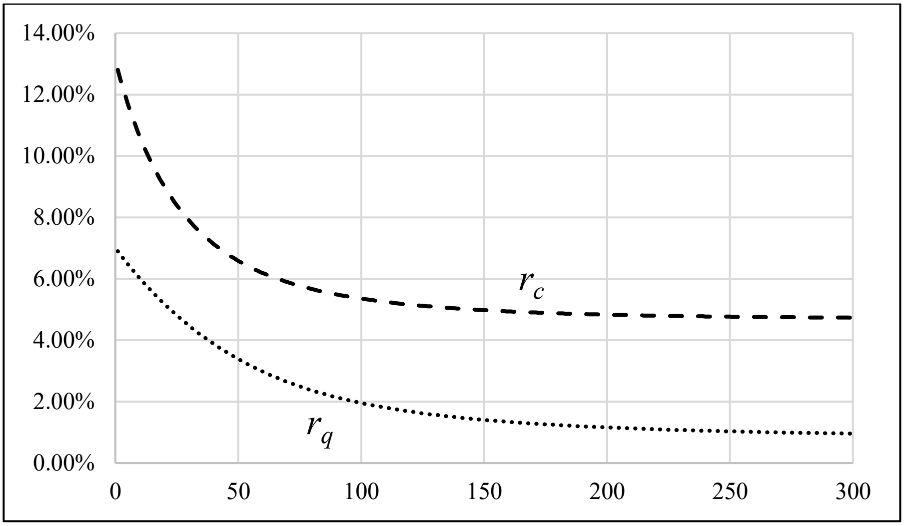


Figure 19. Term structure of economic discount rate r_{ct} and ecological discount rate r_{qt} for China (source: own elaboration)

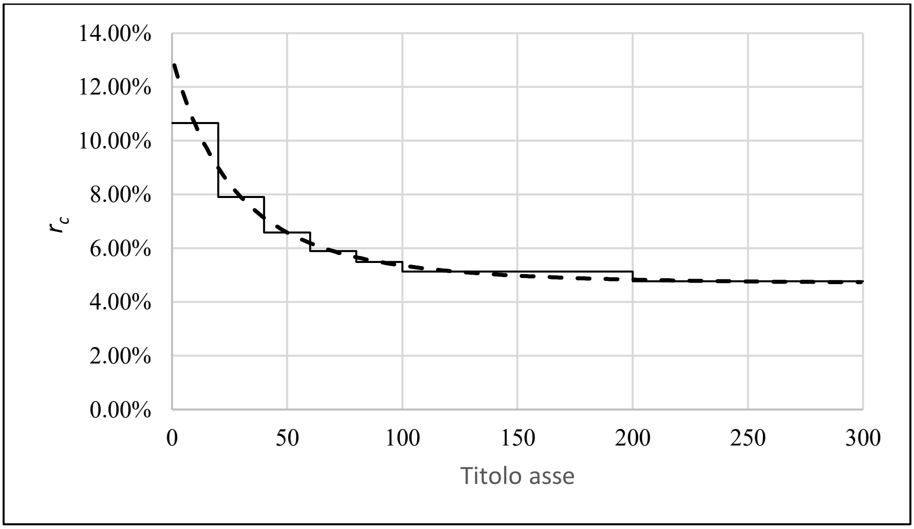


Figure 20. Step structure of economic discount rate r_{ct} for China (source: own elaboration)

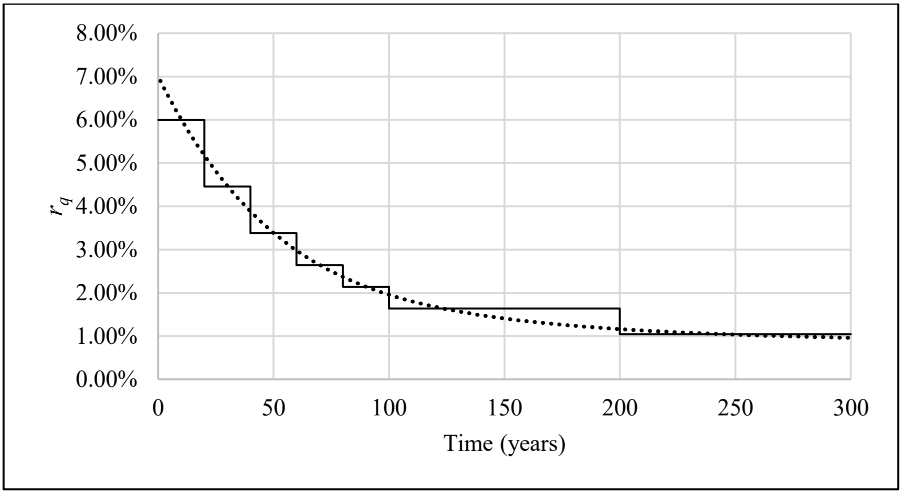


Figure 21. Step structure of environmental discount rate r_{qt} for China (source: own elaboration)

For China, the calculations lead to the following results:

- the economic discount rate function r_{ct} starts from an initial value of 12.81% to reach after 300 years the value of 0.65%, thus decreasing by about 4.74%;
- the environmental discount rate r_{qt}, on the other hand, takes on markedly lower values than r_{ct}, starting at 6.90% and reaching 1.00% after 300 years;
- the average economic discount rate for the first 20 years is about 10.7%, which is slightly higher than the value of the discount rate suggested by the Asian Development Bank (2017) for economic analysis, which is 9.0%;
- the average ecological discount rate for the first 20 years is 6.0%. Averaging the two discount rates r_c and r_q yields a discount rate of 8.4% which is slightly lower than the 9% discount rate suggested by the Asian Development Bank. However, using two different rates for discounting the strictly financial components and the extra-financial components would allow more weight to be given to environmental damages and benefits, thus directing decision-making towards more sustainable investment choices.

Interestingly, the two functions of the discount rate for China start from higher initial values than for Italy but decline much more rapidly from the early years of the period of analysis. The higher initial value is mainly attributable to the higher values of the GDP growth rate for China compared to Italy. However, the faster decline in the term-structures of the discount rates is linked to China's environmental condition. Indeed, as shown by the lower Environmental Performance Index (EPI) value, China is further away from achieving the UN Sustainable Development Goals and therefore highlights the greater need for the country to invest in green projects.

5. Analysis of extra-financial risks associated with China's Belt and Road Initiative (BRI)

Summary

The valuation model defined in Chapter 4 can be implemented to assess the economic risk of complex investment initiatives, characterised by multiple rates of both financial and extra-financial risk. In particular, the focus is on the Belt and Road Initiative (BRI). Also known as the "New Silk Road", the BRI can be described as an ambitious Chinese economic and trade development project launched in 2013 by President Xi Jinping. In a nutshell, it is a long-term strategy for developing maritime and land transport infrastructure between Asia, Europe, the Middle East, and Africa, aimed at enhancing China's trade relations in these geographical areas.

The purpose of this chapter is to provide a study of the strategy to analyse the possible risks associated with the Belt and Road and identify methods to take them into account in *ex-ante* economic assessments. The study is prodromal to the analysis developed in Chapter 5, where the economic model defined will be implemented in a specific case study.

This chapter is divided into five sections. Section 5.1 describes the Belt and Road Initiative (BRI), highlighting its main routes, objectives, and main types of risk. Section 5.2 and 5.3 focus respectively on the analysis of the main intervention strategies in the Euro-Asian continent and in Italy. Section 5.4 defines the investment sectors, regions and cooperation formats of the projects involved in the Initiative. Finally, the last section provides an analysis of the critical variables of the environmental externalities of the interventions involved as well as the methods used to estimate them.

5.1. Objectives, challenges and risks related to the BRI

The Belt and Road Initiative (BRI) – also known as One Belt, One Road or New Silk Road – was officially announced at the end of 2013 by Xi Jinping, President of the People's Republic of China. In September, in Kazakhstan, President Xi launched the proposal to establish the Silk Road Economic Belt (SREB, a Eurasian overland trading network linking China and Europe and modelled on its ancient prototype). The following month, the Indonesian Parliament was the scene of the presentation of the maritime branch of the initiative: the 21st Century Maritime Silk Road (a complementary seaborne trading network). The two proposals together aim at a large project whose purpose is to revive the ancient Silk Road in a modern key. This favours the integration of Asia and Europe through the development of infrastructural networks and maritime connections capable of increasing commercial exchanges (Bertozzi, 2018). So, in other words, both networks together focus on connectivity and economic cooperation along infrastructural trajectories and comprises the establishment or modernization of port, rail, road, pipeline, energy, communication and IT, infrastructure and logistics, urban development and planning.

The SREB focuses on bringing together China, Central Asia, Russia and Europe, on connecting China with the Persian Gulf and the Mediterranean Sea through Central and Western Asia, and on linking China with Southeast Asia, South Asia and the Indian Ocean. The 21st Century Maritime Silk Road is designed to go from China's coast to Europe through the South China Sea and the Indian Ocean, connecting China with Southeast Asia, South Asia, East Africa and the Mediterranean (State Council – The People's Republic of China, 2015). To understand the importance of the initiative, just think that the BRI potentially involves 65 countries in Asia, Africa, the Middle East, and Europe and 4.4 billion people or about 60% of the world's population (Grieger, 2016). Furthermore, the area involved generates around 50% of global GDP and boasts about three-quarters of the world's energy reserves. This would be an investment plan of up to 1,000 billion dollars according to the Whashington Center for Strategic & International Studies forecasts.

In the New Silk Road (NSR) there are several maps, in continuous evolution, in which the updated routes and projects in progress are reported.

The first official map was published in 2014, while the last one in 2016 indicates a more detailed description of the terrestrial corridors, the coverage of the entire Mediterranean basin along a route that continues towards the Atlantic. To the east, instead, maritime routes to the Arctic and beyond Australia are opened.

The not well defined routes want to confirm precisely the open nature of the entire project that has no pre-established designs but that adapts from time to time to concluded political agreements and is always open to new collaborations (Giacchè, 2016). Indeed, according to Stec (2018) «the BRI progresses through an evolutionary process, so much so that at the beginning it was an initiative focused exclusively on infrastructure while currently it also includes industrial, technological, cultural and environmental components. At the same time, the BRI has increased its geographical scope by shifting its focus from the historic Silk Road region to the whole world».

The ever-widening expansion of the geographical regions involved in the initiative also concerns the same name that was changed from the initial "One Belt One Road (OBOR)" to "Belt and Road Initiative (BRI)" as reported by official sources. The acronym OBOR, in fact, risked not being consistent with the ever more numerous projects and routes but seemed to refer to a limited geographical area.

Despite this, all the maps agree in identifying the main economic corridors, both land and sea, along which the initiative is developing.

Along the so-called economic corridors with partner countries, China intends to exploit the current international transport routes, but at the same time implement new trajectories. In this context, the refurbishment or construction of roads, railroad lines, oil and gas pipelines, optic fibre networks as well as intermodal transport hubs may be of key importance.

The economic corridors mentioned above can be grouped into those of the *Silk Road Economic Belt* (SREB) and those of the *21st Century Maritime Silk Road* (MSR).

The SREB envisages the following economic corridors:

1. *New Eurasian Land Bridge Economic Corridor* (Xinjiang-Kazakhstan-Russia): This corridor comprises (at least) two routes through Kazakhstan: either via Almaty or via Astana. Routes reunite in Moscow and continue via Belarus to the EU (Duisburg, Germany, or Rotterdam, Netherlands).
2. *China-Mongolia-Russia Economic Corridor*: This corridor also comprises at least two routes: either Beijing-Ulan Bator-Siberia or Dalian-Harbin-Siberia. This corridor also fits with Mongolia's planned Steppe Road trajectory.

3. *China-Central Asia-West Asia Economic Corridor*: This route is envisioned as an important gateway for oil and natural gas, running from the Arabian Peninsula, Turkey and Iran to Xinjiang.
4. *China-Pakistan Economic Corridor*: This trajectory enables shipping oil from the Middle East (via the Persian Gulf and the Arabian Sea) to the deep-sea port of Gwadar in Pakistan and then carrying it by road, railroad or pipelines via Rawalpindi to Kashgar (province of Xinjiang).
5. *Bangladesh-China-India-Myanmar Economic Corridor*: This route is supposed to connect China with South Asia, running from Kunming (capital of Yunnan, China), Mandalay (Myanmar), Dhaka (the capital of Bangladesh) to Kolkata (capital of West Bengal, India).
6. *China-Indochina Peninsula Economic Corridor*: The central trajectory of this route links southern China with Bangkok and Singapore; new high-speed railroads and highways are planned to run from the Pearl River Delta (around Hong Kong and Guangzhou) to Singapore via Bangkok (Thailand) and Kuala Lumpur (Malaysia).
7. *India-Nepal-China Economic Corridor*: As a centrepiece of this passage, a new railroad line has been proposed which should link Tibet (Lhasa), Nepal and India, and could boost regional and trilateral trade.

The *MSR* envisages the following connections:

1. *China-Myanmar-Indian Ocean-Middle East*: This route (described in the reverse direction) runs from the Persian Gulf via the Indian Ocean to the deep-sea port of Kyaukpyu in the Bay of Bengal (Myanmar); from there, oil and gas pipelines cross Myanmar to Kunming.
2. *China-South China Sea-Indian Ocean-Middle East or China-South China Sea-Indian Ocean-Red Sea-Europe*: Both maritime routes (which bifurcate in the Indian Ocean) are traditional links running via the Strait of Malacca. The second route (via the Red Sea to Europe) has gained prominence recently due to substantial Chinese infrastructural investment activities at the route's European head (Greek port of Piraeus, high-speed rail connection to Budapest, etc.) and due to stepped-up combatting of piracy near the Horn of Africa. The recently established Chinese military base in Djibouti, China's

first overseas base in at least two centuries, supports antipiracy patrols.

3. *China-South China Sea-Indian Ocean-East Africa*: This is a resource supply route, starting with railroad links from the African interior to the coast (Mombasa, Kenya), followed by seaborne connections via the Strait of Malacca to China (Barisitz & Radzyner, 2017).

Only at the beginning of 2018 did the official entry into the BRI of the Arctic Circle arrive, in addition to a first mention of the route in the document "Vision for Maritime Cooperation under the Belt and Road Initiative": in January 2018, in fact, the Chinese government published the white paper China's Artic Policy. Through the Polar Silk Road, there would be the possibility of exploiting the Arctic maritime routes due to global warming to reach Europe in a shorter time and re-join the existing rail corridors. This is also because the Arctic region is rich in untapped mineral resources and it could represent an energy alternative to existing routes (Rosen & Thuringer, 2017).

Figure 22 below shows the main expansion corridors, existing or under construction.

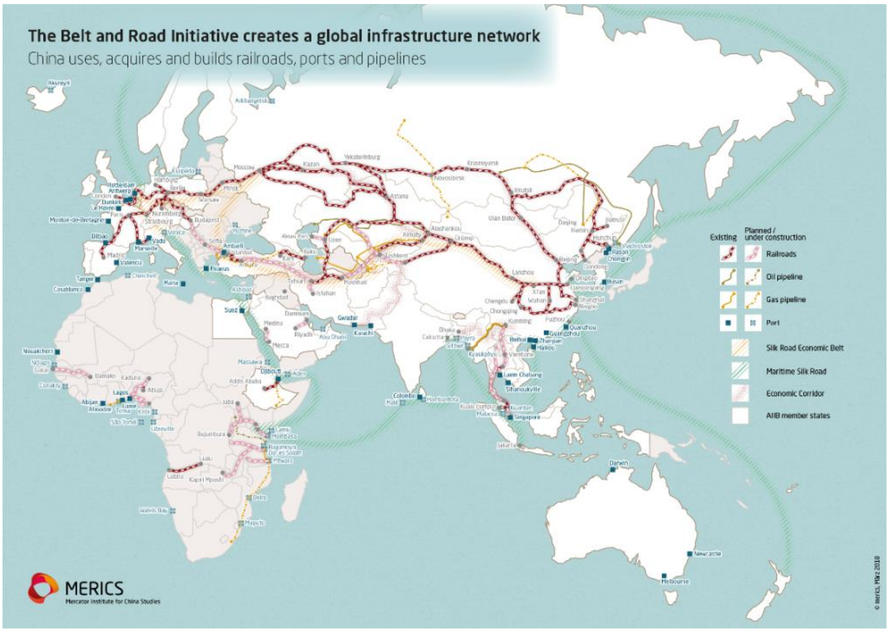


Figure 22. The Belt and Road Initiative: economic corridors spanning Asia, Europe, and Africa (source: Mercator Institute for China Studies, MERICS).

The Belt and Road Initiative aims to achieve numerous objectives closely related to both economic but also geopolitical and environmental issues.

Firstly, through the BRI it is intended to improve transport links, thereby reducing commercial costs (by land and by sea) in Eurasia. The figure according to which three quarters of Chinese imports from Russia and about 60% and those from Kazakhstan are carried out from the ports of St. Petersburg and Vladivostok indicates how the logistical development of the Eurasian land trade is still relatively modest-

Then, it should not be underestimated that the New Silk Road can promote the diversification of markets and suppliers by stimulating exchanges with countries that are difficult to reach. In this sense, the development of infrastructure promoted by the BRI can increase growth in their economies and, consequently, the demand for goods and services from China (Djankov & Miner, 2016).

Another objective to be achieved through the initiative is related to the internationalization of the Chinese Yuan-Renminbi. This to expand bilateral currency exchanges, encouraging partner countries with good credit ratings to issue Yuan-Renminbi bonds.

Certainly, the BRI also wants to be a place to address even strategic problems related to energy and resource security, most of which continue to be transported by sea almost exclusively across the Strait of Malacca between the Indian Ocean and the South China Sea (Escobar, 2015).

Leading the initiative is also an important ecological goal, that is, one related to reducing China's heavy dependence on the use of coal. In order to contain pollution, the authorities have set ambitious goals such as the transition from coal to renewable energy sources such as the natural gas that currently comes mainly from Central Asia and Russia.

Finally, another goal would be to promote the development of some regions of the hinterland of the country. If Chinese growth has favoured the country's eastern and coastal provinces in recent decades, NSR intends to transform the north-western province of Xinjiang into China's infrastructure gateway to central and western Asia, in order to open up investment and business opportunities economic strength in this most distant province. Correspondingly, in the south-west, Yunnan province should become the modernized "open door" for South Asia and the Indian Ocean (Grieger, 2016). Another strategic area is the Yangtze River Economic Belt, where Chongqing serves as a strategic pillar on the Yangtze River Economic Belt, the “Silk Road Economic Bel” and the “21st Century Maritime Silk Road”. It represents the support of the development and opening of western China, the western hub of the Yangtze River economic belt, the core of Chengdu - Chongqing City Cluster, as well as the pilot zone for China’s comprehensive reform of urban and rural areas.

On the other hand, the BRI must overcome also numerous risks. First, the partner countries have very different political and economic conditions, with consequent risks associated with both financial challenges and political and social instability. In this general context, the implementation of large-scale infrastructure projects in the absence of reliable public procurement systems could add problems of local governance.

Likewise, possible negative consequences could also derive from increased geopolitical rivalries or tensions. This can undoubtedly generate the risk that the projects may be victims of an exacerbation of geopolitical competition with other powers (Miao, 2015; Yilmaz & Liu, 2016; Musabelliu, 2017).

In conclusion, although some scholars are not optimistic about the future development prospects of the BRI more scholars hold that they should be cautiously optimistic. This Initiative has the potential to promote the growth of underdeveloped regions as a new dynamic economic pillar and facilitate policy communication to achieve successful cooperation among emerging market economies. However, the construction of the BRI also faces high risks and challenge, such as the lack of an intermediary coordination mechanism, potential conflicts that may arise between different political systems and concepts, and the financial viability of multinational projects (Huang, 2016; Ma, 2017; Gabusi, 2017).

5.2. The Belt and Road in the Euro-Asian continent

Throughout Eurasia, rail transport tends to be cheaper than road transport but more expensive than sea transport. For this reason, almost 95% of European Union trade with China takes place on the sea route. This can also be attributed to the rudimentary state of some Eurasian transport links. However, in recent years, trans-Eurasian rail connections have been improved and the number of containers in transit has doubled. In this regard, it is worth mentioning the Trans-Eurasia-Express train that from 2011 delivers valuable goods from Chongqing to Duisburg. Back in Asia, on the other hand, these trains carry cars, pharmaceuticals and numerous other European goods. Another important link is also the one made in 2016 linking China and Iran (via Kazakhstan and Turkmenistan).

Since land transport is less economic but much faster than sea transport, it is only intended for particular types of goods (high added value goods, high technology products, high fashion products or products that need to be transported as quickly as foodstuffs). Other limits of transcontinental transport concern both the technical and physical constraints of the railways and the border control regimes. These are elements that end up slowing down the overall ground transportation process. For all these reasons, long-distance trade should remain dominated by maritime expeditions, while modernized transcontinental transport should specialize in luxury and time-sensitive goods or, in general, in trade with neighbouring countries that are landlocked.

Overall, while considerable resources have been devoted to the development of Maritime Silk Road, investments in rail and road connections promoted by the BRI are increasingly improving. Most of the Chinese investments in BRI projects currently concern Pakistan, Bangladesh, Malaysia, Indonesia, Russia, Kazakhstan and Kenya. However, compared to the size of the respective host economies, even smaller but strategically located countries are benefiting from it. Think of Djibouti, Sri Lanka, Mongolia, Kyrgyzstan, Laos, Cambodia, Serbia, and Montenegro. The next steps will cover connectivity, trade, and economic dynamism in some important parts of Eurasia (including south-eastern Europe), which will be better connected and more interdependent with China once the planned projects are completed.

Moving attention to Europe, it should be emphasized that 80% of trade is concentrated on Poland, the Czech Republic, Hungary, Romania, and Slovakia. As for the extra-European Union exchanges, half concern only Serbia that is the main Chinese partner in the Balkans also following the signing in 2016 of a “Global strategic partnership”. In fact, in addition to being interested in the China-Europe Land-sea Line project – the railroad that should link Macedonia, Serbia and Hungary to bring goods landed in Piraeus to Europe – Serbia is also involved in another important Chinese investment plan in many sectors: the modernization of the thermoelectric plant in Kostolac, the construction of an industrial park in Belgrade and the 445 km motorway project linking Belgrade to Bar (Montenegro).

In November 2017, Estonia, Lithuania and Slovenia signed a memorandum of understanding with Beijing for the development of the NSR, adding to Latvia and Hungary.

Slovakia has also shown increasing interest in the initiative, so much so that it has become the only country in the area to have a specific "Chinese strategy".

Poland boasts a strategic position in the Eurasian corridor, as enshrined in the memorandum of understanding that the Nation has signed with China in 2015. Already in 2013, the Chendgu-Lodz and Warsaw-Suzhou rail links were activated for the transport of goods, while in 2016 the Kutno-Chendgu connection was signed. Among the projects promoted by the BRI there is also the maritime service between the ports of Gdansk and Shanghai. Other possible projects could include the expansion and modernization of the multimodal logistics hubs of Lodz and Malaszewicze as well as the financing of a new international airport, high-speed railways and industrial parks.

But among the most important interventions in Europe is undoubtedly the acquisition by Cosco of a 67% stake in the Greek port of Piraeus, the largest in Greece and one of the largest in Europe, to turn it into the main centre of transit in south-eastern Europe and a bridge between Europe and Asia. In this regard, Athens has indeed signed an agreement with neighbouring Bulgaria for the construction of the "Sea2Sea" railway network that will connect the Greek ports of Thessaloniki, Kavala and Alexandrupolis to the Bulgarian ports of Varna, Burgas and Ruse.

The logistical and economic presence of China in the Mediterranean, however, is not limited only to the purchase of the port of Piraeus. In this regard, it is worth mentioning the participation of Cosco in the joint venture that manages the container terminal of the Suez Canal, the agreement for the construction in Algeria of a freight transport center in the port of Sarsal and the acquisition of 65% of Kumport terminal in Turkey, near Istanbul.

For what concerns the railway connections implemented in Central Europe it is worth mentioning the "New Eurasian Land Bridge". This 12,000 km route reaches European destinations such as Duisburg, Madrid, and London, but also Rotterdam from eastern China.

From November 2017, the first railway connection between China and Finland was also created. It is the first Nordic country to become a railway hub of the New Silk Road. It is one of the fastest connections among the existing ones and was opened thanks to a collaboration with Russian and Kazakh partners.

Germany, on the other hand, is at the centre of the railway bridge that connects China to Europe. Indeed, already in 2011, the connection between Leipzig and Shenyang was implemented. In 2016 a memorandum of understanding between the state company Deutshe Bahn and China Railways for the further development of Eurasian rail connections was signed.

France, instead, only recently started to develop concrete relations with China for the New Silk Road: in April 2016, a train departed from Wuhan along the Duisburg-Chongqing line arrived in Lyon. However, it seems that French ports will not play a central role in the development of the initiative.

Finally, the Netherlands also represents one of the main Chinese economic partners in the European Union and is connected to China by the Chendgu–Tilburg railway line extended to Rotterdam. Numerous high-tech products from Sony, Samsung and Fuji companies' reach Holland. Indeed, cars, wine, and wood leave Holland to reach the Asian continent. Among the most important collaborations, it is necessary to mention the "New Silk Logistic" joint venture between three Dutch transport companies founded with the aim of providing freight transport services on the Duisburg-Chongqing line. Cosco, instead, bought 35% of the Euromax terminal in the port of Rotterdam (Richet, Rulet, & Wan, 2016).

5.3. An in-depth look at China-Italy collaboration in the BRI

Chinese leaders have always considered Italy as an important reference point for the realization of the Belt and Road Initiative (BRI). In fact, its strategic position in the Mediterranean could allow Italy to be one of the main western terminals of the Maritime Silk Road (MSR). Moreover, the improvement of its railways could guarantee the Nation also to establish itself as a fundamental land passage to reach central, eastern, and northern Europe (Bertozzi, 2018).

These are the reasons that pushed Beijing to consider the Italian ports of Venice, Trieste and Genoa that are close to the continental markets and have better connections than those located in the Balkan corridor.

Italy-China collaboration has been sanctioned by several important events in recent years: the entry of Italy among the founding countries in the Asian Infrastructure Investment Bank (AIIB); participation as the only country of the G7 at the Belt and Road Forum in Beijing in 2017; the recent China-Italy Memorandum of Understanding signed on March 23, 2019.

With reference to the latter, 29 agreements were signed during Chinese President Xi Jinping's visit to Italy. Among these, nineteen agreements are institutional and mainly concern the development of Italian ports, the import-export of Italian and Chinese products and promotion of innovative start-ups, electrical commerce, cultural heritage sites, UNESCO sites, research, and scientific cooperation.

The collaboration between the two countries is also substantiated in the acquisitions, starting in 2008, of small and large brands in those sectors in which Italy has achieved global competitiveness: from instrumental mechanics, to fashion, from motorcycle production to automotive (Casarini, 2017). Equally relevant are the exports of Italian products to China (both long-life and household appliances), thanks to the collaboration with an e-commerce giant like Alibaba.

Another crucial point concerns infrastructure. Indeed, during the New Silk Road Forum, held in Venice in 2015, attention was paid to the “Alliance of the five ports”, one of the main logical-infrastructural interventions that put Italy in the Belt and Road Initiative. It is an alliance between the ports of Venice, Trieste, Ravenna, Koper (Slovenia) and Rijeka (Croatia). The purpose is to attract merchant ships that reach the Mediterranean through the Suez Canal, via an alternative route to the one that from the port of Piraeus arrives in Central Europe through the Balkans.

The idea, developed by the North Adriatic Port Association (Napa), and supported by the Ministry of Infrastructure provides for the construction of an offshore/onshore port system by building a large multi-modal platform off the port of Malamocco (Venice). The structure would rise about 8 miles from the coast, where the depths are more than 20 meters deep. This to allow the docking of large cargo ships. On the mainland, five separate terminals should be built: three in Italy (Marghera, Ravenna, and Trieste), one in Slovenia (Koper) and one in Croatia, in Rijeka (see Fig 23.a).

Placing these 5 ports online would make it possible to achieve the fastest connection ever between the Far East and the heart of Europe (Northern Italy, Austria, Germany, Bosnia, Croatia, Slovakia, Hungary, Czech Republic) where the highest rate of European manufacturing companies is still concentrated today. The Shanghai-North Adriatic route is about 2000 miles shorter than the Shanghai-Hamburg (8630 nautical miles against almost 11 thousand). This corresponds to a saving of about 8 days less navigation, lower freight costs and, very importantly, about 135 kg less CO_2 for each container handled from Shanghai to Munich.

To carry out this project, created by the Italian-Chinese 4C3 consortium, 2.2 billion euros are needed. Approximately 350 million are already allocated for the construction of the offshore terminal and for basic civil works in the ports. 1.25 billion euros of private funds instead would be half destined to equip the terminals and finance off /onshore connection systems and half involved in the construction of a new offshore oil dock (Baroni, 2016).

Recently, China has shown greater interest in the port of Trieste due to its status as a free port. This makes value-added services such as loading, unloading, storage and production possible without having to pay taxes and freedom of transit of goods to other European states. The memorandum of Understanding of March 2019 signed the partnership between the Trieste Port Authority and the China communications construction company (CCCC) for the construction of the railway infrastructures included in the "Trihub" project, a reinforcement plan developed in collaboration with the Italian Railway network (see Fig. 23.b).

The memorandum of understanding of March 2019 also establishes the CCCC's interest also for the port of Genoa. The cooperation concerns the implementation of planned works for moving and strengthening the port dam, improving road and rail links in the last mile, strengthening the port basin.

Even the port of Vado Ligure has attracted the attention of Chinese partners. In this case, the construction of the new container terminal would take place, with Cosco holding 40% of the shares while Qingdao port international development would have 9.9%. The rail link will be fundamental: according to the forecast, from the Savona station 450 meters long trains will leave which will guarantee the connection with the inter-ports of northern Italy, opening new markets in France, Switzerland, Germany, and Austria (see Fig. 23.c).

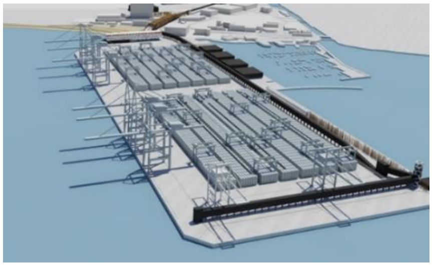
To have a marginal role in the maritime link of the BRI, as has been recently found, instead, would be the ports of southern Italy, despite the geographical proximity to the Suez Canal and their strategic position. This is because there is a lack of infrastructure connectivity that instead characterizes northern Italian ports (Albana, 2018).

Regarding transcontinental rail connections, in November 2017 the first freight train to Chengdu, the capital of Sichuan, departed from the Mortara logistics hub in the province of Pavia, for a journey of eighteen days and almost 11 thousand kilometers. Described as the first Italian train along the new Silk Road, it was loaded with cars, tiles, furniture, and machinery. However, after only a few months, no train was passed along the line.

Another connection from the Busto Arsizio/Gallarate intermodal terminal with the city of Chengdu is still being planned. Also under study is the opening of a connection between Melzo (Milan) and Shanghai for the transport of fruit and vegetables.

Finally, Italy could also have other opportunities to develop the Belt and Road that should not be underestimated. For example, Italian railways are involved in Iran in the railroad construction project between Tehran and Isfahan, and have acquired 100% of Trainose, the main railway operator in Greece that provides freight and passenger transport services at extraurban, regional and national level and international, including logistics services. These operations mark Italy's entry into important expanding contexts related to both infrastructure connections and exchanges between Asia and Europe (Bertozzi, 2018).

a. Photorendering of the Venice Port Project (source: www.port.venice.it)



b. View of the Trieste Port (source: www.la stampa.it)

c. Photorendering of the Project of Vado Ligure Port (source: Grandi Lavori Finconsit, http://www.glf.it/)

Figure 23. Project of Italian ports

5.4. Investment sectors, regions and cooperation formats of the projects involved in BRI

It was emphasized that the BRI must be considered as an evolutionary process, initially focused exclusively on infrastructures, but which involves more and more sectors: from energy and natural resources to agriculture; from technology to logistics; from production to urban development. At the same time, BRI is broadening its geographic reach by shifting its focus from the historic Silk Road region to the entire world. The same paths that are not well-defined want to confirm the open nature of the overall project which has no pre-established designs, but which adapts itself from time to time to the political agreements concluded and is always open to new collaborations. What is clear is that inclusiveness, win-win relationships, openness, economic and social development represent the fundamental conceptual pillars on which the investment programs related to the Belt and Road are based (Rolland, 2017; Xiao, Cheng, & Wang, 2018).

The BRI strategy relies on a panoply of potential lenders: the Asian Infrastructure Investment Bank (AIIB), the Silk Road Fund (SRF), the Asian Development Bank (ADB), the World Bank (BM), the European Bank for Reconstruction and Development (EBRD), the European Investment Bank (EIB), the Exim Bank of China, the China Development Bank, the Agricultural Bank of China, the ICBC, HSBC, and other Chinese and non-Chinese private banks.

The main multilateral institution wanted by Beijing to financially support energy and infrastructure projects in the BRI area is the AIIB. This bank currently includes 84 members – including Italy – who have made available a registered capital of 100 billion USD. The rating agencies have given the AIIB a triple A rating. On the Chinese side, the bank is managed by the Ministry of Finance. The Silk Road Fund, another body appointed to finance BRI projects, with only Chinese capital. There are also several framework agreements between the Chinese government and banks (for example the ADB) to manage financing and loans for projects in the investment sectors useful for achieving the BRI objectives.

There are now several procedural channels to participate in projects and access BIS funding. A pre-condition is to invest in trusting relationships with Chinese operators, proposing joint investments that have a strong industrial value and adequate financial support. In the Chinese world, direct negotiation and mutual knowledge are often fundamental, which go through consolidated relationships.

In this regard, on the Belt and Road Portal by Hong Kong Trade Development Council (HKTDC) there are calls for potential projects related to infrastructure, investment, and other business opportunities. These projects are classified both based on the sector and region and on the cooperation format, which obviously depends strictly on the type of project to be implemented. As regards the latter aspect, the reference for responding to calls is the following cooperative approaches: (i) 100% Takeover; (ii) Majority Shareholdings; (iii) Minority Shareholdings; (iv) Equal Shareholdings; (v) Public – Private Partnership/Concession; (vi) Open for Negotiation; (vii) Seeking for Tenant; (viii) Requisition of Service.

Table 13 shows the classification of investment opportunities on the Belt and Road Portal by HTDC classified by sector, region, and cooperation format.

Table 13. Sectors, regions and cooperation formats of the projects involved in BRI (source: https://beltandroad.hktdc.com/en/project-database)

Sector	Agriculture and Rural Development	Fishing
		Forestry
		Irrigation and Drainage
	Energy & Natural Resources	General Energy
		Mining
		Natural Resources
		Oil & Gas
		Power Plant
		Renewable Energy
	Manufacturing	Industrial Park
		Logistic Park
		Machinery
	Public Utilities	Telecommunications
		Waste Treatment
		Water and Sanitation
	Technology	Biotech
		Clean Teach
		Fin teach
		ICT Infrastructure
		Manufacturing Technology
	Transport & Logistic Infrastructure	Aviation
		Bridge
		Maritime Transport
		Ports
		Railways
		Roads and Highways
		Tunnels
		Urban Transportation

	Urban Development	City Planning
		Education
		Health Facilities
		Hospitality & Tourism
		New Town Development
		Property Development
		Smart City
Region	Mainland China	
	Southeast Asia	
	South Asia	
	Central Asia	
	Northeast Asia	
	Central and Eastern Europe	
	Africa	
	Australasia	
	Latin America	
	Middle East	
	North America	
	Western Europe	
Format of Cooperation	100% Takeover	
	Majority Shareholdings	
	Minority Shareholdings	
	Equal Shareholdings/Concession	
	Licensing	
	Open for Negotiation	
	Seeking for Tenant	
	Requisition of Service	

5.5. Critical variables and extra-financial externalities of the investment projects involved in the BRI

Among the main objectives of the BRI, particular attention must be paid to the promotion of sustainable development. This encourages economic growth and social progress, safeguarding equity and justice, and above all strengthening environmental protection. For this reason, the Belt and Road projects focus on the environmental protection, propose the concept of green development, and promote infrastructure construction to provide hardware support for sustainable development (Xiao, Cheng, & Wang, 2018).

Furthermore, those involved in the Belt and Road are complex projects characterized by multiple risk rates that significantly affect the actual feasibility of the investment. These risks can be divided into six categories (Andric, Wang, & R., 2019):

1. a first category of risks is closely related to BRI Policy. This category includes geopolitical risk, loan risk, and cooperation between China and BRI country. Risks related to BRI Policy are outside of the project, thus their influence is uncontrollable;
2. a second category that consists of risks outside of the project. This category includes economic risk, political risk, law risk, cultural and social differences, and weather;
3. in the third category, environmental risks are considered. Environmental risks on construction sites are soil pollution and site contamination, noise and vibrations, and complex geological conditions of terrain;
4. another category includes design errors and changes in design;
5. the fifth category of risks is related to the construction process and it consists of risks related to the construction site, construction materials, equipment, and quality of construction works;
6. the last group of risks is connected with human resources and management of the project. In this group, the lack of labour, poor planning and management by project manager, poor team communication, accident occurrence, and lack of safety measures on the site are analysed to efficiently manage the project.

In addition, it is necessary to include the risks related to the investment sector and which must be considered in the economic analysis useful to verify the feasibility of the project. Any proposed project may be able to show, for example, how its expected EIRR/ENPV has a particular probability of being acceptable depending on the values for some key variables, or that its expected cost- effectiveness is similarly dependent from unknown results but described in a probabilistic way. The following table 14 describes by sector/type of project:

i. Examples of likely analytical concerns;
ii. Potential key variables to investigate;
iii. Externalities to be considered in the analyzes.

Table 14. Key variables and externalities by sector/type of project (source: own elaboration based on information from Asian Development Bank and European Commission, 2014)

Sector/Project Type	Examples of Likely Analytical Concerns	Potential Key Variables to Investigate	Costs/Benefits to be considered in the analyzes
Agriculture: Plantation	Realized tree crop yields and production; factory/mill throughput; future prices as determinants of farmers' and/or estates' incomes	Price projections; tree crop yield estimates; machinery operating capacity/efficiency	– The principal benefits of agriculture sector projects consist of increased output resulting from improved productivity or enhanced yields and reduced unit production costs or losses. The economic price for each is measured at the farm gate level, by adjusting the world price for transport, distribution, and handling costs from the border or from the port to the farm – Estimate of the value of water for irrigation in terms of shadow price
Agriculture: Irrigation	Scheme maintenance; realized new and existing crop yields; crop prices; adoption/uptake rates; household and farm incomes	Operating/water supply costs; yields and prices (as above); Willingness to pay (WTP) estimates for water demand; adoption/uptake of new varieties	

Energy: Rural Electrification	Operating costs, consumer price elasticity of demand	Capital and operating costs; consumers' demand schedules	– Increase and diversification of energy supply to meet the increase in demand – Increased security and reliability of energy supply – Reduction of energy costs through the replacement of energy sources – Greater energy efficiency – Change in GHG emissions – Change in emissions of pollutants
Energy: Power Generation/ Transmission	Costs of inputs; poor maintenance of equipment; consumer demands for power	Costs of equipment; input prices; operating efficiency; consumer demands	
Environment and Natural Resources: Various	Extent of identification, quantification and valuation of indirect, non-use and option impacts of total economic value (TEV)	Quantities of particular biophysical impacts; alternative methodologies for benefit estimation	– Improvement of health conditions (Statistical value of life) – Productive use of land (market value) – Increase in recreational value (Travel cost method) – Preservation of ecosystems and biodiversity (Transfer of benefits /Declared preferences) – Damage reduction (Average avoided damage/risk insurance premium) – Increase in property value (hedonic price)
Urban: Water Supply and Sanitation/ Wastewater /Solid Waste	Construction costs; value to consumers; willingness of authorities to pursue policy reforms (e.g., charges for service provision)	WTP estimates; probability of success of implementing institutional reforms	– Greater availability of drinking water provided and/or sewage services (defensive expenses/ costs saved) – Savings in the use of water resources (water saved for alternative uses, long-

			term marginal cost for water production) – Impacts on health (declared preferences) – Change in greenhouse gas emissions (shadow price)
Transport: Rural Roads	Construction costs in difficult or unknown environment; traffic composition mixtures; extent of generated traffic and vehicle operating cost (VOC) savings	Quantities of particular biophysical impacts; alternative methodologies for benefit estimation	– Travel time savings (preferences declared, cost saved) – Reduction of vehicle operating costs (market value) – Carrier operating costs (market value) – Reduction of accidents (declared preferences, human capital approach) – Variation in noise pollution (Compensation of willingness to pay / willingness to accept, hedonic price method – Change in air pollution (shadow price of air pollutants) – Change in greenhouse gas emissions (shadow price of greenhouse gas emissions)
Transport: Highway/Toll Roads	Construction costs, price elasticity of demand for new road use; currency depreciation for loan repayment; sustainability of road authority	Construction cost estimates; traffic volumes by types of vehicles; vehicle operating costs (VOCs)	
Transport: Railways and Ports/Shippin g	Future passenger and/or freight volumes; extent of maintenance, operating costs	Contractor's/ analysts' estimates allow for several states of costs; price elasticity of demand for road use; foreign exchange projections	
Forestry	Volume of harvestable wood in 7-20 years time, and price of output (e.g., pulp/wood) at that point	Wood and by-product yields, losses to theft, harvest efficiency, etc. as determinants of production in future periods	– Change in greenhouse gas emissions (shadow price of greenhouse gas emissions) – Change in CO_2 (shadow price of greenhouse gas emissions) – Evaluation of ecosystem services

Fisheries	Impact of new culture technologies from aquaculture; future stocks and landings from capture; fish prices; determinants of fishermen's incomes	Harvest yields and fish stocks; commodity price projections and local variety	– Preservation of ecosystems and biodiversity (Transfer of benefits /Declared preferences)
Health: Primary Care	Service uptake rates; extent of cost recovery from rural poor; benefit estimation methodology (if applied in EIRR calculation)	Use of services and consumer demand/ ability to pay; estimated WTP	– A satisfactory measure of health impact from an intervention must combine mortality and morbidity effects, through lower fatalities and less illness, across different patients, and weigh these in some way. The disability adjusted life years (DALY) measure is the one commonly used in development projects, and discounted cost per DALY saved is the most common approach to costeffectiveness for health projects
Education: Secondary and Post-secondary	Nature of beneficiaries' ultimate employment and the income differentials arising from such employment	Employment rates; income differentials	
Education: Teacher Training	Numbers ultimately failing to find or accept work as teachers after training	Policies such as school construction/funding programs; on-going institutional changes; employment rates	– Economic benefits can include resource cost savings through system improvement, higher employment, and increased labor productivity and earning opportunities – Intangible social benefits can include a healthier lifestyle, greater gender equity and social mobility, and more tolerant cultural attitude

6. Economic analysis with the Environmental Performance Index and Stochastic Growth Rate of Consumption Model: Case study for Chinese urban development investment

Summary

The investment risk assessment model shown in chapter 4 is here validated on an investment program for the development of inclusive green spaces in the Municipality of Zyiang in the province of Sichuan (China). The program aims to improve the urban environment and the liveability of the municipality as well as promote high quality economic growth on a more inclusive green development path. The technical and economic feasibility study was conducted by the Asian Development Bank (2018). The project intends to play a demonstration role for medium-sized cities with similar conditions in the Yangtze River Economic Belt (YREB) in the People's Republic of China.

This chapter is structured as follows. Section 6.1 describes the investment program and the sub-projects of which it is composed. Section 6.2 returns the results of the financial analysis, while Section 6.3 explores the economic feasibility study. Based on the results obtained, in Section 6.4 the economic risk assessment model is implemented on the investment sub-initiatives that are not sustainable or that in any case do not return a sufficiently high EIRR. Here it is made clear how the joint use of the ALARP logic and time-declining environmental discount rates can guide the analyst and orient him towards more sustainable investment choices.

6.1. Rationale and outputs of the investment program

The investment programme under analysis aims at the development of inclusive green spaces in Zyiang Municipality, which is in a strategic point of the Yangtze River Economic Belt (YREB) in turn along the BRI route, concerns the urban development investment sector. This is a multi-sector project that includes subcomponents such as water supply and sanitation, wastewater treatment, solid waste management, urban rehabilitation, and environmental improvements (ADB, 2016a; 2016b).

The YREB is one of the three main engines of economic growth in the PRC. It is made up of nine provinces – Sichuan, Guizhou, Yunnan, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, and Zhejiang – and two municipalities - Chongqing and Shanghai. It covers about a fifth of the Chinese territory and has a population of 600 million, generating over 40% of the country's GDP. Its nine provinces and two specially administered municipalities thus represent over 40% of the population, 40% of freshwater resources and about 45% of the country's economic output. And it is the city of Chongqing that is the junction between the YREB and the Belt and Road Initiative.

Chongqing, one of the central cities of China's according to the national urban system planning, is located at the conjunction of the Yangtze River Pathway and the Baotou - Kunming Route in China's strategic layout of urbanization, known as the "Three Horizontal and Two Vertical Route Network". As for its important strategic location, Chongqing serves as a strategic pillar on the Yangtze River Economic Belt, the "Silk Road Economic Belt" and the "Maritime Silk Road of the 21st Century", which are developed based on the Yangtze River Golden Waterway and the Eurasia Land Bridge respectively. It is the support of the development and opening of the Western China, the west hub of the Yangtze River Economic Belt, the core of Chengdu-Chongqing City Cluster as well as the pilot zone for China's comprehensive reform of urban and rural areas. Chongqing is a central city of China's nine major logistics areas, also one of the 21 national logistics node cities, and the economic center on the upper reaches of Yangtze River. It will embrace the strategic opportunities of "The Belt and Road" to open itself to a wider outside world and to build itself into a window of the inland.

Returning to the specific problems of the YREB, it has been characterized by a profound development since the end of the 1980s, in particular in the eastern delta area. Conversely, the economic growth of the central and upper parts of the Yangtze River basin appears to lag that of the coastal areas. These areas of the YREB still face significant development challenges due to:

i. increasing pollution and pressure on natural resources;
ii. slow transformation in green development and economic

diversification;

iii. limited integration of waterways, ports and intermodal logistics;
iv. weak institutional coordination for strategic planning.

In short, the YREB is facing a growing imbalance between economic performance and environmental quality (ADB, 2018).

To promote economic development and environmental improvement of the upper and middle parts of the YREB, the Asian Development Bank (ADB) has worked in partnership with central and local governments, agreeing to adopt a framework approach. This agreement sets out to provide approximately $2.0 billion in YREB funding over the period 2018-2020 to strategically plan ADB loan support for YREB development initiatives. In doing so, priority is given to the following four areas:

(i) ecosystem restoration, environmental protection and water management;
(ii) inclusive green industrial transformation;
(iii) construction of an integrated multimodal transport corridor;
(iv) institutional strengthening and political reform.

In this context, ADB and the government identified two cities in the upper YREB—the Chongqing and Ziyang municipalities—as suitable candidates for the partnership (ADB, 2017b).

These are two municipalities of very different sizes, respectively of 31 million and 3.6 million inhabitants, but which at the same time face common problems in their economic transition path towards a high quality and more inclusive development path.

It has already been mentioned that the Inclusive Green Development Project in the municipality of Ziyang intends to: (i) improve the liveability of the place; (ii) allow high quality economic growth based on a more inclusive green development path.

This inclusive green development is defined as an integrated approach encompassing sustainable, resilient, accessible, and affordable solutions to the challenges faced by the urban poor and vulnerable groups by enhancing their access to urban services and infrastructure through targeted investments.

This integrated approach encourages an institutional delivery mechanism that brings together all institutions and stakeholders—government, the private sector, and civil society—that have the capacity to deliver systems for inclusive urban service delivery (ADB, 2016a).

Ziyang is a medium-sized municipality that is part of the upper part of the YREB, with a population of 3.6 million inhabitants in 2017, an average per capita income of $2,900 and an area of 5,747 square kilometres, covering hilly land. traditionally used for agriculture. Its centre extends on both banks of the Tuo River, which is a major tributary of the Yangtze River. The city's economy has long been dominated by heavy industries for decades has substantially burdened the Tuo River. Numerous industries have developed along the Yangtze River and its tributaries since 1978, using the waterway as easy access to water resources and low-cost transportation, as well as an easy solution for waste disposal. The upper and middle parts alone account for 80% of the total YREB wastewater discharge.

It follows that the conventional industrial structure and the increasingly rigorous application of environmental laws and policies have led to an unstable labor market that is unable to meet the growing demand of the local population. The Municipal Government therefore needs support to:

1. *tackle the task of improving the damaged ecological environment*. Past industrialization and the resulting increase in wastewater discharge and air pollution have put pressure on the environment. Changes in land use have led to erosion of riverbanks, flood hazards and dwindling vegetation, all aggravated by global climate change. The urban area has grown significantly as economic activity intensifies, so the landfill, a polluted body of water that includes Yannan Lake, is now part of the Ziyang urban centre. Immediate action is needed to rehabilitate the ecological situation, provide green spaces and improve water quality, rainwater management and liveability. In general, ecological restoration, reduction of pollution and improvement of water quality of the Tuo River are part of the national commitment to promote ecological protection and green development in the YREB;
2. *promote the service sector and consequently the creation of jobs at local level*. Moving the engine of growth from heavy industries to the service sector is essential for the municipality's economic transition. Also thanks to its location within the Chengdu-Chongqing urban cluster, Ziyang aims to develop and diversify a service industry (e.g.

health, aviation, hospitality, leisure sports and rural e-commerce) that is respectful of the environment and can create jobs. Ziyang has around 1.1 million migrant workers, representing a third of its 3.6 million inhabitants. It also has significant gaps in human resources skills due to the limited relevance of its technical and vocational education and training (TVET) program, which hinders its efforts towards its development. Businesses need many skilled workers. The interventions of the TVET project are essential for the retraining of returning migrants; and to provide local people, including the poor and women, with jobs in the upcoming service industry;

3. *improve the planning and management of urban development*. This is crucial for achieving the goal of inclusive green development, i.e. the transition from highly polluting heavy industries to ecological services. Indeed, the city has a complex and fragmented urban planning and management system that does not have an effective mechanism for sharing integrated data and information. As the local economy expands, the administrative and environmental management challenges will increase, requiring stronger urban development planning and management systems. Consequently, the support of Information Technology (IT)–based planning and monitoring and evaluation of environmental performance systems is essential.

To meet these needs, the investment program includes multiple sub-projects, through which three outputs are achieved. Figure 24 shows the location of the interventions, described in detail below.

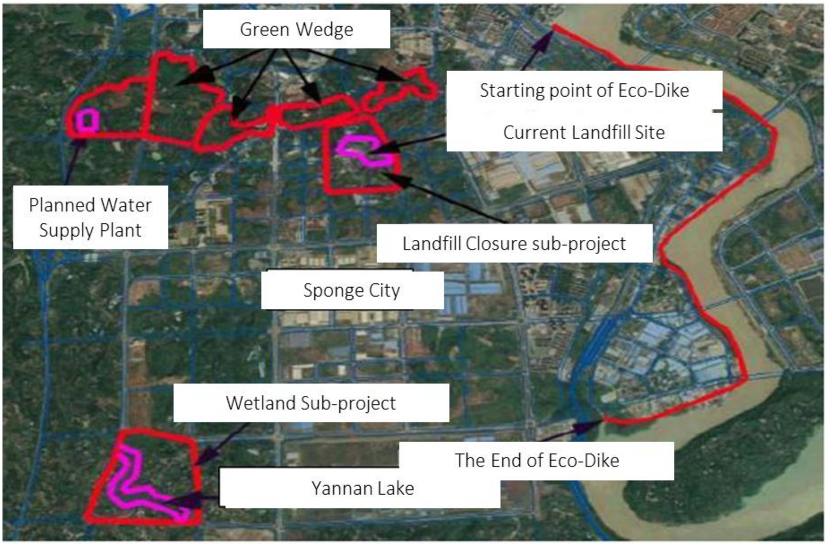


Figure 24. The sub-projects locations (source: ADB's Environmental Impact Assessment)

Output 1: Ecological systems and environmental infrastructure constructed. This output will help stem the degradation of public infrastructure by rehabilitating and developing urban environmental infrastructure. This includes the following six sub-components.

1. Building 5 kilometres of "eco-dike" or flood-control embankment to comply with the requirement for protection against a 1-in-50-years flood event. An eco-embankment uses landscaping to reduce wave action that might surge over the embankment and to provide soil stability for reducing erosion. The proposed embankment is 4.9 km in length on the left side of the Tuo River. The hydraulic analysis calculates an embankment height from 352.87 m to 357.75 m and an additional 0.97 m to 1.24 m for safety. The base of the embankment is hardened and buried to depth of 3 m and the soil conservation plan has been prepared. Figure 25 shows the project details.

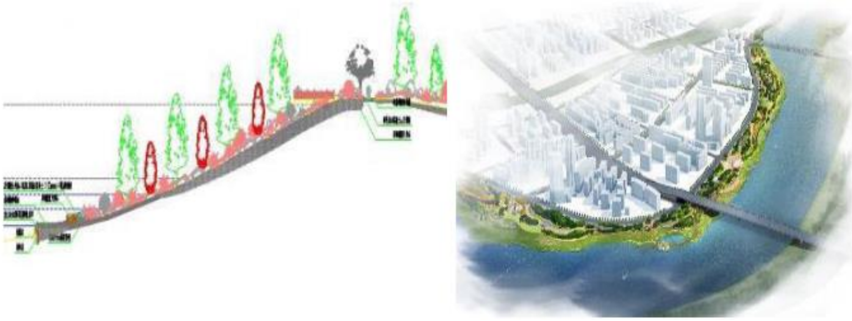


Figure 25. The "Eco-Embankment" sub-project (source: ADB, 2018, Environmental Impact Assessment)

2. Building an 18-hectare (ha) area of "sponge city" interventions to capture stormwater. Sponge city refers to a city that is designed to passively absorb, clean, and use rainfall. The sponge city interventions refer to the replacement of concrete pavements with wetlands, green rooftops, and rain gardens to absorb the stormwater back into the land. The total treated area is at least 18 ha of detention basins to capture stormwater. The storm water runoff can be naturally filtered by the soil as it reaches the groundwater aquifers. The scope of this component includes 10 existing roads with the total length of 13.95 km and the total area of 26 km^2. The component involves constructing sunken greenbelt with a total area of 180,950 m^2. In Figure 26 project details are showed.

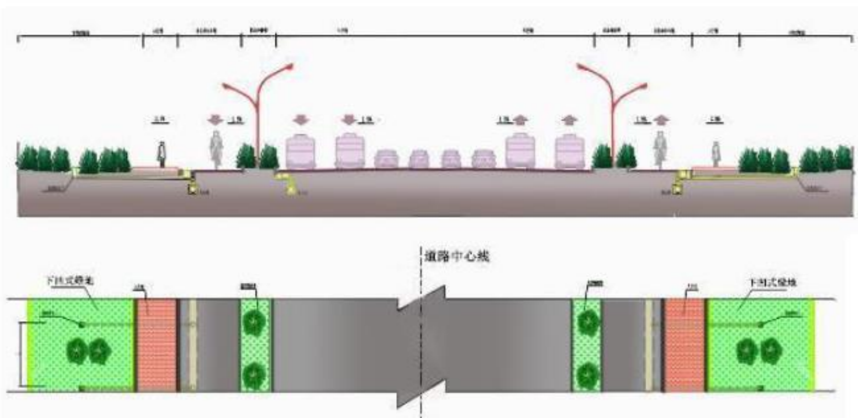


Figure 26. The "Sponge City" project (source: ADB, 2018, Environmental Impact Assessment)

3. Developing and protecting a 25.7 ha wetland area to improve Yannan Lake's water quality and 3.0 kilometres of the Kongzi River in the upper stream, overall to enhance the ecological system. The intervention areas are two: 1) 13.67 ha; 2) 6.07 ha, respectively; the depth of the lake is 1–3 m, and the total catchment area is 4.5 km^2. The designed wetland area is equal to 25.73 ha, including 19.73 ha of water surface area. The major impact factors to the performance of the proposed Lake wetland restoration include: controlling and eliminating pollution sources within the catchment area of the lake; maintaining and improving the water quality; and establishing and strengthening the operation and management of the wetland after the construction completion. See Figure 27 for project details.

Figure 27. The "Wetland area" project (source: ADB, 2018, Environmental Impact Assessment)

4. Closing a landfill and transforming the land into 38.6 ha of green park. Specifically, the project consists in the closure and restoration of the existing and operational sanitary landfill site and the transformation of green public open space on the restored landfill area and surrounding rural area. The situations of the existing landfill are: the current daily disposal capacity is 400 tons, including household waste from municipalities adjacent to the urban area; the total estimated waste in landfills is approximately 1.4 million tons. Activities before and during construction

include: specific monitoring of groundwater quality to identify whether the surrounding groundwater is polluted by the landfill or not; safety inspection and identification of the existing dam; levelling and covering of the landfill area; provision of drainage and insertion of vegetation on the 37-hectare landfill; maintain ongoing landfill gas extraction and treatment of leachate which may have to continue to operate for 13-20 years after landfill closure. Figure 28 shows the landfill area working scheme after closure and the restoration.

Figure 28. Landfill area after closure and restoration (source: ADB, 2018, Environmental Impact Assessment)

5. Creation of a green wedge on 123 hectares of undeveloped hills and gullies as a natural barrier between the old residential and industrial areas of the city. This will improve the urban environment, as well as provide a recreational resource for the community. The remedial works at eight sites will (i) provide stabilization and ground cover, and (ii) reduce vulnerability to weather events. This will involve ecological greening restoration, including grassing, vines, and coconut fibre mesh reinforcement. The existing mountain and gully area is a natural barrier between residential and industrial areas, forms an "urban green lung", improves the urban environment, and can also be a public place for citizens to enjoy nature. The total area is planned to be 123 ha. The eco-restoration (e.g., return cultivated areas to forest; restore illegal dumpsites) is 110 ha and the promotion development component (roads, parking, service-oriented

facilities such as toilets) about 13 ha. The green wedge is planned to spatially coordinate with the green landscaping of the closed landfill and Lake Wetland to form an area for the construction of new city green space. Fig. 29 shows an overview of the Green-Wedge.

Figure 29. Overview of the Green-Wedge (source: ADB, 2018 Environmental Impact Assessment)

6. Preserving the ecology of eight bare hills that are at risk of erosion (Ecological preservation of hilly areas). Improper excavation for roads, buildings, and borrow earth have resulted in earth mounds 30–80 m high, with bare, steep slopes that are vulnerable to soil erosion and have potential landslide. Increased precipitation and more extreme storms will result in even more erosion and perhaps sudden subsidence with landslide. The proposed works at nine sites will provide stabilization and ground cover and reduce vulnerability to weather events. The work involves ecological greening restoration, earth shaping as needed, and drainage. Figure 30 shows *post* interventions of bare hills.

Figure 30. Post restoration of bare hills (source: ADB, 2018, Environmental Impact Assessment)

Output 2: Facilities and programs to support the service industry broadened. This output will remove obstacles to city's emergence as a high-quality and more inclusive green development. This includes establishing:

1. a Research and Development (R&D) center for light industries. Equipment and/or instruments will be provided for five specialty laboratories and seven supporting platforms to facilitate innovation. The five specialty laboratories will be equipped with instruments, equipment, digital engineering, etc. to facilitate innovation;
2. a centre for inspecting and testing equipment and materials. This includes equipment for the following: (i) active testing laboratory for electromagnetic compatibility, electrical safety inspection, active implant medical device, and other professional testing for medical devices testing; (ii) passive testing laboratory for implantable medical devices testing, chemical testing room, physical testing, environmental test, and biological evaluation laboratory; and (iii) animal experimental laboratory;
3. the Technical and Vocational Education and Training (TVET) center, with capacity for 4,000 full-time students. The project includes: student hostel (26,097 m^2); professional teaching practical exercises classrooms (17,557 m^2); educational building (13,902 m^2); underground buildings

(9,071 m^2); and logistics and ancillary rooms (9,672 m^2) for 4,000 students and 170 teachers.

Points (1) and (2) are expected to reduce the time it takes for a product to reach the market and will be guided by existing institutional frameworks in the PRC. Point (3) will increase the relevance and quality of secondary TVET with updated curricula, improved qualifications framework, updated accreditation and evaluation systems, and capacity building for teachers and managers. Skills retraining and lifelong learning courses are also planned for workers, while younger generations will benefit from full-time TVET training. The TVET center includes construction of 14 buildings, with the total land area of 13.33 ha and building construction area of 94,146 square meters (m^2). The project buildings of the TVET center will comply with relevant design standards and codes for energy-efficient, environment-friendly, safe, and green public buildings.

Figure 31 shows the project rendering.

Figure 31. TVET photo rendering (source: ADB, 2018, Environmental Impact Assessment)

Output 3: Urban development planning and management capacity enhanced. This output will overhaul the outdated and inefficient systems for urban development planning and management, and performance Monitoring and Evaluation (M&E). It includes:

1. installing a computerized urban development planning and management component (intelligent park platform—a SMART information system—that provides modular, web-based, interactive, and decision-making support for better management of government operations, the environment, and information sharing). The SMART information system will be equipped with state-of-the-art hardware and software to support a government data management and office system, economy (one-stop enterprise service platform) to promote electronic commerce within the city, management support system, and environmental system. The SMART information system also helps in setting up a government services system that improves efficiency, transparency, resource sharing, and management. All systems will be monitored throughout implementation along clearly defined performance-based benchmarks;
2. setting up an effective urban performance M&E system, including the key performance indicators to measure the performance of the city's master planning and development process;
3. undertaking a comprehensive study on urban green development planning, including a comprehensive gender study. The master plan would serve as a guide for the socioeconomic development in the growth of the municipality, particularly for improved environment, social inclusion and gender mainstreaming, municipal services, urban living conditions, and business development opportunities (ADB, 2018).

6.2. Demand analysis

The Municipality in question is in the midpoint of the Chengdu-Chongqing urban district. is an important industrial city, leader in the export of motorcycles, in the production of cars and its components, in energy saving, in the distribution of food, in the tourism and leisure sector and in general holds the place of development demonstration area innovative economic in Sichuan province.

Subproject "Eco-Dike" (embankment)

Tuo River flows through the municipality with flooding every year. During the period 2009-2013, the annual average direct economic loss caused by the flood disaster was CNY 452 million. Considering that from 2014 to 2017 flood disasters occurred every year with an annual average direct economic loss of 15.3 million CNY. Part of the reduction can be attributed to improved flood protection.

In 1999, the municipal government commissioned a design institute to prepare a flood control plan for the Tuo River. The project envisaged an embankment in the urban area of the Municipality of approximately 10.59 km in length. In this plan, the left bank of the Tuo River was designed according to a flood control standard with a return period of 20 years, and the right bank with a flood control standard with a return period of 50 years. In the following years there has been a rapid urban development which has enlarged the urban area and the flood protection and control embankments proposed in 1999 are no longer adequate. As a result, in 2011 the City commissioned the Sichuan Provincial Institute of Water Resources and Hydroelectric Design to prepare an updated flood control plan for the Tuo River.

Under this revised plan, an additional 17,093 km of embankments have been proposed. However, of the various embankment sections proposed in the 1999 and 2011 plans, not all recommendations have been implemented. This sub-component, therefore, addresses the improvement and beautification of a 6.84 km length of the right bank of the Tuo River, including raising the embankment to provide better flood control and protection. The actual embankment is 5.0 km but the planned works extend over the entire length of 6.84 km.

Subproject "Sponge" city interventions

The local water resources of the Municipality are 1.571 billion cubic meters (m^3); and the water resources per square kilometer is 273,000 m^3. The drainage network, drainage pumping stations, and other facilities of the city are low in running capacity, ageing, and plugging; and they do not meet proper drainage capacity, resulting in poor drainage and low flow rates. It is extremely easy to result in water-logging in extreme weather conditions. The peripheral river systems are seriously affected by plugging. The excess rubbish and mud occupy most of the river's space, resulting in a significant reduction in river flood storage capacity. The water level of the river rises rapidly during heavy rain caused water-logging.

The concept of a “sponge city” is based on diverting rainwater from storm water drains, or delaying its discharge into the city drainage system, with the rainfall in the urban environment being detained and allowed to “soak” into the ground (with the ground acting like a sponge). Ultimately, the water that percolates into the underlying ground strata should contribute to replenishing the groundwater aquifer. In concept therefore, a “sponge city” helps to reduce rainwater runoff from hard surfaces during storm conditions, with the water being available as a groundwater resource during periods of drought.

As the urban development of the Municipality has expanded, many impermeable surfaces have been created because of new building developments, roads, footpaths, and car parking areas. Rain, which previously was falling on agricultural land, woodland and other open areas, is able to flow rapidly across impermeable areas and then is channelled into storm water drains, and ultimately reaches the Tao River. Whereas rainfall was previously being trapped in low-lying areas in these undeveloped tracts of land, and being allowed to soak into the ground, the newly paved surfaces are accelerating the passage of water into the Tao River, exacerbating peak flows and flood events.

Subproject “Wetland area development”

Both the Yingjie Reservoir and Yannan Lake are used for irrigation and flood control. There is aquaculture in both. However, both the water bodies and the connecting stream are severely polluted with water quality worse than Grade V (the lowest category), such pollution is the result of the runoff of agricultural fertilizers, animal waste and improper sanitation, e.g. the lack of septic tanks.

The water quality needs to be improved so that the seized water can be used safely for irrigation and to reduce the pollution flowing into the Tuo River. The immediate goal is to achieve water quality grade IV and finally grade III. There are several agricultural lands, fish ponds, agricultural crops and livestock industries that invade the banks of the river and the slopes around Lake Yannan. The disordered construction waste on the lake shores and the living waste of visitors pollute the water sources, damaging the water quality of the lake and the ecological habitat of the water, as well as occupying the space of the aquatic ecosystem. The ecological habitat of the water is considerably bad. Many water bodies are severely eutrophicated.

The municipal government issued a pledge in March 2018 that prior to the construction of the wetland, all sources of pollution will be closed or eliminated to meet the national standard.

Subproject "Landfill Closure, Restoration, and After-Use"

The main structure of the landfill is silty clay and mud. Due to the geology, the infiltration prevention effect is relatively good. However, due to material limitations of the waterproof system and aging and damage of long-term operating equipment, some leachate infiltrates resulting in an impact on groundwater quality. The leachate treatment station is far from adequate. Leachate that cannot be treated in time is stored in the leachate regulation tank.

The landfill, which covers an area of approximately 17.5 ha, is surrounded by wooded areas and agricultural land, together with some houses and farm buildings. In the general development plan, the landfill is in the center of an approximately rectangular tract of land. The proposed roads will delimit the rectangular area around the landfill, which in total (including the landfill) will cover approximately 37 hectares.

Supbroject "Green Wedges"

The hilly area and existing canal in the Municipality analyzed constitutes a natural barrier between the residential historic center and the southern productive part. This area forms an "urban green lung", improves the urban environment and can also be a public place for citizens to enjoy nature. The green wedge is designed to spatially coordinate with the green landscape of the closed landfill and wetlands of Yannan to form an area of green space.

The proposed sub-component of the green wedge is in the hills of the site, with several rough terrain and bare hills that can cause landslides. To prevent potential disasters and to facilitate the construction of subsequent vegetation communities to enhance the sense of beauty, ecological restoration of existing mountains must be carried out in two ways: engineering measures and vegetation restoration. For non-basic agricultural land, the transfer of agricultural land to forests should be adopted to restore the original natural features of the site. Two waste disposal sites within the site are expected to use ecological methods to accelerate the secondary succession of the site and restore the ecological community as soon as possible.

After the completion of the ecological restoration of the green wedge, it is possible to carry out small developments and reconstructions in the increasing regions to satisfy the recreational functions of the surrounding population and improve the living conditions of the municipality.

Subproject "Ecological Preservation of Bare Hills"

In the wake of the development of the Municipality, the excavation of the mountain destroyed the original vegetation cover, resulting in the emergence of a large area of exposed mountains, which became a scar in the city. This not only affects the environmental landscape of the Municipality, but also causes a series of ecological problems such as soil erosion, landslides, obstruction of municipal pipeline networks, silting up of basins, etc. Improper excavation of roads and buildings and the development of lending shafts (to provide land to fill low-lying areas) has resulted in a series of steep, vegetation-free slopes that are vulnerable to weathering and soil erosion by wind and to water. Increased rainfall and more extreme storms could cause even greater erosion and possibly a sudden slope failure.

Subproject "Research and development platform for equipment for light industries"

Entrants in high-technology, capital-intensive light industry tend to incur large sunk costs, in addition to administration and regulation-related barriers. Moreover, development of a light industry sector entails substantial investment for research and development (R&D), product development, and human resources. The incubation center is expected to build up an expert and professional expertise team for product evaluation, product transformation, investment and financing services, human resource services, and marketing. It is intended to provide one-stop full service for product research and development.

Subproject "Center for testing and inspection of equipment materials for the service industry"

Currently, there are 53 medical device inspection and testing centers in the PRC and most of them are located in Beijing, Shanghai and Guangzhou. In Sichuan Province, Sichuan Medical Equipment Testing Center is responsible for testing and certification of medical equipment and products. However, the existing inspection and testing center does not have sufficient capacity and lacks some specialized equipment, thus requiring manufacturers to send their products to other locations for testing. The location of the inspection and test center near the medical equipment companies in the municipality saves them time in having their products inspected and tested. The turnaround time is less than 1 hour, and the new center has a larger capacity than the nearest medical device testing center, which is located in Chengdu.

Subproject "Technical and Vocational Education and Training center (TVET)

Over the past five years, the number of enrollments and graduates in secondary vocational education in the municipality has shown a trend of rapid decline. The number of enrollments fell from 42,554 to 19,942 and the number of graduates has continuously decreased from 17,682 in 2015 to 12,239 in 2017. The reasons for this decline include: decrease in the school age population; a higher percentage of lower secondary school graduates chose to attend general upper secondary school; Vocational, educational and training (VET) secondary schools have quality problems, such as outdated structures, VET teachers lacking industrial experience and curricula that do not meet the real needs of businesses. It also appears difficult for VET students to obtain higher education opportunities, and a lack of student interest in professions such as construction for which there is a great demand but seen as dirty, noisy, requiring hard physical work. with low pay. Since secondary vocational education does not understand the needs of businesses and lacks channels to connect businesses, the municipality's vocational education is supply-oriented, which cannot meet the needs of economic and social transformation and development.

6.3. Financial analysis and management of the investment program

The estimate, conducted jointly by the administrative committee of the Municipality and by ADB, shows that it is estimated that the project will cost $413.54 million, including taxes and duties of $26.64 million. The main items of expenditure are civil works and the acquisition and resettlement of land (LAR).

The government requested a regular $200 million loan from ADB's ordinary capital resources to help finance the project. The loan will have a duration of 25 years, including a grace period of 6 years. The annual interest rate is determined in accordance with ADB's line of credit based on the London Interbank Loan Rate (LIBOR), with a commitment fee of 0.15% per annum. Based on the straight-line repayment method, the average duration is 15.75 years and the maturity premium due to ADB is 0.10% per annum.

ADB will finance civil works, assets, capacity-building activities, and consultancy services, while the government will finance design, procurement activities, construction management, civil works, project management, LAR, environmental protection, interest and commitment charges, fees and taxes and contingencies, as well as ensuring that counterpart funds for the project are provided in a timely manner.

In addition, climate mitigation is estimated to cost $3.48 million and climate adaptation $0.31 million. ADB will finance 80.66% of the costs of climate adaptation and mitigation.

The following key assumptions underpin the cost estimates and financing plan.

- Exchange rate: CNY 6.46 = $1.00 (as of March 16, 2018).
- The price contingencies, which were based on the cumulative inflation expected in the implementation period, are as follows:
  - Foreign rate of price inflation = 1.6%;
  - Domestic rate of price inflation = 2.3%.

The following table 15 shows the detailed estimate of costs by category of expenditure. Appendix 3 reports: detailed cost estimates by financier (A.3.1); detailed cost estimates by outputs (A.3.2); detailed cost estimates by years (A.3.3).

The sustainability of all sub-projects depends on an effective O&M of the infrastructure. The responsibility for the operation and maintenance of the infrastructure and equipment provided in output 1 and the equipment provided in output 2 rests with the municipality of Ziyang. The ADB analysed economic growth trends and total income and expenses (in and out of budget and transfers). Based on the Council's past financial performance, it has been verified that it will be able to provide counterpart financing during implementation and pay for debt service and O&M funds after the completion of the project.

The financial viability analysis refers to the estimated counterpart funds and expected tax revenues during construction, O&M expenses during operation and the comparison between the reimbursement amount and the expected financial expense. Table A.3.4. in Appendix 4 shows historical tax income and expenses while Table A.3.5 shows the projections.

The financial viability assessment indicates that the Municipality under consideration had sufficient funds to finance the counterparty contributions, debt service and O&M costs during operation. Therefore, the required O&M budget level was assessed as affordable.

Table 15. Estimate of costs by category of expenditure (source: ADB, 2018)

		(CNY million)			($ million)			
	Item	For. Exc.	Local Currency	Total Cost	For. Exch.	Local Currenc y	Total Cost[5]	Percent of Total
				A. Investment Costs				
1	Civil works, loan-based	0.00	1,056.97	**1,056.97**	0.00	163.62	**163.62**	39.57%
	TVET	0.00	204.38	**204.38**	0.00	31.64	**31.64**	7.65%
	Others	0.00	852.59	**852.59**	0.00	131.98	**131.98**	31.91%
	Civil works, non-loan (TVET)	0.00	39.03	**39.03**	0.00	6.04	**6.04**	1.46%
2	Equipment, loan-based (Others)	71.77	287.08	**358.85**	11.11	44.44	**55.55**	13.43%
	Equipment, non-loan (TVET)	0.00	8.00	**8.00**	0.00	1.24	**1.24**	0.30%

[5] Includes taxes and duties of $26.64 million. The government will finance taxes and duties of $4.43 million, and ADB will finance the remaining balance.
Source: Asian Development Bank estimates.

3	Land acquisition, compensation, and resettlement	0.00	649.58	**649.58**	0.00	100.55	**100.55**	24.32%
4	Survey, design, and supervision	0.00	153.39	**153.39**	0.00	23.74	**23.74**	5.74%
5	Consulting services	27.29	0.00	**27.29**	4.23	0.00	**4.23**	1.02%
	Subtotal (A), Total Base Cost	**99.06**	**2,194.05**	**2,293.11**	**15.34**	**339.64**	**354.98**	**85.84 %**
B. Contingencies								
1	Physical contingency	4.95	77.25	**82.20**	0.77	11.96	**12.72**	3.08%
2	Price contingency	4.40	133.19	**137.59**	0.68	20.62	**21.30**	5.15%
	Subtotal (B)	**9.35**	**210.44**	**219.79**	**1.45**	**32.58**	**34.02**	**8.23%**
C. Interest and Commitment Charges								
1	Interest during implementation	0.00	153.83	**153.83**	0.00	23.81	**23.81**	5.76%
2	Commitment charges	0.00	4.73	**4.73**	0.00	0.73	**0.73**	0.18%
	Subtotal (C)	**0.00**	**158.56**	**158.56**	**0.00**	**24.54**	**24.54**	**5.94%**
	Total Project Cost (A+B+C)	**108.41**	**2,563.05**	**2,671.46**	**16.78**	**396.76**	**413.54**	**100%**

6.4. Economic analysis of the investment program

The economic analysis of the project was conducted in accordance with ADB's guidelines on the economic analysis of projects. The assumptions utilized in the economic analysis are the following:

1. All costs were based on constant 2019 prices;
2. Economic costs of capital works and annual operation and maintenance (O&M) were calculated from the project cost estimates; and price contingencies, financial charges, and taxes and duties were excluded in the analysis; but included physical contingencies;
3. The economic cost of capital was assumed at 9%;
4. Analysis was conducted from 2019 to 2045, including 6 years of construction and 20 years of operation.

Estimate of economic costs. The economic cost comprises investment costs (civil works, machinery and equipment, land acquisition and resettlement, environmental protection, survey and design, consulting services, and training); and O&M costs (maintenance and repair, labour, chemicals, and utilities, among others). The detailed conversion factor for each category is shown in the following table 16.

Table 16. Conversion Factor for Civil Works (source: ADB, 2018)

Item	%	Conversion Factor
Material traded	40	1
Non-traded material	10	0.987
Skilled labor	10	1
Unskilled labor	20	0.67
Others	20	0.987
Total	100	0.9301
Conversion Factor for Project Management		
Item	%	Conversion Factor
Skilled labor	60	1
Unskilled labor	20	0.67
Others	20	0.987
Total	100	0.9314
Conversion Factor for Survey and Design		
Item	%	Conversion Factor
Skilled labor	60	1
Unskilled labor	10	0.67
Others	30	0.987
Total	100	0.9631
Conversion Factor for Equipment and Others		
Item	%	Conversion Factor
Equipment	100	1
Others	100	0.987

Estimate of economic benefits. The following economic benefits were considered in evaluating the economic viability of the proposed project investment by subcomponent. Benefits are both direct and indirect, though not all have been quantified.

Economic benefits considered include:

- accelerated growth in the light and service industries;
- improved efficiencies (time-saving) in the testing of equipment for the light industries;
- incremental income from the TVET;
- improved flood protection and avoided damage;
- environment benefits of the increased urban green spaces;
- increased water savings in the sponge city;
- avoidance of costs of poor water quality on human health through wetland development;
- methane capture from the landfill closure;
- avoided traffic interruptions caused by landslide events.

For the subcomponent of improved management system for the High Technology Development Zone (HTDZ), tangible but not readily and reliably quantifiable benefit, which will not be conducted to quantitative analysis, include the following:

- Reduce the time of the residents' affair processing by about 30%;
- Reduce by 50% the administrative staff by using this system;
- Improve by 30% the enterprise's service efficiency after project completion;
- Improve the green environmental quality index of the park by 40%;
- Reduce by 25% on use of energy (water and electricity);
- Parking capacity upgrade by 20% after completion of the project;
- Promote the transformation and upgrade of the industrial park;
- Improvement of people's livelihood.

Subproject "Eco-Dike" (embankment). For eco-dike (flood-control embankment), the economic benefits include:

1. flood damage and economic disruptions of economic activities lost saving for the residents and enterprise along the river, according to (Asian Development Bank, 2016c);
2. increased green area benefits.

For the latter, the monetary effect of evapotranspiration was used to represent the environment benefit (Jim & Chen, 2009).

The benefits of loss of flood damage are estimated as follows.

Flood Damage Avoided Loss/Saving Benefits = Annual Average Flood Damage Lost in Last 5 years and economic disruptions of economic activities within project area = CNY25.90 million (6.1)

Table 17 details the economic plan for this sub-project.

Table 17. Economic Analysis, Eco-dike (source: ADB estimation)

Project Cost				Project Benefit			
Year	**Capital Cost**	**O&M**	**Total Cost**	**Cost Saving of Flood Damage**	**Benefits of Incremental Green Space**	**Total Benefit**	**Net Benefit**
2019	3,124.70	-	3,124.70	-	-	-	-3,124.70
2020	5,917.62	-	5,917.62	-	-	-	-5,917.62
2021	10949.51	-	10,949.51	-	-	-	-10,949.51
2022	16092.47	-	16,092.47	-	-	-	-16,092.47
2023	13299.56	-	13,299.56	-	-	-	-13,299.56
2024	5363.68	-	5,363.68	-	-	-	-5,363.68
2025	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
….							
2032	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2033	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2034	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2035	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2036	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2037	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2038	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2039	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2040	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2041	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2042	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2043	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
2044	-	326.18	326.18	258.97	7,403.00	7,661.97	7,335.79
EIRR(%)							**9.10**
ENPV(UNIT: 10,000 CNY)							**384.33**

Subproject "Sponge" city interventions. For sponge city interventions, the main economic benefits include:

- the savings on water consumption costs for municipal facilities (the calculation of the benefit is shown below);
- economic benefits, in terms of employment and tourism;
- environmental benefits, expressed as a decrease in flooding and improvement of the water quality of the river;
- social benefits such as increased free time (Liang, 2018).

For the estimation of the EIRR, the cost savings of water consumption, tourism, flooding, and leisure benefits are considered.

Water Consumption Cost Saving = Annual Water Saving · Non-resident Water Tariff[6] (6.2)

Table 18 shows the economic plan for this sub-project.

[6] Water Price of China. (n.d.). Retrieved 3 20, 2018, from Nationwide Water Price: http://price.h2o-china.com/ view.php?id=1892&pid=1768&ppid=1890&nian=2017

Table 18. Economic Analysis "Sponge" city interventions (source: ADB estimation)

	Project Cost			Project Benefit		
Year	**Capital Cost**	**O&M**	**Total Cost**	**Drainage and water saving benefits**	**Total Benefit**	**Net Benefit**
2019	102.86	-	102.86	-	-	-102.86
2020	949.54	-	949.54	-	-	-949.54
2021	1347.17	-	1,347.17	-	-	-1,347.17
2022	102.86	-	102.86	-	-	-102.86
2023	-	21.91	21.91	741.31	741.31	719.40
2024	-	21.91	21.91	741.31	741.31	719.40
2025	-	21.91	21.91	741.31	741.31	719.40
2026	-	21.91	21.91	741.31	741.31	719.40
2027	-	21.91	21.91	741.31	741.31	719.40
2028	-	21.91	21.91	741.31	741.31	719.40
2029	-	21.91	21.91	741.31	741.31	719.40
….						
2035	-	21.91	21.91	741.31	741.31	719.40
2036	-	21.91	21.91	741.31	741.31	719.40
2037	-	21.91	21.91	741.31	741.31	719.40
2038	-	21.91	21.91	741.31	741.31	719.40
2039	-	21.91	21.91	741.31	741.31	719.40
2040	-	21.91	21.91	741.31	741.31	719.40
2041	-	21.91	21.91	741.31	741.31	719.40
2042	-	21.91	21.91	741.31	741.31	719.40
2043	-	21.91	21.91	741.31	741.31	719.40
2044	-	21.91	21.91	741.31	741.31	719.40
				EIRR (%)		**21.36**
				ENPV(UNIT = 10,000 CNY)		**2,805.54**

Subproject "Wetland area development". For wetland area development downstream of the HTDZ, wetlands are ecosystems that provide numerous goods and services that have an economic value. They are important sources for food, fresh water, and building materials; and provide valuable services, such as water purification and erosion control (World Wildlife Fund, 2004). For the Wetland area development downstream of the HTDZ, the benefits are estimate din line with the project's expected improvement of the water environment to Class IV standard by 2025 and Class III standard by 2030 from the currently worse than Class V standard of surface water quality by "strict increment control and effective stock reduction" to eliminate the black and odour phenomenon of Yannan Lake. The values used in the EIRR estimate are adjusted from a study on the environment cost of water pollution in Chongqing (Chang, Seip, & Vennemo, 2001). Under the subcomponent, about 26 ha of wetlands will be restored.

The following table 19 returns the economic analysis for this sub-project.

Table 19. Economic Analysis, Wetland area development (source: ADB estimation)

	Project Cost		**Project Benefit**		
Year	**Capital Cost**	**Total Cost**	**Water Quality Improvement**	**Total Benefit**	**Net Benefit**
2019	4,284.72	4,284.72	-	-	-4,284.72
2020	12,917.68	12,917.68	-	-	- 12,917.68
2021	1353.82	1,353.82	-	-	-1,353.82
2022	398.18	398.18	-	-	-398.18
2023	398.18	398.18	-	-	-398.18
2024	238.91	238.91	-	-	-238.91
2025	-	0.00	2,979.26	2979.26	2,979.26
2026	-	0.00	2,979.26	2979.26	2,979.26
2027	-	0.00	2,979.26	2979.26	2,979.26
2028	-	0.00	2,979.26	2979.26	2,979.26
2029	-	0.00	2,979.26	2979.26	2,979.26
2030	-	0.00	2,979.26	2979.26	2,979.26
2031	-	0.00	2,979.26	2979.26	2,979.26
2032	-	0.00	2,979.26	2979.26	2,979.26
2033	-	0.00	2,979.26	2979.26	2,979.26
…..	-				
2038	-	0.00	2,979.26	2979.26	2,979.26
2039	-	0.00	2,979.26	2979.26	2,979.26
2040	-	0.00	2,979.26	2979.26	2,979.26
2041	-	0.00	2,979.26	2979.26	2,979.26
2042	-	0.00	2,979.26	2979.26	2,979.26
2043	-	0.00	2,979.26	2979.26	2,979.26
2044	-	0.00	2,979.26	2979.26	2,979.26
				EIRR (%)	**8.82**
				(UNIT = 10,000 CNY)	**-315.94**

"Landfill Closure, Restoration, and After-Use". For this sub-project, many of the economic benefits are related to the health benefits in terms of, for example, savings in medical costs and reduced morbidity. However, these have not been precisely quantified. The EIRR benefits are calculated based on the carbon value of methane capture, using conservative values estimated in a similar activity, the Gorai landfill closure and gas capture project in India (United Nations Framework Convention on Climate Change, 2014). The values are considered conservative as the organic content of landfill waste is generally higher in the PRC than in India. Once the landfill has been covered, there will also be additional environmental benefits from increasing the urban green area.

The following table 20 shows the forecast of costs and benefits as well as the estimate of the EIRR for this sub-component.

Table 20. Economic Analysis, Landfill closure, restoration, and after-use (source: ADB estimation)

	Project Cost				**Project Benefit**		
Year	**Capital Cost**	**O&M**	**Total Cost**	**Methane Capture of Landfill Closure**	**Benefits of Incremental Green Space**	**Total Benefit**	**Net Benefit**
2019	244.34	-	244.34	-	-	-	-244.34
2020	8,680.58	-	8,680.58	-	-	-	-8,680.58
2021	10493.17	-	10,493.17	-	-	-	-10,493.17
2022	4969.07	-	4,969.07	-	-	-	-4,969.07
2023	3749.33	-	3,749.33	-	-	-	-3,749.33
2024	-	148.05	148.05	5,676.23	-	5,676.23	5,528.18
2025	-	148.05	148.05	4,488.34	2,355.50	6,843.84	6,695.79
2026	-	148.05	148.05	3,644.05	2,355.50	5,999.55	5,851.50
2027	-	148.05	148.05	3,035.24	2,355.50	5,390.74	5,242.69
2028	-	148.05	148.05	2,588.77	2,355.50	4,944.27	4,796.22
2029	-	148.05	148.05	2,255.07	2,355.50	4,610.57	4,462.52
2030	-	148.05	148.05	1,969.47	2,355.50	4,324.97	4,176.92
2031	-	148.05	148.05	1,551.08	2,355.50	3,906.58	3,758.53
2032	-	148.05	148.05	1,399.70	2,355.50	3,755.20	3,607.15
….	-						
2038	-	148.05	148.05	743.86	2,355.50	3,099.36	2,951.31
2039	-	148.05	148.05	669.47	2,355.50	3,024.97	2,876.92
2040	-	148.05	148.05	602.52	2,355.50	2,958.02	2,809.97
2041	-	148.05	148.05	542.27	2,355.50	2,897.77	2,749.72
2042	-	148.05	148.05	488.04	2,355.50	2,843.54	2,695.49
2043	-	148.05	148.05	439.24	2,355.50	2,794.74	2,646.69
2044	-	148.05	148.05	395.32	2,355.50	2,750.82	2,602.77
						EIRR(%)	**11.69**
						ENPV (UNIT = 10,000 CNY)	**4,780.30**

Supbroject "Green Wedges". For the green wedge, the economic benefits assumed was the environmental benefits of the urban green area, using similar values to the evapotranspiration benefits of green areas in Hubei (Asian Development Bank, 2016a).
Table 21 shows the economic plan for this sub-project.

Table 21. Economic Analysis, Green wedge (source: ADB estimation)

	Project Cost			Project Benefit		
Year	**Capital Cost**	**Operation and Maintenance**	**Total Cost**	**Incremental Green Space**	**Total Benefit**	**Net Benefit**
2019	6,256.32	-	6,256.32	-	-	-6,256.32
2020	11,187.56	-	11,187.56	-	-	-11,187.56
2021	16191.75	-	16,191.75	-	-	-16,191.75
2022	5455.5	-	5,455.50	-	-	-5,455.50
2023	174.75	-	174.75	-	-	-174.75
2024	-	67.91	67.91	16,555.80	16555.8	16,487.89
2025	-	67.91	67.91	16,555.80	16555.8	16,487.89
…	-					
2031	-	67.91	67.91	16,555.80	16555.8	16,487.89
2032	-	67.91	67.91	16,555.80	16555.8	16,487.89
2033	-	67.91	67.91	16,555.80	16555.8	16,487.89
2034	-	67.91	67.91	16,555.80	16555.8	16,487.89
2035	-	67.91	67.91	16,555.80	16555.8	16,487.89
2036	-	67.91	67.91	16,555.80	16555.8	16,487.89
2037	-	67.91	67.91	16,555.80	16555.8	16,487.89
2038	-	67.91	67.91	16,555.80	16555.8	16,487.89
2039	-	67.91	67.91	16,555.80	16555.8	16,487.89
2040	-	67.91	67.91	16,555.80	16555.8	16,487.89
2041	-	67.91	67.91	16,555.80	16555.8	16,487.89
2042	-	67.91	67.91	16,555.80	16555.8	16,487.89
2043	-	67.91	67.91	16,555.80	16555.8	16,487.89
2044	-	67.91	67.91	16,555.80	16555.8	16,487.89
					EIRR(%)	**24.00**
					ENPV (UNIT = 10,000 CNY)	**67,938.18**

Subproject "Ecological Preservation of Bare Hills". For this sub-component, the major economic benefits assumed for this component are savings for loss of traffic interruption in which the benefit is calculated as follows.

*Savings for loss of traffic interruption = Total annual traffic flow within area of subproject * average number of passenger in a standard car * average working day personal income per hour * average duration of interruption * probability of occurrence*[7] (6.3)

Where:

the average number of passenger in a standard car is 1.94 in accordance the statistical bulletin for the development of transportation in 2015 by the Ministry of Transport of the PRC;

- the average working day personal income per hour in the Municipality is CNY26.58;
- the average duration of interruption and probability of occurrence is 1 hour and 0.24%.

In the Table 22 is reported the economic plan for this sub-project.

Table 22. Economic Analysis, Ecological preservation of bare hills (source: ADB estimation)

	Project Cost			Project Benefit		
Year	**Capital Cost**	**Operation and Maintenance**	**Total Cost**	**Cost Saving of Traffic Interruption**	**Total Benefit**	**Net Benefit**
2019	99.78	-	99.78	-	-	-99.78
2020	1,245.67	-	1,245.67	-	-	-1,245.67
2021	1245.67	-	1,245.67	-	-	-1,245.67
2022	99.78	-	99.78	-	-	-99.78
2023	-	19.05	19.05	360.30	360.3	341.25
2024	-	19.05	19.05	360.30	360.3	341.25
2025	-	19.05	19.05	360.30	360.3	341.25
2026	-	19.05	19.05	360.30	360.3	341.25
2027	-	19.05	19.05	360.30	360.3	341.25
…	-					
2033	-	19.05	19.05	360.30	360.3	341.25
2034	-	19.05	19.05	360.30	360.3	341.25
2035	-	19.05	19.05	360.30	360.3	341.25
2036	-	19.05	19.05	360.30	360.3	341.25
2037	-	19.05	19.05	360.30	360.3	341.25
2038	-	19.05	19.05	360.30	360.3	341.25
2039	-	19.05	19.05	360.30	360.3	341.25

[7] Code for Seismic Design of Building in the PRC in 2016.

2040	-	19.05	19.05	360.30	360.3	341.25
2041	-	19.05	19.05	360.30	360.3	341.25
2042	-	19.05	19.05	360.30	360.3	341.25
2043	-	19.05	19.05	360.30	360.3	341.25
2044	-	19.05	19.05	360.30	360.3	341.25
					EIRR(%)	**9.56**
					ENPV (UNIT = 10,000 CNY)	**110.14**

Subproject "Research and development platform for equipment for light industries"

The main economic advantage assumed for the research and development (R&D) platform is the increase in the number of companies entering the local area, resulting in greater capacities and revenues. The development plan can attract investments from 200 companies. For prudential purposes, it is assumed that a project will be implemented through cooperation with the platform in each company every year. The result transformation rate is 5%, where the average output value is CNY 4 million with at least 1-year lifecycle in accordance with a similar platform operating experience. Table 23 details the business plan for this sub-project[8].

Table 23. Economic Analysis, R&D platform for equipment for the service industry (source: ADB estimation)

	Project Costs			Project Benefits		
Year	**Capital Cost**	**O&M[9]**	**Total Cost**	**Revenue Generated**	**Total Benefit**	**Net Benefit**
2019	5,403.59	-	5,403.5 9	-	-	- 5,403.59
2020	8,105.39	-	8,105.3 9	-	-	- 8,105.39
2021	86.39	-	86.39	-	-	-86.39
2022	57.59	-	57.59	-	-	-57.59
2023	-	345.45	345.45	1,300.00	1300	954.55
2024	-	345.45	345.45	2,000.00	2000	1,654.55
2025	-	345.45	345.45	3,200.00	3200	2,854.55

[8] The reference benchmark in this case is the Chengdu Biomedical industrial incubation park, Tianhe park.
[9] O&M, Operation & Maintenance Costs.

2026	-	345.45	345.45	2,880.00	2880	2,534.55
……	-					
2033	-	345.45	345.45	4,000.00	4000	3,654.55
2034	-	345.45	345.45	4,000.00	4000	3,654.55
2035	-	345.45	345.45	4,000.00	4000	3,654.55
2036	-	345.45	345.45	4,000.00	4000	3,654.55
2037	-	345.45	345.45	4,000.00	4000	3,654.55
2038	-	345.45	345.45	4,000.00	4000	3,654.55
2039	-	345.45	345.45	4,000.00	4000	3,654.55
2040	-	345.45	345.45	4,000.00	4000	3,654.55
2041	-	345.45	345.45	4,000.00	4000	3,654.55
2042	-	345.45	345.45	4,000.00	4000	3,654.55
2043	-	345.45	345.45	4,000.00	4000	3,654.55
2044	-	345.45	345.45	4,000.00	4000	3,654.55
					EIRR (%)	**14.40**
				ENPV(UNIT = 10,000 CNY)		**8,492.35**

Subproject "Center for testing and inspection of equipment materials for the service industry"

For testing and inspection facilities for light industrial equipment, the main economic benefits generated for the component are substantial in 50% (or 60 days) of time savings for the assisted enterprise that is able to achieve 60 days of anticipated revenue generation. According to the time value of money theory, the anticipated net cash inflow can generate more value for an economic entity (Carther, 2003). The benefits will be estimated as follows.

Benefits of time saving = Annual Total Revenue Generated by Companies in the Development Zone · Industry Profit Margin · Industry Opportunity Cost · 60/365 (6.4)

Where:

– Average Industry Profit Margin during 2013–2016 = 18.60%[10];
– Industry Opportunity Cost = Average Industry Weighted Average Capital Cost during 2013–2016 = 10.76%.

Table 24 shows the economic analysis for this sub-project.

[10] Source: Chinese Stomatological Association in 2016.

Table 24. Economic Analysis, Testing and inspection facilities for equipment for light industries (source: ADB estimation)

	Project Costs			Project Benefits		
Year	**Capital Cost**	**O&M**	**Total Cost**	**Time Saving**	**Total Benefit**	**Net Benefit**
2019	48.54	-	48.54	-	-	-48.54
2020	4,549.87	-	4,549.87	-	-	-4,549.87
2021	6753.69	-	6,753.69	-	-	-6,753.69
2022	48.54	-	48.54	-	-	-48.54
2023	-	2661.23	2,661.23	1,475.52	1475.52	-1,185.71
2024	-	2661.23	2,661.23	2,218.96	2218.96	-442.27
2025	-	2661.23	2,661.23	3,332.36	3332.36	671.13
2026	-	2661.23	2,661.23	4,737.47	4737.47	2,076.24
…..						
2032	-	2661.23	2,661.23	6,579.81	6579.81	3,918.58
2033	-	2661.23	2,661.23	6,579.81	6579.81	3,918.58
2034	-	2661.23	2,661.23	6,579.81	6579.81	3,918.58
2035	-	2661.23	2,661.23	6,579.81	6579.81	3,918.58
…..						
2044	-	2661.23	2,661.23	6,579.81	6579.81	3,918.58
					EIRR (%)	**14.91**
				ENPV (UNIT = 10,000 CNY)		**8,273.17**

Subproject "Technical and Vocational Education and Training center" (TVET). For technical and vocational education and training, the economic benefits are closely related to the increase in personal income. For the income from educational services, the benefits are calculated by multiplying the total number of students by the economic shadow price of the per capita tuition; the benefits of the increase in personal income were calculated according to the Mincer Equation (Mincer, 1958).

$$\text{Benefits} = \text{Average wage} \cdot \text{Amounts of Students in each Grade} \cdot (1 + \text{Rate of Education Return})\ \hat{}\ (\text{Grade}) - \text{Average wage} \quad (6.5)$$

Where:

– Rate of Education Return = 8.15%[11];

[11] Source: Zhou, G. 2018. *Interprovincial Discrepancy on Rate of Education Return*. Social Scientist.

– Average annual personal income in 2016 · (1 + Expectation Inflation Rate in 2017) · (1 + Expectation Inflation Rate in 2018) = CNY53,154.51.

Table 25 shows the economic analysis for this sub-project.

Table 25. Economic Analysis, Technical and vocational education and training (source: ADB estimation)

Year	Project Cost			Project Benefit		
	Capital Cost	O&M	Total Cost	Revenue Generated	Total Benefit	Net Benefit
2019	8,340.21	-	8,340.21	-	-	-8,340.21
2020	16,129.51	-	16,129.51	-	-	-16,129.51
2021	4874.25	-	4,874.25	-	-	-4,874.25
2022	248.09	-	248.09	-	-	-248.09
2023	-	161.34	161.34	5,185.63	5185.63	5,024.29
2024	-	161.34	161.34	5,185.63	5185.63	5,024.29
2025	-	161.34	161.34	5,185.63	5185.63	5,024.29
2026	-	161.34	161.34	5,185.63	5185.63	5,024.29
….						
2044	-	161.34	161.34	5,185.63	5185.63	5,024.29
			EIRR(%)			**12.23**
			ENPV (UNIT = 10,000 CNY)			**8,441.72**

Table 26 summarizes the base case real EIRR and net present value for each component and the overall project. The summary shows that the investment program is overall economically convenient, as the overall EIRR is equal to 14.84%, that is, it is higher than the 9.0% discount rate suggested by the ADB. By analysing the individual sub-projects, however, the sub-component "Wetland area development—downstream of the HTDZ" it is not sustainable (as EIRR <9.0%); while the two sub-projects "Eco-dike (flood-control embankment)" and "Ecological preservation of bare hills" are at the limit (since the EIRR is respectively 9.1% and 9.56%). Therefore, in the next section, the economic risk analysis model defined in the first part of the paper is implemented for these three sub-components. The aim is to identify risk mitigation interventions useful for reducing residual risk.

Table 26. Base Case Economic Internal Rates of Return and Economic Net Present Values (source: ADB estimation)

No	Subproject	EIRR (%)	ENPV at 9% (CNY million)
1	Eco-dike (flood-control embankment)	9.1	3.84
2	Sponge city interventions	21.36	28.06
3	Wetland area development—downstream of the HTDZ	8.82	(3.16)
4	Landfill closure, restoration, and after-use	11.69	47.8
5	Green wedges	24	679.38
6	Ecological preservation of bare hills	9.56	1.1
7	R&D platform for equipment for the service industry	14.4	84.92
8	Testing and inspection facilities for equipment for light industries	14.91	82.73
9	Technical and vocational education and training	12.23	84.4
	Overall	14.84	1042.49

6.5. Implementation of the economic risk assessment model

For the three sub-projects analyzed: (i) Eco-dike (flood-control embankment), (ii) Wetland area development—downstream of the HTDZ, (iii) Ecological preservation of bare hills, the investment risk is assessed, also taking into account the extra-monetary effects that these interventions generate on the territory. This is why the economic risk assessment model is implemented, the logical-operational steps of which have been defined in section 4.2.

For each of the three projects, the current investment risk is assessed, the possibility of planning risk mitigation interventions is verified, and the residual risk (or post-mitigation interventions) is evaluated. To show how much the choice of the discount rate can affect the valuation result, the analysis will be conducted both using the 9.0% rate suggested by the ADB and using the economic and environmental declining discount rates estimated in section 4.3.

6.5.1. Subproject "Eco-Dike" (embankment)

The economic risk management model that we implement retraces the logical-operational steps illustrated in Figure 1. Since phase 1 "Establish the context", which translates into the estimation of economic performance indicators has already been implemented in the previous section, we proceed with Phase 2 of Risk Assessment. This phase, in turn, translates into: (2.1) identification of variable risks; (2.2) risk analysis; (2.3) risk estimation.

Step 2.1. Identification of risky variables. This phase is embodied in the sensitivity analysis which allows us to understand how much more or less significantly the sensitive variables of the system affect the economic performance of the initiative. In this case, the sensitive variables are:

- Capital Costs;
- Operating Cost;
- Total Benefits.

The following Table 27 returns the results of the sensitivity analysis in five different situations.

Table 27. Sensitivity analysis for sub-project "Eco-Dike" (source: ADB estimation)

		Situation 1	**Situation 2**	**Situation 3**	**Situation 4**	**Situation 5**
	Base Case	**10% Increase in Capital Cost**	**10% Increase in Operating Cost**	**10% Decrease in Net Benefit**	**Combination of Situations 1–3**	**1-Year Delay**
EIRR	9.10%	8.38%	8.74%	8.04%	7.01%	8.15%
ENPV*	384.33	-2385.95	-977.41	-3406.99	-7539.01	-3166.42

*(UNIT: CNY 10.000)

Step 2.2. Risk analysis, which first requires the attribution of the probability distribution for each risky variable, then the forecast of the cumulative probability distribution of the economic performance indicator, implementing the Monte Carlo analysis. The study of similar projects and the analysis of the demand developed by the Asian Development Bank have led to the attribution of a non-symmetrical triangular distribution to the sensitive variables of the project, where:

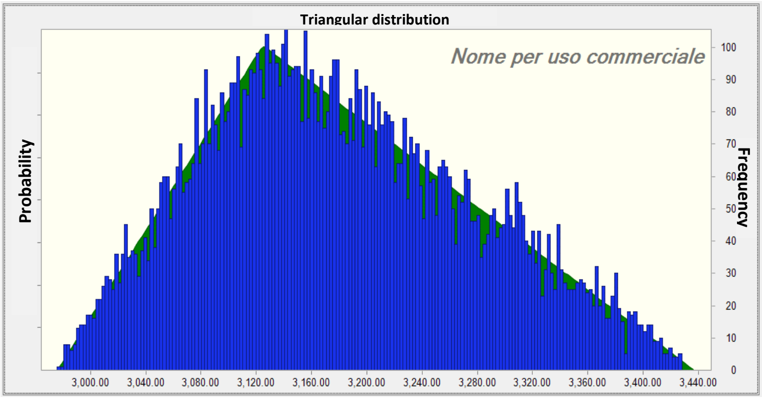
- The value of the variable estimated and used in the economic analysis was considered the most likely;

- For prudential purposes, it was considered that cost items could increase by 10% and decrease by only 5%, while benefits could increase by 5% and decrease by 10%.

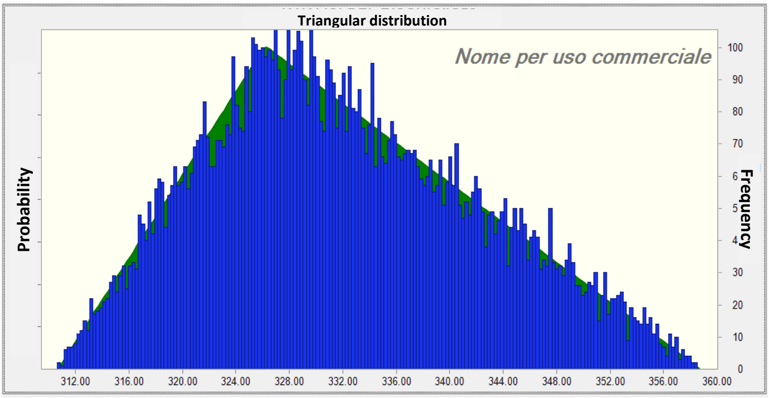
Specifically, the following assumptions were defined:

- The maximum value of the “capital costs” and “operation and maintenance costs” is obtained by increasing the base value by 10% for each year, while the minimum value is obtained by decreasing the base value by 5%;
- The maximum value of each benefit is obtained by increasing the most probable value by 5%, while the minimum value is obtained by decreasing the estimated base value by 10%.

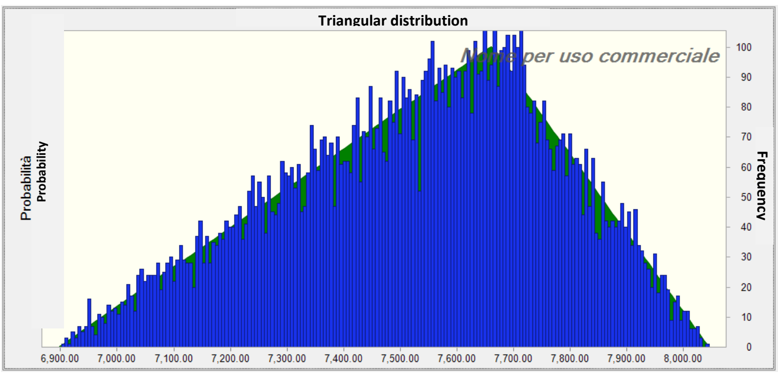
Figure 32 shows the probability distribution typically attributed to “capital costs”, “operating costs” and “total benefits”.



a) Probability distributions of capital costs (year 2019)



b) Probability distributions of operation and maintenance costs



c) Probability distributions of benefits

Figure 32. Probability distributions of critical variables for sub-project "Eco-Dike" (source: own elaboration)

Based on the assumptions made for the critical variables, the implementation of the risk analysis was conducted according to the following two cases:

1. Using the constant discount rate of 9.0% and an analysis period from 2019 to 2045, including 6 years of construction and 20 years of operation, as suggested by the ADB;
2. Using the declining economic and environmental discount rates, estimated in chapter 4 and an analysis period of forty years, from 2019 to 2058. This is a legitimate assumption, as it involves intergenerational interventions, the effects of which affect generations other than those who bear the costs. Consider, among others, the introduction of incremental green space. In this case, the benefits are fully manifested only after 20 years from planting. Specifically, from the analysis of similar projects, it was considered consistent to consider a precautionary factor that would increase the benefits deriving from the increase of green spaces proportionally over time, to reach full capacity twenty years after planting. The following precautionary factors Φ were adopted:
   - $\Phi = 0.2 \cdot$ full capacity for the period 6-12 years from planting;
   - $\Phi = 0.4 \cdot$ full capacity for the period 13-16 years from planting;
   - $\Phi = 0.6 \cdot$ full capacity for the period 17-20 years from planting.

   In addition, starting from year 27 (which corresponds to the twentieth year of operation) maintenance costs have been revised, as the loan has been extinguished and the amortization rate has been reduced. Similarly, the costs for the renovation of the eco-dam from year 27 to year 30 were considered as a share of the initial cost of capital invested. The detail of this financial plan (years 2019-2058) is in Table A3.6 (Appendix 3).

   The economic discount rates and environmental discount rates are estimated in section 4.4 and are summarized in the following Table 28.

Table 28. Environmental DDR (r_q) and Economic DDR (r_e)

	Years 1-20	Years 21-40
r_q	6.0%	4.5%
r_e	11.0%	8.0%

In both cases 100,000 simulations were implemented.

With reference to **case 1**, the base case, i.e. the deterministic ENPV value is 384.33 (CNY million). The mean value of the simulation, which corresponds to the arithmetic mean of a set of numerical observations - or the sum of the observations divided by the number of observations - is -336.61 (CNY million).

The median, which corresponds to the intermediate value, at the order level, between the minimum possible value and the maximum possible value, is -318.89 (CNY million). This discrepancy between mean and median is because the probability distributions of the critical variables are not symmetric. The values of the simulations range from a minimum of -2,652.32 to a maximum of 1,574.62.

Instead, with reference to **case 2**, the base case is equal to 809.54 (CNY million). The mean value of the simulation - is -217.90 (CNY million), while the median is -202.44 (CNY million). The values of the simulations range from a minimum of -2,691.96 to a maximum of 1,929.93.

Another statistical parameter that is taken into consideration is the standard deviation is the square root of the variance for a distribution. Like the variance, it is a measure of dispersion about the mean and is useful for describing the "average" deviation. Variance is a measure of the dispersion, or spread, of a set of values about the mean. When values are close to the mean, the variance is small. When values are widely scattered about the mean, the variance is larger. The variance and mean square deviation values in the two cases are of the same order of magnitude. The values of the two standard deviations are respectively equal to 550.85 and 570.44. In order to obtain a lower standard deviation, we would have had to make assumptions about the "more restrictive" critical variables (ie variables in a much narrower range). However, this is not possible due to the lack of useful data to define starting hypotheses "closer to the average".

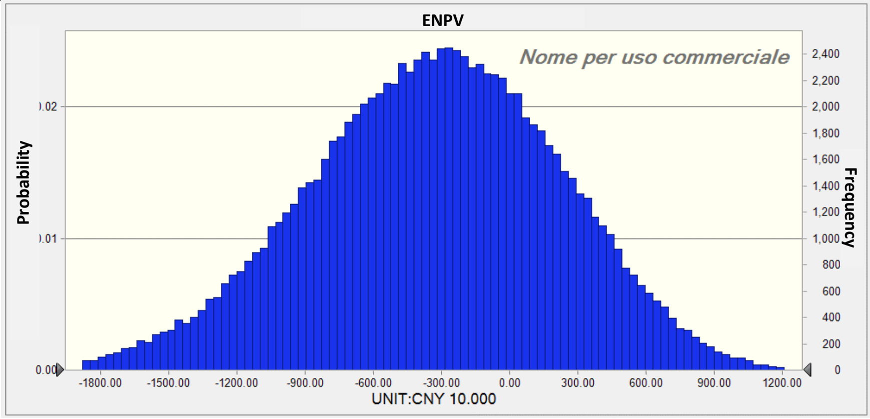
Kurtosis refers to the peakedness of a distribution and it is calculated by finding the fourth moment about the mean and dividing by the quadruple of the standard deviation. Since in practice, a normal distribution is used as the reference standard and has a kurtosis of 3, it is assumed that distributions with kurtosis values less than 3 are described as platicurtic (meaning flat) and distributions with kurtosis values greater than 3 at 3 are leptocurtic (meaning with peak). It follows that the two distributions under consideration are slightly more flattened than a normal distribution.

The mean standard error statistic enables you to determine the accuracy of your simulation results and how many trials are necessary to ensure an acceptable level of error. This statistic tells you the probability of the estimated mean deviating from the true mean by more than a specified amount. The mean standard error statistic provides information only on the accuracy of the mean and can be used as a general guide to the accuracy of the simulation.

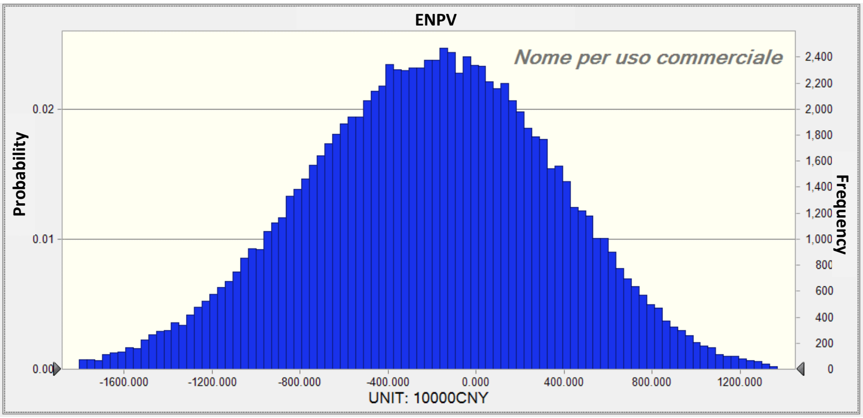
The average standard error statistic helps determine the accuracy of the simulation results and the number of tests required to ensure an acceptable level of error. This statistic indicates the probability that the estimated mean will deviate from the true mean by more than a specified amount.

The mean standard error statistic provides information only on the accuracy of the mean and can be used as a general guide for simulation accuracy. The mean standard error resulting from a number of simulations equal to 100,000 was considered acceptable. In fact, with reference to case 1, we went from an average standard error of 5.56 for 10,000 simulations to 1.74 for 100,000 simulations. With reference to case 2, we went from an error of 5.70 for 10,000 simulations to 1.79 for 100,000 simulations.

The results of the risk analysis are in the numerical values of Table 29. Figure 33 returns the probability distribution of the ENPV for the two cases.



a) Probability distributions of ENPV for the case 1



b) Probability distributions of ENPV for the case 2

Figure 33. Probability distributions of ENPV for the case 1 and case 2, for sub-project “Eco-Dike” (source: own elaboration)

Table 29. Risk analysis statistics in the two cases, sub-project "Eco-Dike" (source: own elaboration)

	Forecast values (case 1, constant SDR; years 2019-2044)	**Forecast values** (case 2, dual DDR; years 2019-2058)
Tests carried out	100,000	100,000
Base case	384.33	809.54
Mean	-336.61	-217.90
Median	-318.89	-202.44
Standard deviation	550.85	570.44
Variance	303,431.14	320,449.12
Kurtosis	2.84	2.88
Minimum	-2,652.32	-2,691.96
Maximum	1,574.62	1,929.93
Mean standard error	1.74	1.79

The analysis demonstrates how by using environmental discount rates other than economic ones and with a structure declining over time, higher ENPV values are obtained than in the case of constant discount rates if, as in the project under consideration, the environmental benefits environmental damage. It follows that if the project had presented significant environmental damage, the ENPV in case 2 would have been lower than the ENPV in case 1.

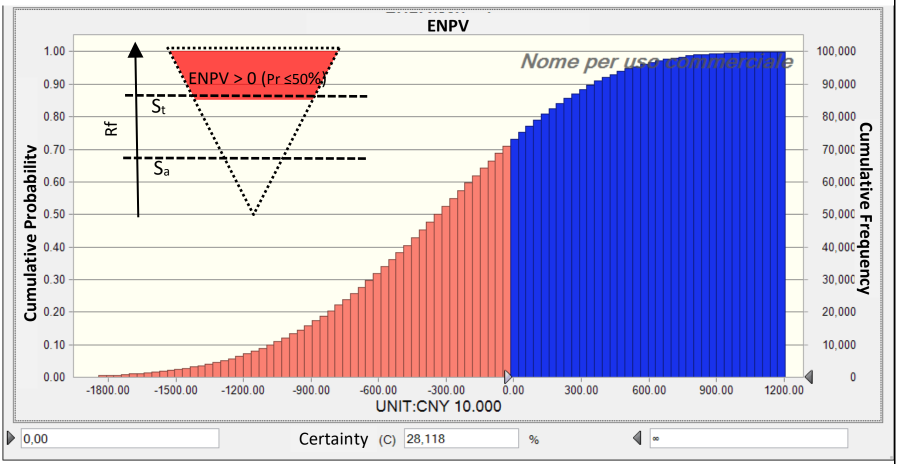
It should be remembered that the result is not obvious. In fact, if on the one hand a broader period of analysis was considered, on the other, environmental benefits deriving from the increase in green spaces that have grown over time (and not fully operational since the first year of operation) were considered. In addition, the costs for renovating the civil works after the twentieth year of activity were also considered.

Step 2.3. Risk estimation. Here we verify the acceptability of the investment risk, based on the ALARP logic, that is, the investment risk is assessed with reference to acceptability and tolerability thresholds.

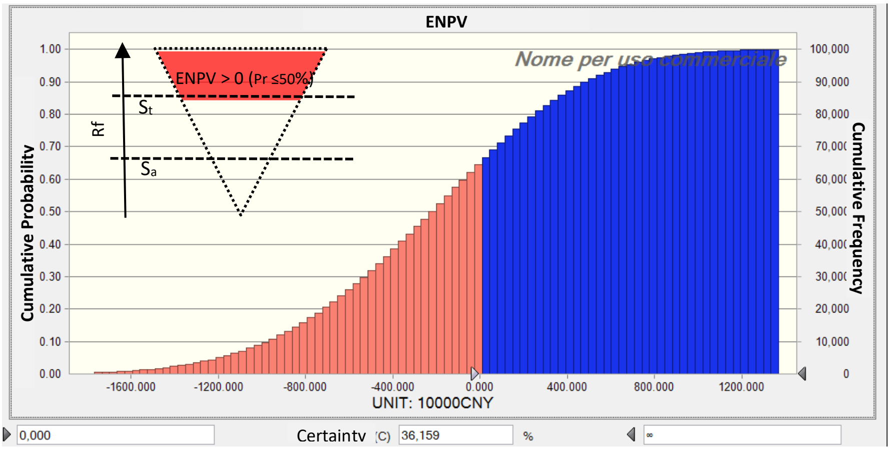
Since these are public projects with long-term effects on the community, the following acceptability criteria are defined, discussed in chapter 4:

- The intervention is widely acceptable if the probability of having a ENPV ≥ 0 is 75%. In this case, it is not necessary to define risk mitigation measures in order to increase the return of the project;
- The intervention is not tolerable if the probability of having a ENPV ≥ 0 is less than or at most equal to 50%. In this case, the project is not sustainable, so it is necessary to define improvement interventions capable of reducing the risk of failure or increasing the profitability of the initiative;
- The intervention falls within the ALARP area if the probability of having a ENPV ≥ 0 is between 50% and 75%. In this case, it is necessary to implement those mitigation interventions that do not have disproportionate costs compared to the achievable benefits.

From the calculations, summarized in Figure 34, the following results derive.
In case 1, the probability of having an ENPV>0 is 28.1%; while in case 2, the probability of having an ENPV> 0 is 35.2%. This means that in both cases the project is not tolerable as the probability of having a positive ENPV is less than 50%. Therefore, it is necessary to define improvement measures capable of increasing the financial feasibility of the initiative.



a) Cumulative probability of ENPV (case 1)



b) Cumulative probability of ENPV (case 2)

Figure 34. Cumulative probability of ENPV for the case 1 and case 2, for sub-project "Eco-Dike" (source: own elaboration)

Step 2.4. Risk treatment. Here it is necessary to first define changes to the project, then evaluate the residual risk, that is the one that remains despite the containment strategy undertaken.

Indeed, urban nature provides important social and psychological benefits to human societies, which enrich human life. They provide spaces for social interaction, improving community cohesion and contributing to a healthier lifestyle. Another advantage is linked to improving air quality and protecting the climate thanks to their ability to store carbon. Although public preferences for environmental attributes may vary among individual citizens based on their socio-economic characteristics and daily activities, these benefits are well recognized by most citizens, with obvious consequences on housing choices. Furthermore, green spaces can be used as factors to increase the attractiveness of a city, making it green and pleasant (Gomes & Florentino, 2015; Chieh-Lu, 2020).

The analysis of the area in which the intervention is located confirmed the interest that the construction of the park can arouse in the inhabitants of both the neighborhood and outside the neighborhood. This is mainly due to three reasons: (i) for the great diffusion of the "culture of urban green" which is spreading more and more in China (Jim & Shan, 2013; Li, Fan, Li, & al., 2020); (ii) for thre presence of infrastructures and connections in the city; (iii) due to the current absence of other urban parks in the intervention area (Asian Development Bank, 2018).

In this case it is assumed to infrastructure the green area created thanks to the intervention of eco-embakment between the river and the urban area. This is to make the green space not only an ecological barrier but an urban park that can have a recreational, socio-cultural, as well as environmental function.

The park will be divided into functional zones, providing: (i) rest areas; (ii) mixed pedestrian cycle path; (iii) areas for outdoor sports activities particularly practiced in the city (tai chi, martial arts ...); (iv) cultural and recreational centers; (v) exhibition pavilions for local artists; (vi) stages for exhibitions; (vii) pavilions/refreshment points.

The project, therefore, intends to pursue the following objectives:

- to create an integrated socio-cultural offer that enhances the area;
- relaunch the image of the city and citizens' sense of belonging, especially by dedicating exhibition spaces to local artists and for socio-cultural events;
- to improve the quality of life of residents;
- improvement of air quality and microclimate, as green areas help fight air and noise pollution, absorb rainwater, create a habitat for local fauna.

On the one hand, the planned interventions involve higher investment costs linked to the infrastructure of the green area. On the other hand, however, they generate:

a) environmental benefits linked to the increase of green spaces;
b) value (in use) that park users associate with the offer socio-cultural;
c) the territorial enhancement of the area in which the intervention is located.

The estimated investment costs to infrastructure the park are shown in the following table 30 and were added to the capital costs incurred in the sixth year, or the last year of construction. The management costs of the urban park are almost comparable with those that would occur in the project scenario of construction of the eco-dam only. While the revenues due from kiosk rentals are a few thousand CNY per year and therefore negligible for the purposes of estimating the economic performance indicator.

Table 30. Investment costs to infrastructure the urban park (source: own elaboration)

Description of infrastructure/ piece of furniture	Unit cost ($/unit)	Line length/ Number of pieces	Total cost ($)	Source
Multi-purpose pedestrian/cycle path	25,070/mile	7 mile - 11.265km	175,490	(Bushell, Poole, Zegeer, & Rodriguez, 2013)
Outdoor stainless steel bicycle metal parking stand bike rack	$55.00/piece	500	27,500	https://www.alibaba.com/product-detail/Arlau-outdoor-stainless-steel-bicycle-metal_60758647737.html?spm=a2700.pc_countrysearch.main07.119.23df6cebnAV5YT
High performance-price ratio 2020 LED Street Light IP67 IK09 150W	$90.00/piece	250	22,500	https://www.alibaba.com/product-detail/High-Performance-price-Ratio-2020-LED_62589662790.html?spm=a2700.pc_countrysearch.main07.1.1224299eqPepnD
Benches	$139.50/piece	200	27,900	https://www.alibaba.com/product-

				detail/Metal-Outdoor-Benches-Outdoor-Metal-Aluminum_1600141197711.html?spm=a2700.pc_countrysearch.main07.1.25f966a39udlfP
Pagoda octagonal tent pavilion, 36m2 (for artists exhibitions)	$1250/piece	4	5,000	https://www.alibaba.com/product-detail/pagoda-octagonal-tent-pavilion_60174169766.html?spm=a2700.pc_countrysearch.main07.22.46ea9a80aljbdn
Stage for outdoor concerts	$42.85/m2	80 (2x40m2)	3,428	https://www.alibaba.com/product-detail/Easy-install-hot-sale-mobile-event_60746363210.html?spm=a2700.pc_countrysearch.main07.29.4e355553h1TtH9
China Prefabricated Bathroom Design Outdoor Portable Toilets Mobile Shower Room	$299.00/piece	30	8,970	https://www.alibaba.com/product-detail/China-Prefabricated-Bathroom-Design-Outdoor-Portable_60445684810.html?spm=a2700.galleryofferlist.normal_offer.d_image.2f7c704frJWmFD
Prefabricated Kiosk bar/prefabricated restaurant	$1,420.00/piece (11.5mx5.95m)	8	8,520	https://www.alibaba.com/product-detail/professional-metal-customized-40-feet-mini_1600103024700.html?spm=a2700.details.deiletai6.3.49fa6977FNnETH

Cost of civil works ($)	279,308
Cost of civil works (CNY)	1,806,620
Cost of civil works (CNY = 10,000 UNIT)	180.662
Conversion factor (source: ADB, 2018)	0.93
Cost of civil works · Conversion factor (CNY = 10,000 UNIT)	
TOT COST = Sum of investment costs per year 6 and park infrastructure costs	5,725.004

As for the environmental benefit (a) linked to the increase in green space, the reference is the estimate conducted by the ADB (2018) which evaluated the monetary effect of evapotranspiration as suggested by Jim & Chen (2013). As for the benefit (b), the provision of the cultural offer can be evaluated in terms of the use value associated with the use of the services offered. This expresses the increase in well-being experienced by users who make use of the cultural infrastructure. In other words, it is necessary to estimate their willingness to pay for the cultural services offered by the urban park through the travel cost method.
It has been assumed that only a part of the residents will be able to use the socio-cultural services offered by the intervention - i.e. corresponding to the inhabitants who manage to reach the park in a maximum of 25-30 minutes by car or corresponding to about 5% of the inhabitants local. In addition, it has been assumed that the residents will be able to reach the park in the following ways: by car (30% of the residents), by public transport (20% of the residents), on foot (30% of the residents), and by bicycle (20% of the residents).

To this must be added the time taken for the visit, assumed on average to be one and a half hours, and estimated by attributing to free time about 40% of the working time as suggested in section 3.8.1 of the CBA Guide (2014).

The following table 31 summarizes the result of the estimate carried out.

Table 31. Estimation of the cultural offer can be evaluated in terms of willingness to pay for the cultural services (source: own elaboration)

Fuel Price (Unit cost)	km to be covered in 50 min (= 0.83h) at 40 km/h	km per liter (Hp = 7 liters every 100 km in urban areas)	Total liters for the trip	Diesel cost for the trip (CNY)
6.21 CNY/liter Source: https://it.globalpetrolprices.com/China/gasoline_prices/	33.3	14.29	2.33	14.49
Return ticket CNY (Public transport)	10 CNY for the first 3 km. For distances greater than 3 kilometers and no more than 15, 2 CNY is added for each additional kilometer = 64 CNY (round trip) Source: market research			
Return ticket (Taxi) CNY	Average Ziyang bus ticket cost for 20-30km distance is approximately = 20 CNY Source: market research			
Travel cost (feet/bicycle) CNY	Hourly value of free time · travel time = 0.5· 68.9 = 34.5			

Hourly labour costs (CNY)	172.33 Source: https://ilostat.ilo.org/topics/labour-costs/
Hourly free time value (CNY) - equal to 40% of labour costs	68.932
Total Users for year (n.)	180,000
Users by cars (n.; 30% of the total)	54,000
Users by public trasport (n.; 20% of the total)	36,000
Users by taxi (n.; 20% of the total)	36,000
Users by feet/bicycle (n.; 30% of users)	54,000

	Travel time a/r (h)	Return ticket - Diesel cost (CNY)	Travel cost (CNY)	Residence time (h)	Willing. to pay for users (CNY)	Willing. to pay (for years) (CNY)
Cars	0.83	14.49	-	1.3	117,888	6,365,952
Public transport	1	20.0	-	1.3	123,398	4,442,328
Taxi	0.83	68.0	-	1.3	171,398	6,170,328
Feet/bicycle	0.5	-	34.50	1.3	137,864	7,444,656
						24,423,264

To estimate the benefit linked to the enjoyment of a better quality of life in an enhanced and more attractive territory (benefit c), the hedonic prices method is used. It consists in estimating the real estate revaluation that will occur following the project in the area of interest.

Based on the available data about the real estate units close to the intervention area (mainly residential), the surfaces affected by the real estate revaluation effect are first quantified, then the increase in real estate value due to urban redevelopment is estimated.

By adopting a topographical criterion, depending on the location of the urban recovery interventions, it is expected that the properties located along the river bank (length 5.32 km) for a 100 m deep strip ($A = 0.53$ km^2) will benefit from the revaluation. Knowing the population density of the Municipality and the standard endowment per inhabitant, the inhabited area was estimated. From the studies conducted by the ADB (2018) we derived the average real estate value of the residential buildings in the area concerned (as also confirmed by market surveys, source:

https://www.ceicdata.com/en/china/property-price-residential-prefecture-level-city/cn-property-price-residential-sichuan-ziyang).

Finally, adopting a prudential approach, an increase in the property value due to the redevelopment of 3% was assumed. This hypothesis was adopted considering, as a reference term, the real estate values of another urban area with characteristics like those of the area in question, in terms of the quality of the street furniture (Asian Development Bank, 2016a).
The following table 32 summarizes the estimate made.

Table 32. Benefit deriving from the increase in real estate value (source: own elaboration)

Area (km^2)	Density (inhab./km^2)	Inhabitants in the area affected by the project	Standard equipment per inhabitant (sqm per inhabitant)	Inhabited areas (m^2)	Real estate value (CNY/m^2)	Present value of the properties (CNY)
0.532	611.66	651	15	9,762.1	4,200	20,500,397
Valuation hypothesis			3%	Increased value		21,115,408

A possible negative externality is linked to the increase in air pollution due to the increase in cars entering the road system. Therefore, by multiplying the unit values of the social cost of pollution available in the literature and the number of additional vehicle-km considering the average length of the route, the effect of air pollution generated by cars can be assessed in monetary terms.

However, since the number of vehicles is very low, this is a social cost equal to a few thousand CNY per year and therefore with a negligible effect for the purpose of calculating the economic performance indicator.
In appendix 3, the table A3.7 returns the detail of the post-mitigation economic analysis in case 1, i.e. using constant discount rates, while table A3.8 returns the post-mitigation economic plan in case 2, i.e. using declining discount rates.

Also in this case 100,000 simulations were implemented.

With reference to **case 1**, the base case, i.e. the deterministic ENPV value is 16,069.81 (CNY million). Instead, with reference to **case 2**, the base case is equal to 33,008.25 (CNY million). This shows that the use of dual and cdeclining discounting determines an economic performance indicator amplified by a coefficient of 2.06 with respect to the case in which the constant rate is used, for the reasons explained above.

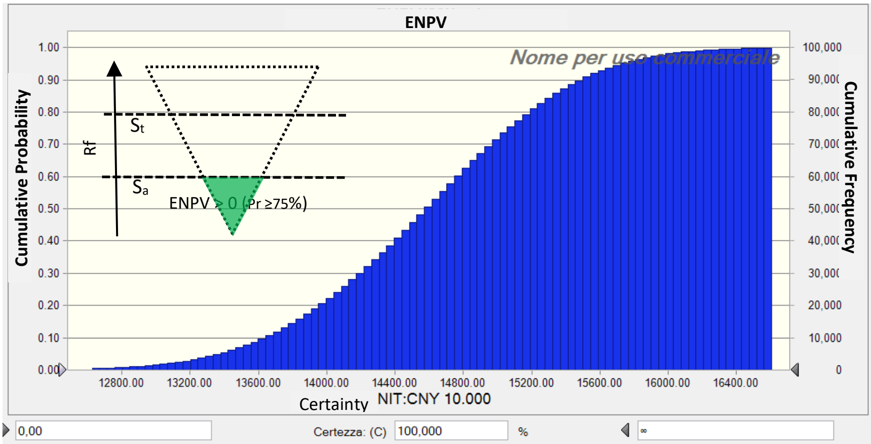
The mean standard error, which provides information only on the accuracy of the mean demonstrates that the 100,000 simulations are a sufficient number of tests to determine the accuracy of the prediction, as this value in both cases becomes about three times smaller in going from 10,000 to 100,000 simulations. Trying to further increase the number of tests, however, the average standard error decreases much less rapidly and the simulation times are considerably longer. Therefore the result obtained with a number of tests equal to 100,000 is considered acceptable.

The values of the statistical indices deriving from the simulation, the meaning of which has already been explained, are summarized in the Table 33.

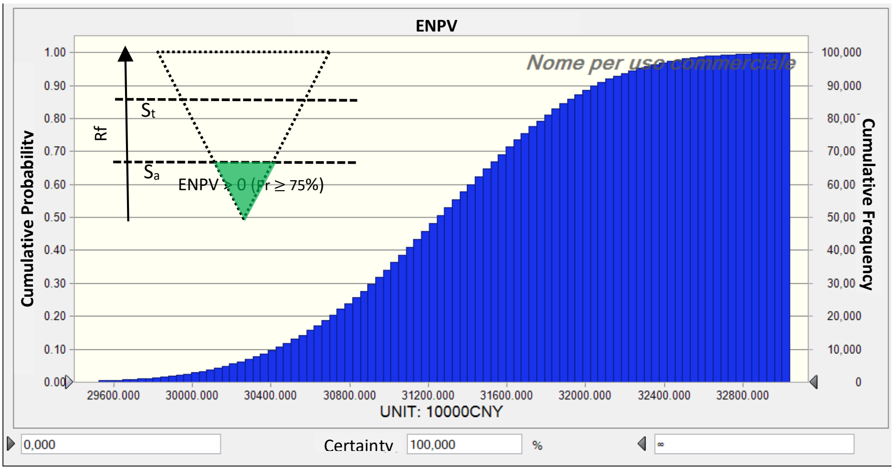
Table 33. Risk analysis statistics post mitigation interventions in the two cases, sub-project "Eco-Dike" (source: own elaboration)

	Forecast values (case 1, constant SDR; years 2019-2044)	**Forecast values** (case 2, dual DDR; years 2019-2058)
Tests carried out	100,000	100,000
Base case	16,069.81	33,008.25
Mean	14,594.02	31,263.08
Median	14,605.06	31,274.51
Standard deviation	718.67	634.08
Variance	516,480.32	402,058.20
Kurtosis	2.91	2.92
Minimum	11,150.11	28,185.47
Maximum	17,392.42	33,769.79
Mean standard error	2.27	2.01

From the calculations, derive the results summarized in Figure 35.
In either case, the post-mitigation risk of failure is largely acceptable as the probability of having a positive ENPV is approximately 100%.



a) Cumulative probability of ENPV post mitigation (case 1)



b) Cumulative probability of ENPV post mitigation (case 2)

Figure 35. Cumulative probability of ENPV post mitigation for the case 1 and case 2, sub-project "Eco-Dike" (source: own elaboration)

6.5.2. Subproject "Wetland area development"

Step 2.1. Identification of risky variables. Also for this sub-project the following risky variables are identified:

- Capital Costs;
- Operating Cost;

– Total Benefits.

The following Table 34 returns the results of the sensitivity analysis in five different situations.

Table 34. Sensitivity analysis for sub-project Wetland area development (source: ADB estimation)

		Situation 1	**Situation 2**	**Situation 3**	**Situation 4**	**Situation 5**
	Base Case	**10% Increase in Capital Cost**	**10% Increase in Operating Cost**	**10% Decrease in Net Benefit**	**Combination of Situations 1–3**	**1-Year Delay**
EIRR	7.98%	8.80%	7.96%	7.12%	7.78%	7.98%
ENPV *	-1,929.04	-356.06	-1,790.15	-3,443.37	-2,246.01	-1,929.04

*(UNIT: CNY 10.000)

From the sensitivity analysis it can be deduced that the project as foreseen is not convenient, therefore it is necessary to carry out the risk analysis as well as to foresee interventions that allow its reduction.

Step 2.2. Risk analysis. The same assumptions of the previous sub-project are defined on the costs, namely:

– The value of the variable estimated and used in the economic analysis was considered the most likely;
– For prudential purposes, it was considered that cost items could increase by 10% and decrease by only 5%, while benefits could increase by 5% and decrease by 10%.

The same procedure already implemented in the previous paragraph will be repeated, therefore the risk analysis is conducted with reference to two different cases:

1. Using the constant discount rate of 9.0% and an analysis period from 2019 to 2045, including 6 years of construction and 20 years of operation, as suggested by the ADB;
2. Using an economic discount rate other than the environmental one. In this case it is legitimate to assume that the benefits of the intervention, expressed in terms of water quality improvment, are manifested as soon as the works are completed, ie from the first year of operation.

For this reason, it is also permissible in this case to conduct the analysis on period (2019-2044) as proposed in the ADB studies (2018). An environmental discount rate of 6.0% and an economic discount rate of 11% are therefore used.
In Appendix 3, table A3.9 gives the detail of the economic analysis with dual discounting.

The result that the simulation returns in this case is of great interest.

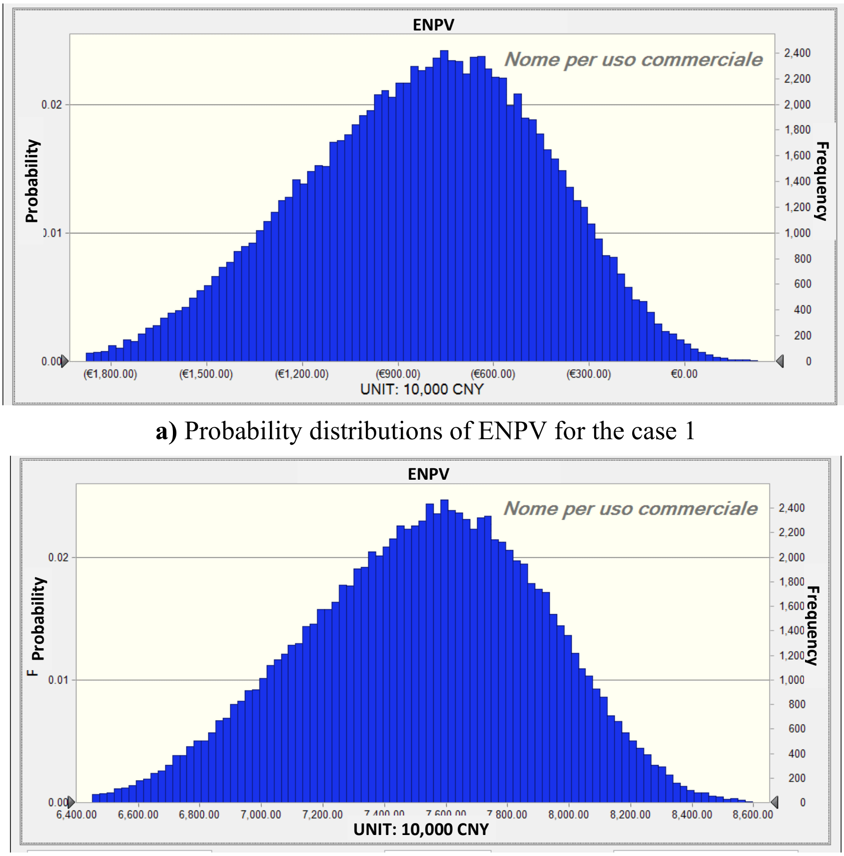
With reference to **case 1**, the base case, i.e. the deterministic ENPV value is negative and precisely equal to -315.94 (CNY million), while **condition 2** returns a value of the base case positive and equal to 8,129.21. Similarly, the mean value, or more probable is equal to -824.99 (in case 1) and equal to 7,523.41 (in case 2).

For both simulations it turns out that the mean and the median do not coincide since the probability distributions associated with the critical variables are triangular and not symmetrical. The distributions also appear "leptocurtic" since they have a kurtosis coefficient of just under 3. The variance and standard deviation are quite high, but also in this case this is due to the fact that the probability distributions of the sensitive variables vary between a minimum and maximum relatively distant. Mean standard error instead shows that 100,000 simulations return a a fairly accurate simulation.

The results of the risk analysis are in the numerical values of Table 34. Figure 36 returns the probability distribution of the ENPV for the two cases.

Table 34. Risk analysis statistics in the two cases, for sub-project "Wetland area development" (source: own elaboration)

	Forecast values (case 1, constant SDR; years 2019-2044)	**Forecast values** (case 2, dual DDR; years 2019-2044)
Tests carried out	100,000	100,000
Base case	-315.94	8,129.21
Mean	-824.99	7,523.41
Median	-802.12	7,545.41
Standard deviation	375.48	382.86
Variance	140,981.74	146,579.24
Kurtosis	2.62	2.8
Minimum	-2,184.27	6,014.99
Maximum	303,69	8,752.52
Mean standard error	1.19	1.79



a) Probability distributions of ENPV for the case 1

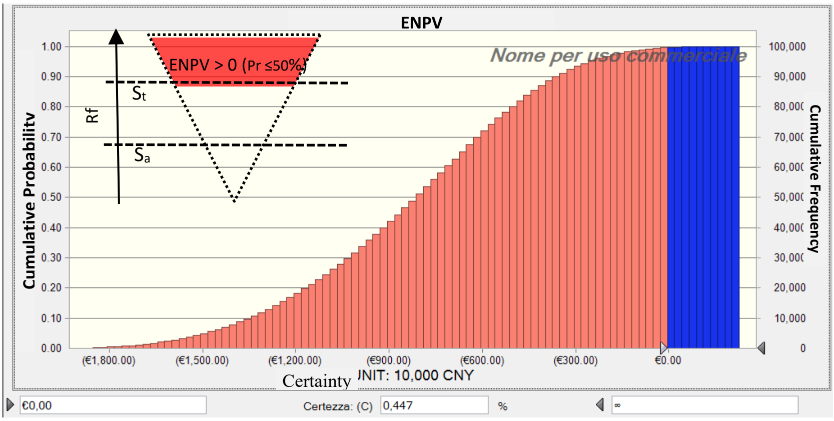
b) Probability distributions of ENPV for the case 2

Figure 36. Probability distributions of ENPV for the case 1 and case 2, wetland area development (source: own elaboration)

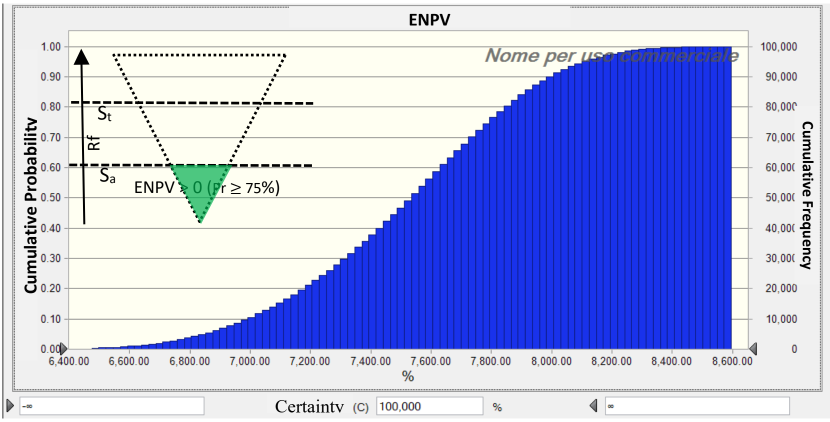
Step 2.3. Risk estimation.

From the calculations, summarized in Figure 37, the following results derive.

In case 1, the probability of having an ENPV > 0 is 0.5%; while in case 2, the probability of having an ENPV > 0 is 100%. This means that in the first case the project is not tolerable as the probability of having a positive ENPV is less than 50%. Instead, using the double discount rate, the project is tolerable, in which case the probability of having an ENPV less than 0 is practically nil. This shows how much the choice of the discount rate influences the final result of the evaluation. In this case, there are only positive environmental effects that manifest themselves immediately and "weigh" much more in the analysis than in case 1 in which the environmental effects are treated in the same way as the financial ones. It is therefore not necessary to plan risk mitigation interventions. In this regard, moreover, it should be emphasized that the ADB (2018) has alrea which allowed to select between two alternatives the less expensive option (for further information, see ADB, 2018).



a) Cumulative probability of ENPV (case 1)



b) Cumulative probability of ENPV (case 2)

Figure 37. Cumulative probability of ENPV for the case 1 and case 2, for sub-project "Wetland area development" (source: own elaboration)

6.5.3. Subproject "Ecological preservation of bare hills"

Step 2.1. Identification of risky variables. For this sub-project the following risky variables are identified:

- Capital Costs;
- Operating Cost;
- Total Benefits.

The following Table 35 returns the results of the sensitivity analysis in five different situations.

Table 35. Sensitivity analysis for sub-project "Wetland area development" (source: ADB estimation)

		Situation 1	**Situation 2**	**Situation 3**	**Situation 4**	**Situation 5**
	Base Case	**10% Increase in Capital Cost**	**10% Increase in Operating Cost**	**10% Decrease in Net Benefit**	**Combination of Situations 1–3**	**1-Year Delay**
EIRR	8.49%	9.49%	8.43%	7.35%	8.30%	8.49%
ENPV *	-107.12	97.40	-108.97	-338.97	-143.43	-107.12

*(UNIT: CNY 10.000)

From the sensitivity analysis it follows that it is necessary to estimate the economic performance indicator in stochastic terms.

Step 2.2. Risk analysis. The same assumptions of the previous sub-projects are defined on the costs. In particular*:*

- The value of the variable estimated and used in the economic analysis was considered the most likely;
- For prudential purposes, it was considered that cost items could increase by 10% and decrease by only 5%, while benefits could increase by 5% and decrease by 10%.

Also in this case, the risk analysis is conducted with reference to two different cases:

1. Using the constant discount rate of 9.0% and an analysis period from 2019 to 2045, including 6 years of construction and 20 years of operation, as suggested by the ADB;

2. Employing dual discounting. As for the previous project, it is assumed that the benefits deriving from the interruption of traffic will manifest themselves from the first year of operation. Therefore, an analysis period is considered which includes 6 years of construction site and 2 years of operation and an environmental discount rate of 6.0% and an economic discount rate of 11%. In Appendix 3, table A3.10 provides the details of the economic analysis with dual discounting.

Implementing the risk analysis returns the following results.

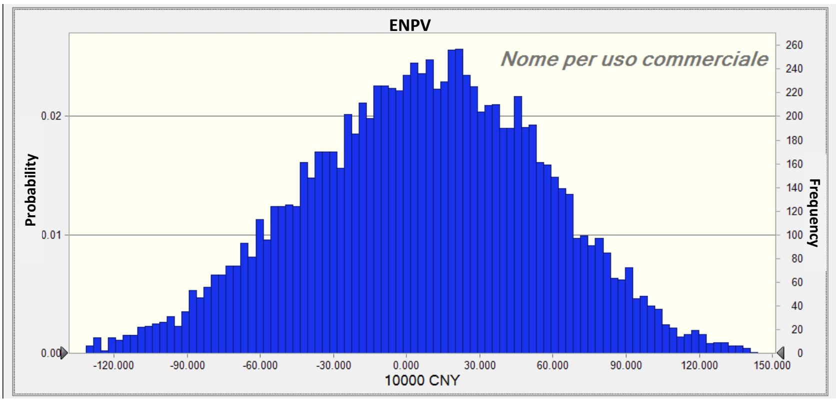
With reference to **case 1**, the base case, i.e. the deterministic ENPV value is positive and precisely equal to 110.14 (CNY million), while **condition 2** returns a value of the base case equal to 1,256.51. Similarly the mean value, or more probable is equal to 5.74 (in case 1) and equal to 1,093.28 (in case 2).

For both simulations it results that the mean and the median do not coincide since the probability distributions associated with the sensitive variables of the project are not symmetric. In case 1 the mean and median are positive but have a very low value. The distributions also appear “leptocuric” as they have a kurtosis coefficient of just under 3. The variance and standard deviation are more content than in the other sub-projects. It follows, in fact, that the average standard error is very low already with reference to 10,000 simulations, which are thus sufficient to provide an accurate simulation.

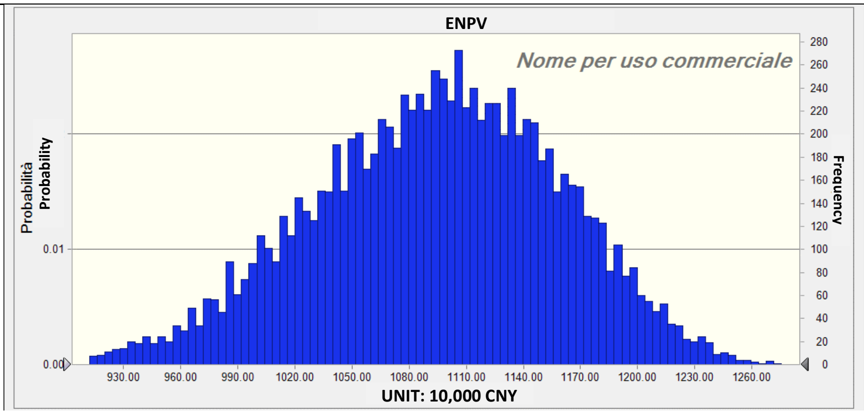
The results of the risk analysis are in the numerical values of Table 36. Figure 38 returns the probability distribution of the ENPV for the two cases.

Table 36. Risk analysis statistics in the two cases for sub-project "Ecological preservation of bare hills" (source: own elaboration)

	Forecast values (case 1, constant SDR; years 2019-2044)	**Forecast values** (case 2, dual DDR; years 2019-2044)
Tests carried out	10,000	10,000
Base case	110.14	1,256.51
Mean	5.74	1,093.28
Median	6.88	1,096.92
Standard deviation	49.23	65.23
Variance	2,423.56	4,254.96
Kurtosis	2.75	2.81
Minimum	-176.53	849.57
Maximum	153.651	1,291.47
Mean standard error	0.49	0.65



a) Probability distributions of ENPV for the case 1

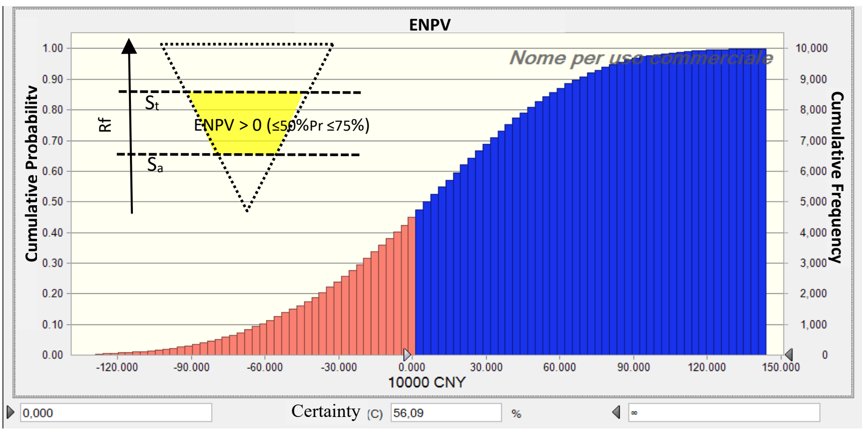


b) Probability distributions of ENPV for the case 2

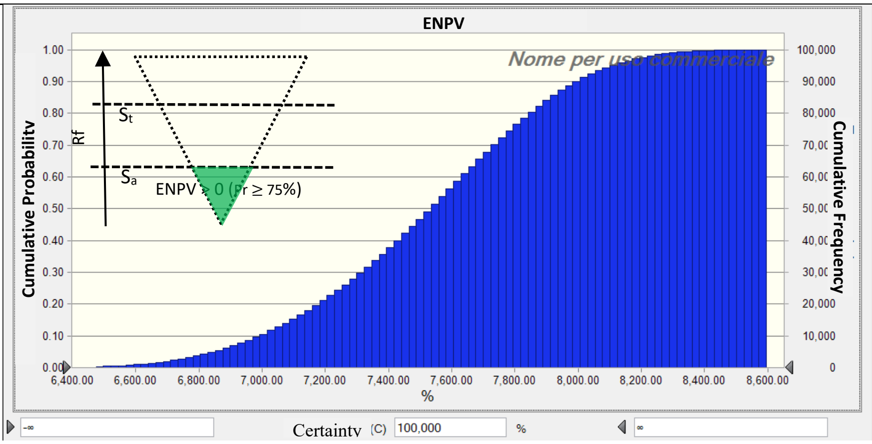
Figure 38. Probability distributions of ENPV for the case 1 and case 2 for sub-project "Ecological preservation of bare hills" (source: own elaboration)

Step 2.3. Risk estimation.

In case 1, the probability of having an ENPV> 0 is approximately 56%, therefore the risk is ALARP, i.e. risk mitigation interventions should be defined if the costs of such interventions are not disproportionate to the obtainable benefits. In case 2, the use of the double discount rate leads to a widely acceptable risk already pre-mitigation interventions. The elaborations, shown in Figure 39, return the following results.



a) Cumulative probability of ENPV (case 1)



b) Cumulative probability of ENPV (case 2)

Figure 39. Cumulative probability of ENPV for the case 1 and case 2 for sub-project "Ecological preservation of bare hills" (source: own elaboration)

From the analysis of the ADB project (2018) it emerges that the benefits generated by the trees located along the base of the hills were not taken into account in the analysis. Thus, in order to have a more complete evaluation and to confirm or not the results already discussed, the analysis is updated and the analysis and risk assessment are repeated taking into account the positive environmental externalities generated by greenery in terms of ecosystem services.

In fact, trees, green areas, and ecosystems perform countless beneficial functions for public health and urban quality, through the related ecosystem services that must be taken into account in the relevant analyzes (Bolund & Hunhammar, 1999; Himes, Puettmann, & Muraca, 2020). The latter are represented by the numerous benefits ranging from functional aspects linked to the nutrient cycle and the water cycle, to the improvement of air quality, landscape characterization, recreational and social aspects.

According to literature data, the annual value of all ecosystem services is \$1.0 billion, or \$110.63 per tree. If you consider a management fee of \$19.00 per tree/ year, for every dollar invested, you can get benefits for \$5.82 (McPherson, N., & J., 2016). From the analysis of the characteristics of the project area, medium-sized trees are used which at the time of planting are ten years old and require little maintenance. From market analysis it is estimated that the purchase cost of a tree with the aforementioned characteristics, including the manpower necessary to plant it, is about 260 $ per tree, or 1790 CNY.

Table 37 shows the summary data deriving from the implementation of the mitigation measure for the sub-project being analysed.

Table 37. Estimation of costs and benefits for trees for sub-project "Ecological preservation of bare hills" (source: own elaboration)

	for tree	**Ecological preservation of bare hills**	
		n. of tree	1608
Investment cost (10.000 CNY)	0.179	287.832	
Maintenance cost (10.000 CNY)	0.013067	21.011736	
Benefits (10.000 CNY)	0.076038	122.269104	

Since the trees at the time of planting are already of medium size and are between 7 and 10 years old, it is assumed that ecosystem services are 50% from year 6 to year 10 of operation and 100% from year 11 in then. To estimate the economic performance indicator, in case 1 the discount rate of 9% suggested by the ADB was used, while in case 2 the dual and declining discount rates reported in table 27 were used.

In Appendix 3, table A3.10 details the economic plan of the project considering the ecosystem services of the trees and an analysis period from 2019-2044; while table A3.11 details the economic plan in the case of an analysis period from 2019 to 2058.

The following results emerge from the risk analysis.

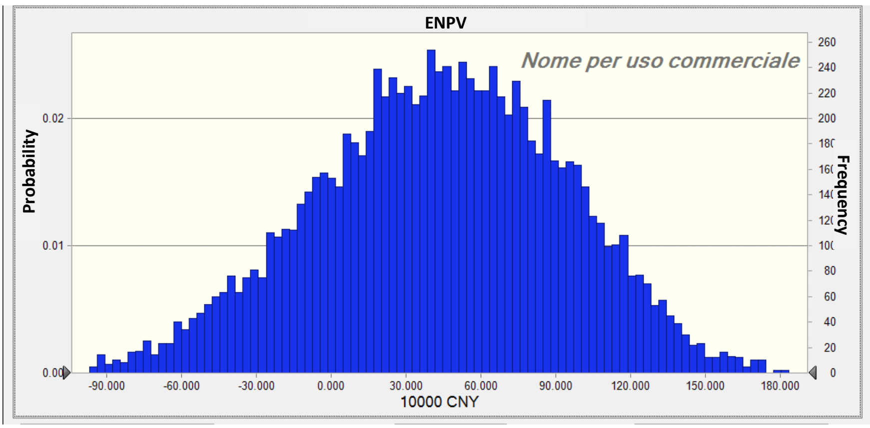
With reference to **case 1**, the deterministic ENPV value is positive and precisely equal to 127.99 (CNY million), while **condition 2** returns a value of the base case positive and equal to 3,397.48. Similarly, the mean value, or more probable is equal to 43.41 (in case 1) and equal to 3,296.44 (in case 2).

For both simulations it results that the mean and the median do not coincide since the probability distributions associated with the sensitive variables of the project are not symmetric. In both conditions the mean and median have a lower value than the base case. In both cases the two distributions are "leptocuric", while the variance and standard deviation are more content with respect the other sub-projects. It follows, that the average standard error is very low already with reference to 10,000 simulations, which are thus sufficient to provide an accurate simulation.

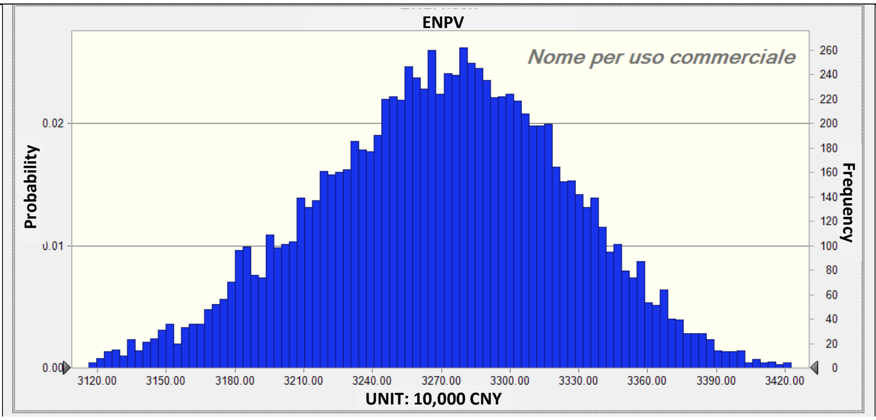
The results of the risk analysis are in the numerical values of Table 38. Figure 40 returns the probability distribution of the ENPV for the two cases.

Table 38. Risk analysis statistics in the two cases for sub-project "Ecological preservation of bare hills" (source: own elaboration)

	Forecast values (case 1, constant SDR; years 2019-2044)	**Forecast values** (case 2, dual DDR; years 2019-2058)
Tests carried out	10,000	10,000
Base case	127.99	3,397.48
Mean	43.41	3,296.44
Median	44.81	3,271.70
Standard deviation	50.10	56.64
Variance	2,510.25	2,985.34
Kurtosis	2.76	2.85
Minimum	-160,79	3,080.77
Maximum	195.53	3453,80
Mean standard error	0.50	0.55



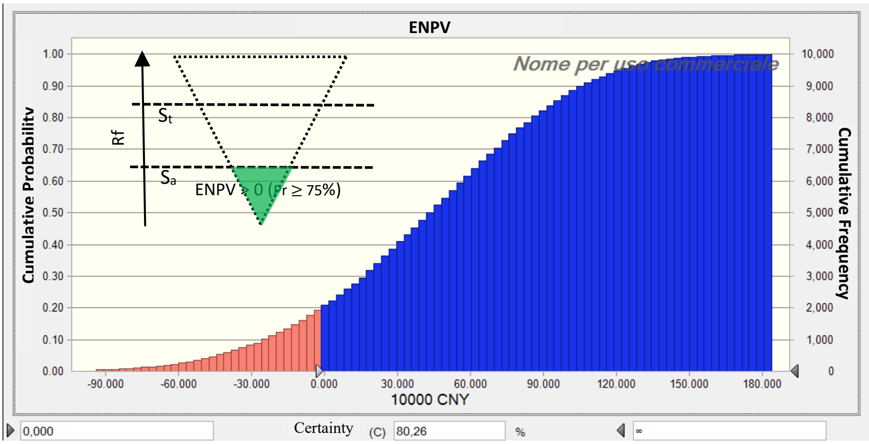
a) Probability distributions of ENPV for the case 1



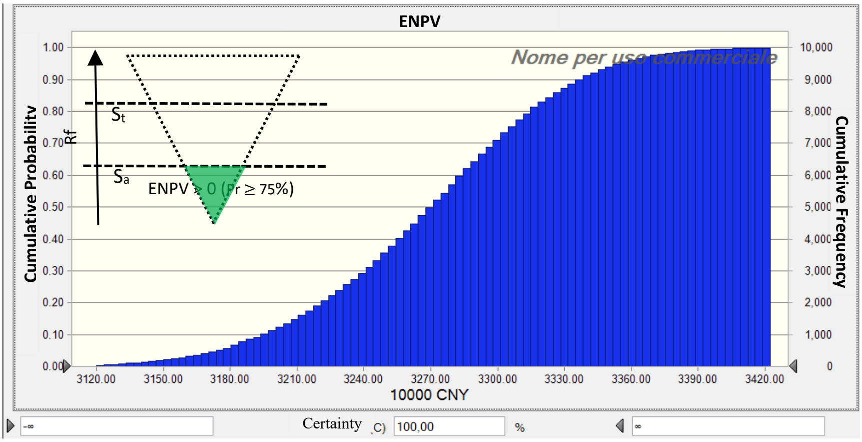
b) Probability distributions of ENPV for the case 2

Figure 40. Probability distributions of ENPV for the case 1 and case 2 for sub-project "Ecological preservation of bare hills" (source: own elaboration)

This means that by including in the analyzes the costs and benefits related to the trees included in the ecological conservation project of the bare hills, the risk changes from ALARP to widely acceptable. As is obvious, this result is also confirmed in the case in which the analysis is conducted using declining discount rates (i.e. in condition 2). The following figure 40 shows the result of the two simulations.



a) Cumulative probability of ENPV (case 1)



b) Cumulative probability of ENPV (case 2)

Figure 41. Cumulative probability of ENPV for the case 1 and case 2 for sub-project "Ecological preservation of bare hills" (source: own elaboration)

7. Conclusions

The aim of this thesis is to define innovative investment risk management models that can support the decision maker:

(i) in *financial analysis*, or conducted from the point of view of the private investor;
(ii) in *economic analysis*, which instead reflects the point of view of the public operator or the community.

In the case of *financial analysis* (i), the main limitation concerns the lack of project risk acceptance thresholds both in the sector literature and in the community and extra-EU regulatory guidelines.

The goal is therefore to define an innovative risk management model that can support the investor in the decision-making process by basing the assessment of the investment risk on shared criteria and objective data.

There are two main new elements of the model: the first concerns the definition of the minimum levels of acceptance of the investment risk; the second concerns the characterization of the method for estimating these threshold values.

With reference to the first element, risk acceptability and tolerability thresholds are borrowed from the As Low As Reasonably Practicable (ALARP) logic. In accordance with this principle, a risk is defined as ALARP if it lies between the aforementioned thresholds or if the costs for its mitigation appear disproportionate to the achievable benefits.

As regards the methodology for estimating the threshold values, the theoretical framework of reference is the Capital Asset Pricing Model (CAPM) which defines how to evaluate the minimum expected return from an investment project with a given risk profile. Thus, the joint use of the CAPM and statistical survey tools makes it possible to estimate risk limit values both as a function of the investment sector and with reference to the territorial context in which the project is located.

The proposed model is implemented to estimate the tolerable expected return and the acceptable expected return with reference to both the European and Chinese economic context in the following sectors:

(i) Engineering – Construction;
(ii) Environmental & Waste Services;
(iii) Green & Renewable Energy.

The calculations carried out show how the risk acceptability and tolerability thresholds differ significantly both according to the country and the investment sector. Specifically, these thresholds have significantly higher values in China than in Europe, due to the different systemic risk in the two countries.
In Europe, the Engineering/Construction investment sector is slightly more risky than the Green & Renewable Energy and Environmental & Waste Services sectors.
In China, on the other hand, the Environmental & Waste Services investment sector is less risky than the Engineering/Construction and Green & Renewable Energy sectors.

Therefore, the comparison between the expected return of a civil project and the estimated risk limit values in the different sectors can effectively guide the analyst in the investment risk assessment, as well as guide him towards the selection of of project alternatives more financial sustainable.

In the case of *economic analysis* (ii), the previous problem is added to by the need to give due "weight" to the environmental, social and cultural externalities of the investment, which often manifest themselves in the long term and which one would risk underestimating or not taking into account in the analysis.

This is because the result of the Cost-Benefit Analysis (CBA) is significantly influenced by the choice of the Social Discount Rate (SDR), a parameter that makes it possible to make the Cash Flows that occur at different times compared to the time of assessment economically comparable. The use of constant discount rates, generally used in practice, makes it possible to attribute a progressively lower "weight" to the current value of costs and benefits progressively more distant over time, ending up by not considering at all the intergenerational effects of an initiative of intervention.

Hence, the idea is to define an evaluation protocol in which both the investment risk, which tends to increase over time, and the need to give due weight to the environmental and social impacts of the project are considered jointly. In fact, if on the one hand it is true that these are terms that are not known with certainty, on the other hand the combined "risk-discounting" effect would lead to underestimating significant environmental and social effects.

Also in this case the reference for risk assessment is the ALARP logic. However, the result will not be expressed in terms of "tolerable" and "acceptable" expected return, but in terms of the probability that the investment will fail or return a positive Economic Net Present Value (ENPV).

This assumption is legitimate, since public interventions must be economically sustainable but do not necessarily have to produce high profit margins as is the case for initiatives promoted by private investors.

For this reason, the following limit values are assumed:

- tolerable threshold with a probability of not less than 50% of having an ENPV ≥ 0, i.e. it is assumed that the public financing body has a "neutral" attitude to risk;
- acceptability threshold with a probability of not less than 75% of having an ENPV ≥ 0, a limit derived from *ex-post* evaluation studies carried out by the Asian Development Bank (2017a) which reveal that the average failure rate of public investment on the existing project portfolio is around 25%.

There are two main innovations in the risk assessment model for intergenerational public projects.

The first is that the riskiness of cash flows is treated separately from the macroeconomic riskiness. This means that costs and benefits are modelled stochastically, i.e. each risky variable is assigned a probability distribution, while macroeconomic risk is incorporated into the assessment of the discount rate, as the growth rate of consumption is also modelled in probabilistic terms.

The second is that the discounting of cash flows is based on the joint use of Declining Discounting and Dual Discounting. In other words, a new methodology is defined for estimating the economic discount rate and the environmental discount rate, both with a declining structure over time. This can be done by introducing environmental quality into the mathematical scheme that governs the estimation of the social discount rate over time. Environmental quality is expressed as a function of the Environmental Performance Index (EPI), which allows us to determine how close countries are to achieving the UN's 2015 Sustainable Development Goals.

The implementation of the methodology to the Italian and Chinese economies yields the following main results:

- for Italy, the economic discount rate function starts from an initial value of 3.32% to reach a value of 0.65% after 300 years, thus decreasing by about 2.6%. The environmental discount rate, on the other hand, takes on markedly smaller values than the economic discount rate, starting from a value of 2.37% and reaching a value of 0.17% after 300 years;
- for China, the economic discount rate function starts from an initial value of 12.81% to reach a value of 0.65% after 300 years, thus decreasing by about 4.74%. The environmental discount rate, on the other hand, starts from a value of 6.90% and reaches a value of 1.00% after 300 years.

It is evident that the higher uncertainty related to environmental quality rather than economic developments leads to a lower environmental discount rate than the economic one. In addition, it is extremely interesting to highlight how the two functions of the discount rate for China start from higher initial values than Italy, but decline much more rapidly from the early years of the analysis period. The higher initial value is correlated with the higher values of the GDP growth rate for China compared to Italy. However, the faster decline in the two discount rate functions is related to China’s environmental condition. In fact, the lower value of the Environmental Performance Index (EPI) for China shows that it is further away from achieving the UN Sustainable Development Goals and therefore highlights the greater need to invest in environmentally sustainable projects.

In the last part of the work, the economic risk assessment model is tested on an investment programme for urban development in the Sichuan region of China along the route of the Belt and Road Initiative. It can be defined as the development strategy of the People’s Republic of China for improving its infrastructure and trade links with countries in Eurasia and Africa.

The Inclusive Green Development Project in the municipality of Ziyang intends to:

(i) improve the liveability of the place;
(ii) allow high quality economic growth based on a more inclusive green development path.

These objectives are achieved through the implementation of nine sub-projects. From the economic analysis of all the interventions of the program it emerges that the sub-project “Wetland area development” is not sustainable, while the sub-projects “Eco-Dike” and “Ecological preservation of bare hills” have an EIRR slightly higher than the discount rate of 9% suggested by the ADB. The defined economic risk assessment model is therefore applied for these three interventions.

Two main results emerge from the application to the case studies.

The first is that the model defined, thanks to the introduction of acceptability and tolerability thresholds borrowed from ALARP logic, represents a useful guide for the analyst who has to choose risk mitigation interventions and assess the residual investment risk.

Secondly, it demonstrates how important it is to properly choose the Social Discount Rate depending on the assessment. This is in order to correctly estimate the environmental and social externalities that the project generates on the territory.

In fact, the use of dual and declining discount rates leads to significantly higher values of the economic performance indicator than in the case in which the constant discount rate of 9% suggested by the ADB (2018) is used. It follows that by resorting to dual and declining discounting, greater weight is attributed to both damage and environmental benefits progressively more distant over time than that assigned to financial components.

In other words, the use of conventional discounting procedures, or based on time-invariant discount rates, would lead to choices that are not always sustainable. This is because the analyst, on the one hand, would neglect alternatives whose benefits are felt by generations following those who have implemented them. On the other hand, it would focus on investments with high initial returns, but with long-term environmental repercussions.

In conclusions, the policy implications that the implementation of the proposed model can determine on the entire environmental decision-making are therefore very relevant, also in terms of a more rapid achievement of sustainability goals.

References

Albana, A. (2018). Belt and road, i porti del sud Italia tagliati fuori dalla connectivity,. Cineforum.

Ale, B. (2005). Tolerable or acceptable, a comparison of risk regulation in the UK and in the Netherlands. Risk Analysis, 2, 231-241.

Ale, B., & Hartford, D. S. (2015). ALARP and CBA all in the same game. Safety Science, 90-10.

Almansa, C., & Martínez-Paz, J. (2011). What Weight Should Be Assigned to Future Environmental Impacts? A Probabilistic Cost-Benefit Analysis Using Recent Advances on Discounting. Science of The Total Environment, 409(7), 1305-14. doi:10.1016/j.scitotenv.201

Althaus, C. (2005). A Disciplinary Perspective on the Epistemological Status of Risk. Risk Analysis, 25(3), 567-588.

Althaus, C., Bridgman, P., & Davis, G. (2007). The Australian policy guidance (4th ed.). Sydney: Allen & Unwi.

Amram, M., & Kulatilaka, N. (1999). Real Options: Managing Strategic Investment in an Uncertain World. Oxford: Oxford University Press.

Andric, J., Wang, J., & R., Z. (2019). Identifying the Critical Risks in Railway Projects Based on Fuzzy and Sensitivity Analysis: A Case Study of Belt and Road Projects. Sustainability 11, 1302;. doi:doi:10.3390/su11051302.

Arrow, K., Cropper, M., Gollier, C., Groom, B., & al. (2013). How Should Benefits and Costs Be Discounted in an Intergenerational Context? The Views of an Expert Panel. Resources for the Future Discussion Paper,, 12–53. doi:http://dx.doi.org/10.2139/ssrn.2199511

Asian Development Bank (ADB). (2002). Handbook for Integrating Risk Analysis in the Economic Analysis of Projects. Handbook for Integrating Risk Analysis in the Economic Analysis of Projects: ADB.

Asian Development Bank (ADB). (2015). Technical Assistance to the People's Republic of China for Strengthening Provincial Planning and Implementation Capacity for Yangtze River Economic Belt. Manila: ADB.

Asian Development Bank (ADB). (2015). Technical Assistance to the People's Republic of China for Strengthening Provincial Planning and Implementation Capacity for Yangtze River Economic Belt. Manila: ADB.

Asian Development Bank (ADB). (2016a). GrEEEn Solutions for Livable Cities. Manila: ADB.

Asian Development Bank (ADB). (2016b). Yangtze River Economic Belt Environmental Protection and Rehabilitation Project—A Preliminary Study. Manila: ADB.

Asian Development Bank (ADB). (2016c). Financial and Economic Analysis of Jiangxi Xinyu Kongmu River Watershed Flood Control and Environmental Improvement Project: Economic benefit of improved flood management. Consultant's report. Manila: ADB.

Asian Development Bank (ADB). (2017b). Technical Assistance to the People's Republic of China for Preparing the Yangtze River Economic Belt Projects. Manila: ADB.

Asian Development Bank (ADB). (2018). People's Republic of China: Sichuan Ziyang Inclusive Green Development Project. Project Administration Manual. Manila: ADB.

Asian Development Bank (ADB). (2018). Technical Assistance to the People's Republic of China for the Chongqing Green Transformation and Development Project. Manila: ADB.

Asian Development Bank. (2013). Cost-Benefit Analysis for development: A pratical guide. Mandaluyong City: Asian Development Bank.

Asian Development Bank. (2017a). Guidelines for the economic analysis of the project. Manila, Philippines: Asian Development Bank.

Association of Professional Engineers and Geoscientists of British Columbia (APEGBC). (2010). Guidelines for legislated landslide assessments for proposed residential developments in BC. APEGBC.

Aven, T. (2015). Risk analysis (2nd ed). Chichester: Wiley.

Aven, T. (2016). Risk assessment and risk management: review of recent advances on their foundation. European Journal of Operational Research, 253(1), 1-13.

Aven, T. (2018). An Emerging New Risk Analysis Science: Foundations and Implications. Risk Analysis, 34(5), 876-888.

Aven, T., & Abrahamsen, E. (2007). On the use of cost-benefit analysis in ALARP processes. International Journal of Performability Engineering, 3, 345-353.

Aven, T., & Renn, O. (2009). On risk defined as an event where the outcome is uncertain. Journal of Risk Research, 12(1), 1-11. doi:DOI: 10.1080/13669870802488883

Aven, T., & Renn, O. (2009). The Role of Quantitative Risk Assessments for 582 Characterizing Risk and Uncertainty and Delineating Appropriate Risk Management Options, with Special Emphasis on Terrorism Risk. Risk Analysis, 29(4), 587-600.

Aven, T., & Vinnem, J. (2007). Risk Management, with Applications. London: Springer.

Banks, E., & Dunn, R. (2003). Practical risk management: An executive guide to avoiding surprises and losses. Chichester, England: John Wiley & Sons.

Barisitz, S., & Radzyner, A. (2017). The New Silk Road, part I: a stocktaking and economic assessment. Focus on European Economic Integration,. Oesterreichische Nationalbank (Austrian Central Bank).

Baroni, P. (2016). La nuova via della seta parte dall'Adriatico con cinque porti. La Stampa. Retrieved from https://www.lastampa.it/2016/02/26/economia/la-nuova-via-della-seta-parte-dalladriatico-con-cinque-porti-MAEvFZ3hQ5OzrmnH2LbndO/pagina.html

Baumgärtner, S., Klein, A., Thiel, D., & Winkler, K. (2015). Ramsey discounting of ecosystem services. Environmental and Resource Economics, 61, 273–296.

Belli, P., Anderson, J., Barnum, H., Dixon, J., & Tan, J.-P. (1998). Handbook on economic analysis of investment operations. Washington DC: Operational Core Services Network, Learning and Leadership Center/World Bank.

Bertozzi, D. (2018). La Belt and Road Initiative. La nuova via della seta e la Cina globale. Imprimatur ed.

Black, F. (1993). Beta and Return. Journal of Portfolio Management, 20(1), 8-18.

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. Ecological Economics, 29, 293-301.

Bushell, M., Poole, B., Zegeer, C., & Rodriguez, D. (2013). Costs for Pedestrian and Bicyclist Infrastructure Improvements A Resource for Researchers, Engineers, Planners, and the General Public Authors. UNC Highway Safety Research Center Prepa. Retrieved from https://ssti.us/wp-content/uploads/sites/1303/2013/10/PedBikeCosts.pdf

Cardin, M. (1987). Dominanza stocastica con avversione al rischio. Rivista di Matematica per le Scienze Economiche e Sociali, 10, 23-32. doi:https://doi.org/10.1007/BF02090473

Carther, S. (2003). Understanding the Time Value of Money. Retrieved from Investopedia: https://www.investopedia.com/articles/ 03/082703.asp.

Casarini, F. (2017). Chinese Investments in Italy: Changing the Game? In J. Seaman, M. Huotari, & M. Otero-Iglesias, Chinese Investment in Europe: A Country-level Approach. Paris, France: European Think-tank Network on China (ETNC).

Chang, Y., Seip, H. M., & Vennemo, H. (2001). The environmental cost of water pollution in Chongqing, China. . Environment and Development Economics, 313–333.

Chieh-Lu, L. (2020). Quality of life: The perspective of urban park recreation in three Asian cities. Journal of Outdoor Recreation and Tourism, 29, 100260.

Cowell, F., & Gardiner, K. (1999). Welfare Weights. STICERD, London: London School of Economics.

Cropper, M., Freeman, M., Groom, B., & William, A. (2014). Declining Discount Rates. American Economic Review, 104(5), 538-543.

Dallocchio, M. (1995). Finanza d'azienda. Analisi e valutazioni per le decisioni d'impresa. Milano: EGEA.

Dallocchio, M., & Salvi, A. (2011a). Finanza aziendale 1: finanza ordinaria. Milano: Egea.

Dallocchio, M., & Salvi, A. (2011b). Finanza aziendale 2: finanza ordinaria. Milano: Egea.

Djankov, S., & Miner, S. (2016). China's Belt and Road Initiative – Motives, Scope, and Challenges. Peterson Institute for International Economics. Retrieved from https://piie.com/publications/piie-briefings/chinas-belt-and-road-initiative-motive

Drèze J., & Stern N. (1987). The Theory of Cost-Benefits Analysis. In S. N. Drèze J., & A. A. Feldstein (Ed.), Handbook of Public Economics (Vol. II, pp. 909-989). North-Holland: Elsevier Science Publishers B. V.

Drupp, M. (2018). Limits to substitution between ecosystem services and manufactured goods and implications for social discounting. Environmental and Resource Economics, 69, 135–158.

Echazu, L., Nocetti, D., & Smith, W. (2012). A new look into the determinants of the ecological discount rate: disentangling social preferences. The B.E. Journal of Economic Analysis & Policy, 12(1), 1-44.

Elbannan, M. A. (2015). The Capital Asset Pricing Model: An Overview of the Theory. International Journal of Economics and Finance, 7(1), 216-228.

ERM-Hong Kong Ltd. (1998). Landslides and boulder falls from natural terrain: Interim risk guidelines, 183. . ERM-Hong Kong Ltd.: The Government of Hong Kong Special Administrative Region.

Escobar, P. (2015). Is there a place for the West along China's Silk Road? The Nation. Retrieved from www.thenation.com/article/is-there-a-place-for-the-west-along-chinas-new-silk-road/

European Commission. (2002). First Report on the Harmonisation of Risk Assessment Procedures. Brusselles: Health and Consumer Protection Directorate General.

European Commission. (2003). Guide to the cost-benefit analysis of investment projects (Structural Funds, Cohesion Fund, and ISPA). Bruxelles: Evaluation Unit, DG for Regional Policy and Cohesion, European Commission.

European Commission. (2013). Regulation (EU) No 1303/2013 of the European Parliament and of the Council of 17 December 2013,. Bruxelles: European Commission:. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R1303&from=it,

European Commission. (2014). Guide to Cost-Benefit Analysis. Brussels: Directorate-General for Regional and Urban policy.

Evans, D. (2006). Social Discount Rates for the European Union. Management and Quantitative Methods at Università degli Studi di Milano.Department of Economics, Management and Quantitative Methods at Università degli Studi di Milano., Departmental Working Papers 2006-20.

Evans, D., & Kula, E. (2009). Social discount rates and welfare weights for public investment decisions under budgetary restrictions: the case of Cyprus. Milan European Economic Workshop, University of Milan, Vol. VIII, Working Paper No.19.

Fell, R. (1994). Landslide risk assessment and acceptable risk. Canadian Geotechnical Journal, 31, 261–272.

Fischhoff, B., Watson, S., & Hope, C. (1984). Defining risk. Policy Sciences, 17(2), 123-139.

Florio, M., & Sirtori, E. (2013). The social cost of capital: recent estimates for the EU Countries. Centre for industrial studies, Working Paper No. 03. Retrieved from http://www.csilmilano.com/docs/WP2013_03.pdf

Freeman, M. (n.d.).

Freeman, M., Groom, G., Panopoulou, E., & Pantelidis, T. (2013). Declining discount rates and the Fisher effect: Inflated past, discounted future? Journal of Environmental Economics and Management, 73, 32-49.

French, S., Bedford, T., & Atherton, E. (2007). Supporting ALARP decision making by cost benefit analysis and multi-attribute utility theory. Journal of Risk Research, 8, 207-223.

Gabusi, G. (2017). “Crossing the River by Feeling the Gold": The Asian Infrastructure Investment Bank and the financial support to the Belt and Road Initiative . China World Eco, 25, 23–45.

Giacchè, V. (2016). La nuova Via della seta – un progetto per molti obiettivi. Gnosis-Rivista italiana di intelligence, 167-173.

Gollier, C. (2008). Discounting with Fat-Tailed Economic Growth,. Journal of Risk and Uncertainty, 37, 171-186.

Gollier, C. (2010). Ecological discounting. Journal of Economic Theory, 145, 812–829. doi:https://doi.org/10.1016/j.jet.2009.10.001

Gollier, C. (2010). Ecological discounting. Journal of Economic Theory, 145, 812-829.

Gollier, C. (2012). Pricing the planet’s future: The economics of discounting in an uncertain world. Princeton, NJ.: Princeton University Press.

Gomes, S., & Florentino, T. (2015). The role of urban parks in cities' quality of life. European Real Estate Society (ERES), 183.

Grieger, G. (2016). One Belt, One Road (OBOR): China's regional integration initiative. European Parliamentary Research Service.

Groom, B., Koundouri, P., Panopoulou, E., & Pantelidis, T. (2007). Discounting the DistantFuture: How much does model selection affect the certainty equivalent rate? Journal of Applied Econometrics, 22, 641-656.

Hasselmann, K., Hasselmann, S., Giering, R., Ocana, V., & von Storch. (1997). Sensitivity study of optimal CO2 emission paths using a simplified structural integrated assessment model. Climate Change, 345–386.

Heal, G. (2009). The economics of climate change: a post-stern perspective. Climatic Change, 96, 275-297.

Health and Safety Executive (HSE). (1992). The tolerability of risk from nuclear power stations. London: Her Majesty's Stationery Office.

Health and Safety Executive. (2001). Reducing risks, protecting people: HSE's decision-making. London: HSE Books.

Health and Safety Executive. (2014). Principles and Guidelines to Assist HSE in its Judgements that Dutyholders have Reduced Risk as Low as Reasonably Practicable. London: HSE.

Health and Safety Executive. (2014). Principles and Guidelines to Assist HSE in its Judgements that Dutyholders have Reduced Risk as Low as Reasonably Practicable. London: HSE. Retrieved from http://www.hse.gov.uk/risk/theory/alarp1.htm

Himes, A., Puettmann, K., & Muraca, K. (2020). Trade-offs between ecosystem services along gradients of tree species diversity and values. Ecosystem Services, 44, 101133.

HM Treasury. (2018). The Green Book - Central Government Guidance on Appraisal and Evaluation. London. Retrieved from http://www.gov.uk/government/publications

Ho, K., Leroi, E., & Roberds, B. (2000). Quantitative risk assessment application, myths and future direction. . Proceedings of the international conference on geotechnical and geological engineering (pp. 269–312). Australia: Melbourne: GeoEng2000.

Hoel, M., & Sterner, T. (2007). Discounting and relative prices. Climatic Change, 84, 265–280.

Huang, Y. (2016). Understanding China's Belt & Road initiative: Motivation, framework and assessment. China Economic Review 40, 314–321.

International Atomic Energy Agency. (1995). Guidelines for Integrated Risk Assessment and Management in Large Industrial Areas. Vienna: IAEA.

IPCS and WHO. (2004). Risk Assessment Terminology. Geneva: World Health Organization.

ISO 31000. (2009). Risk Management – Principles and Guidelines. ISO/TC 262.

Jim, C., & Chen, W. Y. (2009). Ecosystem services and valuation of urban forests in China. Cities, 187-194.

Jim, C., & Shan, X. (2013). Socioeconomic effect on perception of urban green spaces in Guangzhou, China. Cities, 123-131.

Jones-Lee, M., & Aven, T. (2011). ALARP—What does it really mean? Reliability Engineering & System Safety, 96(8), 877-882.

Knight, F. (1921). Risk, uncertainty, and profit. New York: Hart, Schaffer & Marx.

Kula, E. (2004). Estimation of a social rate of interest for India. Journal of Agricultural Economics, 55, 91-99.

Kula, E., & Evans, D. (2011). Dual discounting in cost-benefit analysis for environmental impacts. Environmental Impact Assessment, 31(3), 180-186. doi:https://doi.org/10.1016/j.eiar.2010.06.001.

Kumamoto, H. (2007). Satisfying Safety Goals by Probabilistic Risk. London: Sprenger.

Li, Y., Fan, S., Li, K., & al., e. (2020). Microclimate in an urban park and its influencing factors: a case study of Tiantan Park in Beijing, China. Urban Ecosystems.

Liang, X. (2018). Integrated Economic and Financial Analysis of China's Sponge City Program for Water-Resilient Urban Development. Sustainability. Sustainability, 10,669. doi:doi:10:3390/su10030669

Lintner, J. (1965). The Valuation of risk assets and the selection of risky investments in stock portfolios and capital budgets. The Review of Economics and Statistic, 47(1), 13-37.

Lucas, R. (1978). Asset prices in an exchange economy. Econometrica, 1429-46.

Luce, R., & Raiffa, H. (1957). Games and decisions: Introduction and critical survey. Wiley: New York.

Ma, J. (2017). The challenge of different perceptions on the Belt and Road Initiative. Croatian International Relations Review, 149–168.

Macciotta, R., & Lefsrud, L. (2018). Framework for developing risk to life evaluation criteria associated with landslides in Canada. Geoenvironmental Disasters, 5(10).

Markowitz, H. (1952). Portfolio selection. Journal of Finance, 7(1), 77–99.

McPherson, E., N., v. D., & J., d. G. (2016). Structure, function and value of street trees in California, USA. Urban Forestry & Urban Greening, 17, 104-115.

Meyer, T., & Reniers, G. (2013). Engineering risk management. Berlin: De Gruyter Graduate.

Miao, J. (2015). Expectations and Realities: Managing the risks of the "Belt and Road" Initiative. China Q. Int. Strat. Stud., 1, 497–522.

Mincer, J. (1958). Investment in Human Capital and Personal Income Distribution. Journal of Political Economy., 66(4), 281–302. doi: doi:10.1086/258055

Morgenstern, N. (1995). Managing risk in geotechnical engineering. The 3rd Casagrande lecture. Proceedings 10th Pan-American Conference on Soil Mechanics and Foundation Engineering, (pp. 102–126). Guadalajara, Mexico 4.

Mun, J. (2002). Real Options Analysis: Tools and Techniques, . Hoboken, New Jersey: John Wiley and Sons.

Musabelliu, M. (2017). China's Belt and Road Initiative Extension to central and eastern European countries-sixteen nations, five summits, many challenges. Croatian International Relations Review, 23, 57–76.

Nesticò, A. (2019). L'analisi economica del rischio di progetto. Criteri e tecniche. LaborEst, 18, 41-48. doi:10.19254/LaborEst.18.06

Nesticò, A., & Maselli, G. (2019). Intergenerational Discounting in the Economic Evaluation of Projects. In C. F., Della Spina L., & B. C. (Ed.), New Metropolitan Perspectives. ISHT 2018. Smart Innovation, Systems and Technologies (pp. 260-268). Cham.: Springer. doi:https://doi.org/10.1007/978-3-319-92102-0_28

Nesticò, A., & Maselli, G. (2020). A protocol for the estimate of the social rate of time preference: the case studies of Italy and the USA. Journal of Economic Studies, 527-545. doi:10.1108/JES-02-2019-0081

Nesticò, A., He, S., De Mare, G., & Maselli, G. (2018). The ALARP Principle in the Cost-Benefit Analysis for the Acceptability of Investment Risk. Sustainability, 10(4668).

Newell, R., & Pizer, W. (2003). Discounting the Distant Future: How Much Do Uncertain Rates Increase Valuations? Journal of Environmental Economics and Management, 46(1), 52-71. doi:https://doi.org/10.1016/S0095-0696(02)00031-1

Nordhaus, W. (2008). A Question of Balance: Weighing the Options on Global Warming Policies. New Haven: Yale University Press.

OECD. (2018). Cost-Benefit Analysis and the Environment: Further Developments and Policy Use. Paris: OECD Publishing. Retrieved from https://doi.org/10.1787/9789264085169-en

Park, K., & Shapira, Z. (2017). Risk and Uncertainty. In M. Augier, & D. Teece, The Palgrave Encyclopedia of Strategic Management. London: Palgrave Macmillan.

Pearce, D., & Ulph, D. (1999). Environmental Economics: Essays in Ecological Economics and Sustainable Development. In D. Pearce, A social Discount Rate for United Kingdom (pp. 268-285). Cheltenham: Edward Elgar.

Percoco, M. (2008). A social discount rate for Italy. Applied Economics Letters, 73-77. Retrieved from doi: 10.1080/13504850600706537

Plambeck, E., Hope, C., & Anderson, J. (1997). The PAGE95 model: integrating the science and economics of global warming. Energy Economics, 19, 77-101.

Porter, M., Jakob, M., & Holm, k. (2009). Proposed landslide risk tolerance criteria. 62nd Canadi-an Geotechnical Conference and 10th Joint CGS/IAH-CNC Groundwater Conference, (pp. 533–541). Halifax, Nova Scotia, Canada.

Price, C. (1993). Time, Discounting and Value. Oxford: Blackwell.
Price, C. (2003). Diminishing marginal utility: the respectable case for discounting? . International Journal of Sustainable Development, 6, 117– 132.
Redmill, F. (2010). ALARP Explored. Newcastle upon Tyne: Computing Science, University of Newcastle upon Tyne.
Reilly, F. K., & Brown, K. (2003). Investment analysis portfolio management. South-Western: Thomson.
Renn, O. (2008). Risk Governance. Coping with Uncertainty in a Complex World. London: Earthscan.
Richards, T., & Green, G. (2015). Environmental and Resource Economics. Environmental choices and hyperbolic discounting: an experimental analysis, 62, 83–103.
Richet, x., Rulet, J., & Wan, X. (2016). New Belts and Roads: Redrawing EU-China Relations. In A. Amighini, China's Belt and Road: a game changer? Novi Ligure: Ispi, Edizioni Epoké,.
Rolland, N. (2017). China's "Belt and Road Initiative": Underwhelming or game-changer? The Washington Quarterly 40, 127–142.
Rosen, M., & Thuringer, C. (2017). Unconstrained Foreign Direct Investment: An Emerging Challenge to Arctic Security. CAN Analysis and Solution.
Rosenberg, B., & Guy, J. (1976). Beta and Investment Fundamentals. Financial Analysts Journal, 32(3), 60-72.
Sharpe, W. F. (1964). Capital Asset Prices: A theory of Market Equilibrium under Conditions of Risk. Journal of Finance, 19, 425-442.
Skjong, R., Vanem, E., & Øyvind, E. (2005). Risk Evaluation Criteria. Design, Operation and Regulation for Safety - SAFEDOR Project. The SAFEDOR Consortium.
Society of Risk Analysis. (2015, November 2019). Glossary society for risk analysis. Retrieved from SRA: www.sra.com/resources
Society of Risk Analysis. (2015). Society for risk analysis Glossary . SRA. Retrieved from www.sra.com/resources
Stec, C. (2018). China's Belt and Road Initiative is Neither a Strategy, Nor a Vision. It is a Process. European Institute for Asian Studies.
Steen, R. (2015). A risk assessment approach to support the launching of new products, services or processes. International Journal of Business Continuity and Risk Management, 6(1), 17-35.
Stern, N. (2007). The Economics of Climate Change: The Stern Review. Cambridge, UK.: Cambridge University Press. doi:https://doi.org/10.1017/CBO9780511817434
Sterner, T., & Persson, M. (2008). An Even Sterner Report: Introducing Relative Prices into the Discounting Debate. Rev. Environ. Econ. Policy, 2(1), 61-76.

Teng, K.-Y., Thekdi, S. A., & Lambert, J. H. (2012). Identification and evaluation of priorities in the business process of a risk or safety organization. Reliability Engineering & System Safety, 99, 74-86.

U.S. Environmental Protection Agency. (2020). Guidelines for Preparing Economic Analyses. Washington: National Center for Environmental Economics, U.S. Environmental Protection Agency.

UK Cabinet Office. (2002). Risk: Improving Government's Capability to Handle Risk and Uncertainty, Strategy Unit Report, Uncertainties beyond Expected Values and Probabilities. Chichester, UK: Wiley.

United Nations Framework Convention on Climate Change. (2014). Clean Development Mechanism Project Design Document Form—Gorai Landfill Closure and Gas Capture Project. Mumbai, India.

Vanem, E. (2012). Principles for setting risk acceptance criteria for safety critical activities. In B. G., & G. Soares, Advances in Safety, Reliability and Risk Management (pp. 1741–1751).

Vazquez-lavin, F., Oliva, R., Hernandez, J., Gelcich, S., Carrasco, M., & Quiroga, M. (2019). Exploring dual discount rates for ecosystem services: Evidence from a marine protected area network. Resource and Energy Economics, 55, 63–80.

Viscusi, W., Huber, J., & Bell, J. (2008). Estimating discount rates for environmental quality from utility-based choice experiments. Journal of Risk and Uncertainty, 37, 199-220. doi:https://doi.org/10.1007/s11166-008-9045-x

Weikard, H., & Zhu, X. (2005). Discounting and environmental quality: When should dual rates be used? Economic Modelling, 22, 868–878. doi:https://doi.org/10.1016/j.econmod.2005.06.004

Weitzman. (1998). Why the Far-Distant Future Should be Discounted at its Lowest Possible Rate. Journal of Environmental Economics and Management, 36(3), 201–208. doi:https://doi.org/10.1006/jeem.1998.1052

Weitzman, M. (2001). Gamma Discounting. American Economic Review, 91(1), 261-271. doi:doi: 10.1257/aer.91.1.260

Wendling, Z. A., Emerson, J., Esty, D., L. M., de Sherbinin, A., & al., e. (2018). 2018 Environmental Performance Index. New Haven, CT: ale Center for Environmental, Law & Policy. Retrieved from https://epi.yale.edu/

World Health Organization. (2002). IPCS Risk Assessment Terminology. Geneva: WHO.

World Wildlife Fund. (2004). The Economic Values of the World's Wetlands. . Amsterdam: Gland. : World Wildlife Fund.

Xiao, H., Cheng, J., & Wang, X. (2018). Does the Belt and Road Initiative Promote Sustainable Development? Evidence from Countries along the Belt and Road. Sustainability, 10(12):4370. doi: DOI: 10.3390/su10124370

Yang, Z. (2003). Dual-rate discounting in dynamic economic-environmental modelling. Economic Modelling, 20, 941-957.

Yasseri, S. (2013). The ALARP argument. Fire and Blast information group - FABIG newsletter.

Yilmaz, S., & Liu, C. (2016). The Rise of New Eurasianism: China's "Belt and Road" Initiative and its implications for Euro-Atlanticism. China Q. Int. Strat. Stud., 401–419.

Zhuang, J., Liang, Z., Lin, T., & De Guzman, F. (2007). Theory and practice in the choice of social discount rate for cost-benefit analysis: a survey. mANILA: ERD Economics and Research Department, Asian Development Bank, Working Paper No. 94.

Zio, E. (2007). An introduction to the basics of reliability and risk analysis. Singapore: World Scientific Publishing.

Sitography

1. Alibaba, https://www.alibaba.com
2. Ceicdata, https://www.ceicdata.com/en/china/property-price-residential-prefecture-level-city/cn-property-price-residential-sichuan-ziyang
3. European Central Bank, https://www.ecb.europa.eu/stats/financial_markets_and_interest_rates/euro_area_yield_curves/html/index.en.html
4. Global Petrol Prices, https://it.globalpetrolprices.com/China/gasoline_prices/
5. Ilostat, https://ilostat.ilo.org/topics/labour-costs/
6. Investopedia, https://www.investopedia.com/terms/c/certaintyequivalent.asp
7. OECD, https://www.oecd-ilibrary.org/sites/9789264085169-12-en/index.html?itemId=/content/component/9789264085169-12-en
8. Sst, https://ssti.us/wp-content/uploads/sites/1303/2013/10/PedBikeCosts.pdf
9. Tax summaries, https://taxsummaries.pwc.com/peoples-republic-of-china/individual/taxes-on-personal-income
10. Trading Economics, https://tradingeconomics.com/china/government-bond-yield

Appendices

Appendix 1

Table A1.1. European companies panel (Source: Damodaran, 2020)

Company Name	*Industry Group*	*Country*
01Cyberaton S.A. (WSE:01C)	Green & Renewable Energy	Poland
7C Solarparken AG (XTRA:HRPK)	Green & Renewable Energy	Germany
a.i.s. AG (DB:LUM)	Environmental & Waste Services	Germany
Abengoa, S.A. (BME:ABG)	Engineering/Construction	Spain
ABO Invest AG (DUSE:ABO)	Green & Renewable Energy	Germany
ABO-Group Environment NV (ENXTBR:ABO)	Environmental & Waste Services	Belgium
ACS, Actividades de Construcción y Servicios, S.A. (BME:ACS)	Engineering/Construction	Spain
Adapteo Oyj (OM:ADAPT)	Engineering/Construction	Finland
Advantag Aktiengesellschaft (DUSE:A62)	Environmental & Waste Services	Germany
Aega ASA (OB:AEGA)	Green & Renewable Energy	Norway
AEGEK S.A. (ATSE:AEGEK)	Engineering/Construction	Greece
AF Gruppen ASA (OB:AFG)	Engineering/Construction	Norway
Agatos S.p.A. (BIT:AGA)	Engineering/Construction	Italy
Aggregated Micro Power Holdings plc (AIM:AMPH)	Green & Renewable Energy	United Kingdom
Agripower France SA (ENXTPA:ALAGP)	Engineering/Construction	France
Airtificial Intelligence Structures, S.A. (BME:AI)	Engineering/Construction	Spain
Aksu Enerji ve Ticaret Anonim Sirketi (IBSE:AKSUE)	Green & Renewable Energy	Turkey
ALBA SE (DB:ABA)	Environmental & Waste Services	Germany
Albioma (ENXTPA:ABIO)	Green & Renewable Energy	France
Alerion Clean Power S.p.A. (BIT:ARN)	Green & Renewable Energy	Italy
ALTEO Energiaszolgaltato Nyilvanosan Mukodo Reszvenytarsasag (BUSE:ALTEO)	Green & Renewable Energy	Hungary
Ambienthesis S.p.A. (BIT:ATH)	Environmental & Waste Services	Italy
Anel Elektrik Proje Taahhüt ve Ticaret Anonim Sirketi (IBSE:ANELE)	Engineering/Construction	Turkey
Aqua S.A. (WSE:AQA)	Engineering/Construction	Poland
Arcadis NV (ENXTAM:ARCAD)	Engineering/Construction	Netherlands

Arise AB (publ) (OM:ARISE)	Green & Renewable Energy	Sweden
Astaldi S.p.A. (BIT:AST)	Engineering/Construction	Italy
Athena Investments A/S (CPSE:ATHENA)	Green & Renewable Energy	Denmark
Atlantica Yield plc (NasdaqGS:AY)	Green & Renewable Energy	United Kingdom
ATON-HT S.A. (WSE:ATO)	Environmental & Waste Services	Poland
Atrem S.A. (WSE:ATR)	Engineering/Construction	Poland
Audax Renovables, S.A. (BME:ADX)	Green & Renewable Energy	Spain
Augean plc (AIM:AUG)	Environmental & Waste Services	United Kingdom
Aurea SA (ENXTPA:AURE)	Environmental & Waste Services	France
Avax S.A. (ATSE:AVAX)	Engineering/Construction	Greece
aventron AG (BRSE:AVEN)	Green & Renewable Energy	Switzerland
Awbud S.A. (WSE:AWB)	Engineering/Construction	Poland
Balfour Beatty plc (LSE:BBY)	Engineering/Construction	United Kingdom
BAUER Aktiengesellschaft (XTRA:B5A)	Engineering/Construction	Germany
Befesa S.A. (XTRA:BFSA)	Environmental & Waste Services	Luxembourg
Biancamano S.p.A. (BIT:BCM)	Environmental & Waste Services	Italy
Biffa plc (LSE:BIFF)	Environmental & Waste Services	United Kingdom
Bilby Plc (AIM:BILB)	Environmental & Waste Services	United Kingdom
Billington Holdings Plc (AIM:BILN)	Engineering/Construction	United Kingdom
Bioter S.A. (ATSE:BIOT)	Engineering/Construction	Greece
Biovolt AG (WBAG:VOLT)	Green & Renewable Energy	Switzerland
Bomonti Elektrik Muhendislik Musavirlik Insaat Turizm Ve Ticaret A.S. (IBSE:BMELK)	Green & Renewable Energy	Turkey
Bouygues SA (ENXTPA:EN)	Engineering/Construction	France
Budimex SA (WSE:BDX)	Engineering/Construction	Poland
Burkhalter Holding AG (SWX:BRKN)	Engineering/Construction	Switzerland
ByggPartner i Dalarna Holding AB (publ) (OM:BYGGP)	Engineering/Construction	Sweden
CD Deutsche Eigenheim AG (HMSE:D2B)	Engineering/Construction	Germany
Centrum Nowoczesnych Technologii S.A. (WSE:CNT)	Engineering/Construction	Poland
CLERHP Estructuras, S.A. (BME:CLR)	Engineering/Construction	Spain
CNIM Group S.A. (ENXTPA:COM)	Environmental & Waste Services	France

Colas SA (ENXTPA:RE)	Engineering/Construction	France
Compagnie d'Entreprises CFE SA (ENXTBR:CFEB)	Engineering/Construction	Belgium
Compagnie Industrielle et Financière d'Entreprises SA (ENXTPA:INFE)	Engineering/Construction	France
Consti Yhtiöt Oyj (HLSE:CONSTI)	Engineering/Construction	Finland
Costain Group PLC (LSE:COST)	Engineering/Construction	United Kingdom
DB Energy S.A. (WSE:DBE)	Environmental & Waste Services	Poland
Dekpol S.A. (WSE:DEK)	Engineering/Construction	Poland
Derichebourg (ENXTPA:DBG)	Environmental & Waste Services	France
Domiki Kritis S.A. (ATSE:DOMIK)	Engineering/Construction	Greece
Driver Group plc (AIM:DRV)	Engineering/Construction	United Kingdom
Drop S.A. (WSE:DRP)	Environmental & Waste Services	Poland
Duro Felguera, S.A. (BME:MDF)	Engineering/Construction	Spain
EAM Solar ASA (OB:EAM)	Green & Renewable Energy	Norway
Ecoslops S.A. (ENXTPA:ALESA)	Environmental & Waste Services	France
Ecosuntek S.p.A. (BIT:ECK)	Green & Renewable Energy	Italy
EdiliziAcrobatica S.p.A. (BIT:EDAC)	Engineering/Construction	Italy
Edisun Power Europe AG (SWX:ESUN)	Green & Renewable Energy	Switzerland
EDP Renováveis, S.A. (ENXTLS:EDPR)	Green & Renewable Energy	Spain
Eiffage SA (ENXTPA:FGR)	Engineering/Construction	France
Ekobox S.A. (WSE:EBX)	Engineering/Construction	Poland
Ekter SA (ATSE:EKTER)	Engineering/Construction	Greece
Elecnor, S.A. (BME:ENO)	Engineering/Construction	Spain
Electrawinds SE (DB:EWI)	Green & Renewable Energy	Belgium
Elektromont Spólka Akcyjna (WSE:ELM)	Engineering/Construction	Poland
Elemental Holding S.A. (WSE:EMT)	Environmental & Waste Services	Poland
Ellaktor S.A. (ATSE:ELLAKTOR)	Engineering/Construction	Greece
Eltel AB (publ) (OM:ELTEL)	Engineering/Construction	Sweden
Encavis AG (XTRA:CAP)	Green & Renewable Energy	Germany
Energie Europe Service (ENXTPA:MLEES)	Green & Renewable Energy	France
Energoaparatura SA (WSE:ENP)	Engineering/Construction	Poland
Eolus Vind AB (publ) (OM:EOLU B)	Engineering/Construction	Sweden
EQTEC plc (AIM:EQT)	Green & Renewable Energy	Ireland
Erbud S.A. (WSE:ERB)	Engineering/Construction	Poland

Etrion Corporation (TSX:ETX)	Green & Renewable Energy	Switzerland
Europlasma S.A. (ENXTPA:ALEUP)	Environmental & Waste Services	France
Eurosystem Spólka Akcyjna (WSE:ERS)	Engineering/Construction	Poland
EWPG Holding AB (publ) (OM:EWP)	Green & Renewable Energy	Sweden
Fabryka Konstrukcji Drewnianych S.A. (WSE:FKD)	Engineering/Construction	Poland
Falck Renewables S.p.A. (BIT:FKR)	Green & Renewable Energy	Italy
Ferrovial, S.A. (BME:FER)	Engineering/Construction	Spain
Filta Group Holdings plc (AIM:FLTA)	Environmental & Waste Services	United Kingdom
Fomento de Construcciones y Contratas, S.A. (BME:FCC)	Engineering/Construction	Spain
Forbuild SA (WSE:BTX)	Engineering/Construction	Poland
Frendy Energy S.p.A. (BIT:FDE)	Green & Renewable Energy	Italy
Galliford Try plc (LSE:GFRD)	Engineering/Construction	United Kingdom
GEK TERNA Holdings, Real Estate, Construction S.A. (ATSE:GEKTERNA)	Engineering/Construction	Greece
Geotrans S.A. (WSE:GTS)	Environmental & Waste Services	Poland
Global EcoPower Société Anonyme (ENXTPA:ALGEP)	Engineering/Construction	France
Green Landscaping Group AB (publ) (OM:GREEN)	Environmental & Waste Services	Sweden
Greenalia, S.A. (BME:GRN)	Green & Renewable Energy	Spain
Greencoat Renewables PLC (ISE:GRP)	Green & Renewable Energy	Ireland
Grenergy Renovables, S.A. (BME:GRE)	Green & Renewable Energy	Spain
Griñó Ecologic, S.A. (BME:GRI)	Environmental & Waste Services	Spain
Groupe Pizzorno Environnement (ENXTPA:GPE)	Environmental & Waste Services	France
Grupa RECYKL S.A. (WSE:GRC)	Environmental & Waste Services	Poland
Grupo Empresarial San José, S.A. (BME:GSJ)	Engineering/Construction	Spain
Heijmans N.V. (ENXTAM:HEIJM)	Engineering/Construction	Netherlands
HOCHTIEF Aktiengesellschaft (XTRA:HOT)	Engineering/Construction	Germany
Hutter & Schrantz Stahlbau AG (WBAG:HST)	Engineering/Construction	Austria
IDH Development S.A. (WSE:IDH)	Engineering/Construction	Poland
Implenia AG (SWX:IMPN)	Engineering/Construction	Switzerland

Iniziative Bresciane S.p.A. (BIT:IB)	Green & Renewable Energy	Italy
Instal Kraków S.A. (WSE:INK)	Engineering/Construction	Poland
Instalco AB (publ) (OM:INSTAL)	Engineering/Construction	Sweden
Intracom Constructions Societe Anonyme Technical and Steel Constructions (ATSE:INKAT)	Engineering/Construction	Greece
J. Smart & Co. (Contractors) PLC (LSE:SMJ)	Engineering/Construction	United Kingdom
John Laing Group plc (LSE:JLG)	Engineering/Construction	United Kingdom
Keller Group plc (LSE:KLR)	Engineering/Construction	United Kingdom
Kier Group plc (LSE:KIE)	Engineering/Construction	United Kingdom
Kollect on Demand Holding AB (publ) (OM:KOLL)	Environmental & Waste Services	Ireland
Koninklijke BAM Groep nv (ENXTAM:BAMNB)	Engineering/Construction	Netherlands
Krynicki Recykling Spólka Akcyjna (WSE:KRC)	Environmental & Waste Services	Poland
Lassila & Tikanoja Oyj (HLSE:LAT1V)	Environmental & Waste Services	Finland
Lehto Group Oyj (HLSE:LEHTO)	Engineering/Construction	Finland
Maire Tecnimont S.p.A. (BIT:MT)	Engineering/Construction	Italy
Martifer SGPS, S.A. (ENXTLS:MAR)	Engineering/Construction	Portugal
MDI Energia S.A. (WSE:MDI)	Green & Renewable Energy	Poland
Metallvärden i Sverige AB (publ.) (NGM:METV)	Environmental & Waste Services	Sweden
Mirbud S.A. (WSE:MRB)	Engineering/Construction	Poland
Mitie Group plc (LSE:MTO)	Environmental & Waste Services	United Kingdom
Mo-BRUK S.A. (WSE:MBR)	Environmental & Waste Services	Poland
Morgan Sindall Group plc (LSE:MGNS)	Engineering/Construction	United Kingdom
Mostostal Plock S.A. (WSE:MSP)	Engineering/Construction	Poland
Mostostal Warszawa S.A. (WSE:MSW)	Engineering/Construction	Poland
Mostostal Zabrze S.A. (WSE:MSZ)	Engineering/Construction	Poland
Mota-Engil, SGPS, S.A. (ENXTLS:EGL)	Engineering/Construction	Portugal
Mountfield Group Plc (AIM:MOGP)	Engineering/Construction	United Kingdom
Moury Construct SA (ENXTBR:MOUR)	Engineering/Construction	Belgium
MT Højgaard Holding A/S (CPSE:MTHH)	Engineering/Construction	Denmark
Muehlhan AG (XTRA:M4N)	Engineering/Construction	Germany
Naturel Yenilenebilir Enerji Ticaret A.S. (IBSE:NATEN)	Green & Renewable Energy	Turkey

NCC AB (publ) (OM:NCC B)	Engineering/Construction	Sweden
Neoen S.A. (ENXTPA:NEOEN)	Green & Renewable Energy	France
New Sources Energy NV (ENXTAM:NSE)	Green & Renewable Energy	Netherlands
Nexus Infrastructure plc (AIM:NEXS)	Engineering/Construction	United Kingdom
Nigbas Nigde Beton Sanayi Ve Ticaret A.S. (IBSE:NIBAS)	Engineering/Construction	Turkey
nmcn plc (LSE:NMCN)	Engineering/Construction	United Kingdom
NRC Group ASA (OB:NRC)	Engineering/Construction	Norway
Obrascón Huarte Lain, S.A. (BME:OHL)	Engineering/Construction	Spain
Oranjewoud N.V. (ENXTAM:ORANW)	Engineering/Construction	Netherlands
Orege Société Anonyme (ENXTPA:OREGE)	Environmental & Waste Services	France
Orge Enerji Elektrik Taahhüt Anonim Sirketi (IBSE:ORGE)	Engineering/Construction	Turkey
Orzel Bialy S.A. (WSE:OBL)	Environmental & Waste Services	Poland
Ostim Endüstriyel Yatirimlar ve Isletme A.S. (IBSE:OSTIM)	Engineering/Construction	Turkey
P.A. Nova S.A. (WSE:NVA)	Engineering/Construction	Poland
PannErgy Plc (BUSE:PANNERGY)	Green & Renewable Energy	Hungary
PBG S.A. (WSE:PBG)	Engineering/Construction	Poland
Peab AB (publ) (OM:PEAB B)	Engineering/Construction	Sweden
Pekabex S.A. (WSE:PBX)	Engineering/Construction	Poland
Per Aarsleff Holding A/S (CPSE:PAAL B)	Engineering/Construction	Denmark
Philipp Holzmann AG (DB:HOZ)	Engineering/Construction	Germany
PLC S.p.A. (BIT:PLC)	Engineering/Construction	Italy
Poenina Holding AG (SWX:PNHO)	Engineering/Construction	Switzerland
Polenergia S.A. (WSE:PEP)	Green & Renewable Energy	Poland
Polimex-Mostostal S.A. (WSE:PXM)	Engineering/Construction	Poland
PORR AG (WBAG:POS)	Engineering/Construction	Austria
Pri Ekopark Spólka Akcyjna (WSE:EPR)	Engineering/Construction	Poland
Prochem S.A. (WSE:PRM)	Engineering/Construction	Poland
Proodeftiki S.A. (ATSE:PRD)	Engineering/Construction	Greece
Przedsiebiorstwo Modernizacji Urzadzen Energetycznych REMAK S.A. (WSE:RMK)	Engineering/Construction	Poland
Przedsiebiorstwo Przemyslu Betonów PREFABET - Biale Blota S.A. (WSE:PBB)	Engineering/Construction	Poland
Quantafuel AS (OTCNO:QFUEL)	Environmental & Waste Services	Norway

R Energy 1 S.A. (CSE:ROEN)	Green & Renewable Energy	Greece
REACT Group plc (AIM:REAT)	Environmental & Waste Services	United Kingdom
Renergetica S.p.A. (BIT:REN)	Green & Renewable Energy	Italy
Renew Holdings plc (AIM:RNWH)	Engineering/Construction	United Kingdom
Renewi plc (LSE:RWI)	Environmental & Waste Services	United Kingdom
Rentokil Initial plc (LSE:RTO)	Environmental & Waste Services	United Kingdom
Resbud SE (WSE:RES)	Engineering/Construction	Poland
Royal Boskalis Westminster N.V. (ENXTAM:BOKA)	Engineering/Construction	Netherlands
Royal VolkerWessels nv (ENXTAM:KVW)	Engineering/Construction	Netherlands
RPS Group plc (LSE:RPS)	Environmental & Waste Services	United Kingdom
Sächsische & Oldenburgische Agrar Aktiengesellschaft (DB:BUF)	Engineering/Construction	Germany
Sacyr, S.A. (BME:SCYR)	Engineering/Construction	Spain
Salcef Group S.p.A. (BIT:SCF)	Engineering/Construction	Italy
Salini Impregilo S.p.A. (BIT:SAL)	Engineering/Construction	Italy
Saxlund Group AB (publ) (OM:SAXG)	Environmental & Waste Services	Sweden
Scandinavian Enviro Systems AB (publ) (OM:SES)	Environmental & Waste Services	Sweden
Scanship Holding ASA (OB:SSHIP)	Environmental & Waste Services	Norway
Scatec Solar ASA (OB:SSO)	Green & Renewable Energy	Norway
Sdiptech AB (publ) (OM:SDIP B)	Environmental & Waste Services	Sweden
Séché Environnement SA (ENXTPA:SCHP)	Environmental & Waste Services	France
Serco Group plc (LSE:SRP)	Environmental & Waste Services	United Kingdom
Serneke Group AB (publ) (OM:SRNKE B)	Engineering/Construction	Sweden
Severfield plc (LSE:SFR)	Engineering/Construction	United Kingdom
Skanska AB (publ) (OM:SKA B)	Engineering/Construction	Sweden
Slitevind AB (OM:SLITE)	Green & Renewable Energy	Sweden
Solaria Energía y Medio Ambiente, S.A. (BME:SLR)	Green & Renewable Energy	Spain
SRV Yhtiöt Oyj (HLSE:SRV1V)	Engineering/Construction	Finland
Strabag SE (WBAG:STR)	Engineering/Construction	Austria
Studsvik AB (publ) (OM:SVIK)	Environmental & Waste Services	Sweden
SW Umwelttechnik Stoiser & Wolschner AG (WBAG:SWUT)	Engineering/Construction	Austria
Sweco AB (publ) (OM:SWEC B)	Engineering/Construction	Sweden

TClarke plc (LSE:CTO)	Engineering/Construction	United Kingdom
Teixeira Duarte, S.A. (ENXTLS:TDSA)	Engineering/Construction	Portugal
Tekfen Holding Anonim Sirketi (IBSE:TKFEN)	Engineering/Construction	Turkey
Terna Energy Societe Anonyme Commercial Technical Company (ATSE:TENERGY)	Green & Renewable Energy	Greece
TiksPac AB (publ) (NGM:TIKS)	Environmental & Waste Services	Sweden
Tomra Systems ASA (OB:TOM)	Environmental & Waste Services	Norway
Torpol S.A. (WSE:TOR)	Engineering/Construction	Poland
Trakcja PRKiI S.A. (WSE:TRK)	Engineering/Construction	Poland
Trention AB (publ) (OM:TRENT)	Green & Renewable Energy	Sweden
TREVI - Finanziaria Industriale S.p.A. (BIT:TFI)	Engineering/Construction	Italy
ULMA Construccion Polska S.A. (WSE:ULM)	Engineering/Construction	Poland
UNIBEP S.A. (WSE:UNI)	Engineering/Construction	Poland
Van Elle Holdings plc (AIM:VANL)	Engineering/Construction	United Kingdom
Veidekke ASA (OB:VEI)	Engineering/Construction	Norway
Velcan Holdings S.A. (ENXTPA:ALVEL)	Green & Renewable Energy	Luxembourg
Verditek plc (AIM:VDTK)	Environmental & Waste Services	United Kingdom
VINCI SA (ENXTPA:DG)	Engineering/Construction	France
Vistal Gdynia S.A. (WSE:VTL)	Engineering/Construction	Poland
VivoPower International PLC (NasdaqCM:VVPR)	Green & Renewable Energy	United Kingdom
Voltalia SA (ENXTPA:VLTSA)	Green & Renewable Energy	France

Table A1.2. Chinese companies panel (Source: Damodaran, 2020)

Company Name	*Industry Group*
A-Living Services Co., Ltd. (SEHK:3319)	Environmental & Waste Services
Anhui Construction Engineering Group Co., Ltd. (SHSE:600502)	Engineering/Construction
Anhui Gourgen Traffic Construction Co., Ltd. (SHSE:603815)	Engineering/Construction
Anhui Guozhen Environment Protection Technology Joint Stock Co., Limited (SZSE:300388)	Environmental & Waste Services
Anhui Zhonghuan Environmental Protection Technology Co., Ltd. (SZSE:300692)	Environmental & Waste Services
AVIC Sanxin Co., Ltd. (SZSE:002163)	Engineering/Construction
Baoye Group Company Limited (SEHK:2355)	Engineering/Construction
Beijing Airport High-Tech Park Co., Ltd. (SHSE:600463)	Engineering/Construction

Beijing GeoEnviron Engineering & Technology, Inc. (SHSE:603588)	Environmental & Waste Services
Beijing Kaiwen Education Technology Co., Ltd. (SZSE:002659)	Engineering/Construction
Beijing Orient Landscape & Environment Co.,Ltd. (SZSE:002310)	Engineering/Construction
Beijing Originwater Technology Co., Ltd. (SZSE:300070)	Environmental & Waste Services
Beijing Qianjing Landscape Co.,Ltd (SHSE:603778)	Environmental & Waste Services
Bestway Marine & Energy Technology Co.,Ltd (SZSE:300008)	Engineering/Construction
Black Peony (Group) Co., Ltd. (SHSE:600510)	Engineering/Construction
Boyuan Construction Group, Inc. (TSX:BOY)	Engineering/Construction
CEC Environmental Protection Co., Ltd. (SZSE:300172)	Environmental & Waste Services
CECEP Solar Energy Co.,Ltd. (SZSE:000591)	Green & Renewable Energy
CECEP Wind-power Corporation Co.,Ltd. (SHSE:601016)	Green & Renewable Energy
Center International Group Co.,Ltd. (SHSE:603098)	Engineering/Construction
Central Plains Environment Protection Co.,Ltd. (SZSE:000544)	Environmental & Waste Services
Changjiang & Jinggong Steel Building (Group) Co., Ltd (SHSE:600496)	Engineering/Construction
Changsha Broad Homes Industrial Group Co., Ltd. (SEHK:2163)	Engineering/Construction
Changshu Fengfan Power Equipment Co., Ltd. (SHSE:601700)	Engineering/Construction
Chanhigh Holdings Limited (SEHK:2017)	Engineering/Construction
Chengbang Eco-Environment Co.,Ltd. (SHSE:603316)	Engineering/Construction
Chengdu Road & Bridge Engineering CO.,LTD (SZSE:002628)	Engineering/Construction
China Aluminum International Engineering Corporation Limited (SHSE:601068)	Engineering/Construction
China Boqi Environmental (Holding) Co., Ltd. (SEHK:2377)	Environmental & Waste Services
China CAMC Engineering Co., Ltd. (SZSE:002051)	Engineering/Construction
China Communications Construction Company Limited (SEHK:1800)	Engineering/Construction
China Communications Services Corporation Limited (SEHK:552)	Engineering/Construction
China Datang Corporation Renewable Power Co., Limited (SEHK:1798)	Green & Renewable Energy
China Energy Engineering Corporation Limited (SEHK:3996)	Engineering/Construction
China Gezhouba Group Company Limited (SHSE:600068)	Engineering/Construction

China Greenland Broad Greenstate Group Company Limited (SEHK:1253)	Environmental & Waste Services
China Haisum Engineering Co., Ltd. (SZSE:002116)	Engineering/Construction
China Industrial Waste Management, Inc. (OTCPK:CIWT)	Environmental & Waste Services
China Longyuan Power Group Corporation Limited (SEHK:916)	Green & Renewable Energy
China Machinery Engineering Corporation (SEHK:1829)	Engineering/Construction
China National Chemical Engineering Co., Ltd (SHSE:601117)	Engineering/Construction
China New Energy Limited (AIM:CNEL)	Engineering/Construction
China Nuclear Engineering Corporation Limited (SHSE:601611)	Engineering/Construction
China Railway Construction Corporation Limited (SHSE:601186)	Engineering/Construction
China Railway Group Limited (SHSE:601390)	Engineering/Construction
China Railway Hi-tech Industry Corporation Limited (SHSE:600528)	Engineering/Construction
China Recycling Energy Corporation (NasdaqCM:CREG)	Environmental & Waste Services
China Resources and Environment Co.,Ltd. (SHSE:600217)	Environmental & Waste Services
China Saite Group Company Limited (SEHK:153)	Engineering/Construction
China State Construction Engineering Corporation Limited (SHSE:601668)	Engineering/Construction
China Tianbao Group Development Company Limited (SEHK:1427)	Engineering/Construction
China Tianying Inc. (SZSE:000035)	Environmental & Waste Services
China U-Ton Holdings Limited (SEHK:6168)	Engineering/Construction
China Yangtze Power Co.,Ltd. (SHSE:600900)	Green & Renewable Energy
China Zhonghua Geotechnical Engineering Group Co., Ltd. (SZSE:002542)	Engineering/Construction
Chongqing Construction Engineering Group Corporation Limited (SHSE:600939)	Engineering/Construction
Country Garden Services Holdings Company Limited (SEHK:6098)	Environmental & Waste Services
CSD Water Service Co., Ltd. (SHSE:603903)	Environmental & Waste Services
CSSC Science & Technology Co., Ltd. (SHSE:600072)	Engineering/Construction
Daqian Ecology&Environment Group Co.,Ltd. (SHSE:603955)	Environmental & Waste Services
Datang Environment Industry Group Co., Ltd. (SEHK:1272)	Environmental & Waste Services
Dionics, Inc. (OTCPK:DION)	Environmental & Waste Services
Dongzhu Ecological Environment Protection Co.,Ltd (SHSE:603359)	Environmental & Waste Services

Dynagreen Environmental Protection Group Co., Ltd. (SEHK:1330)	Environmental & Waste Services
East China Engineering Science and Technology Co., Ltd. (SZSE:002140)	Engineering/Construction
Far East Wind Power Corp. (OTCPK:FEWP)	Green & Renewable Energy
Flower King Eco-Engineering Inc. (SHSE:603007)	Environmental & Waste Services
Focused Photonics (Hangzhou), Inc. (SZSE:300203)	Environmental & Waste Services
Fujian Haixia Environmental Protection Group Co.,Ltd. (SHSE:603817)	Environmental & Waste Services
GCL Energy Technology Co., Ltd. (SZSE:002015)	Green & Renewable Energy
GEPIC Energy Development Co., Ltd. (SZSE:000791)	Green & Renewable Energy
Guangdong Adway Construction (Group) Holdings Company Limited (SEHK:6189)	Engineering/Construction
Guangdong Liantai Environmental Protection Co.,Ltd. (SHSE:603797)	Environmental & Waste Services
Guangdong Meiyan Jixiang Hydropower Co., Ltd. (SHSE:600868)	Green & Renewable Energy
Guangdong No.2 Hydropower Engineering Company, Ltd. (SZSE:002060)	Engineering/Construction
Guangxi Bossco Environmental Protection Technology Co.,Ltd. (SZSE:300422)	Environmental & Waste Services
GuiZhou QianYuan Power Co., Ltd. (SZSE:002039)	Green & Renewable Energy
Haibo Heavy Engineering Science and Technology Co., Ltd. (SZSE:300517)	Engineering/Construction
Hang Xiao Steel Structure Co.,Ltd (SHSE:600477)	Engineering/Construction
Hangzhou Freely Communication Co., Ltd. (SHSE:603602)	Engineering/Construction
Hebei Construction Group Corporation Limited (SEHK:1727)	Engineering/Construction
Henan Provincial Communications Planning & Design Institute Co., Ltd. (SZSE:300732)	Engineering/Construction
HES Technology Group Co., Ltd. (SZSE:002963)	Engineering/Construction
Hongrun Construction Group Co., Ltd. (SZSE:002062)	Engineering/Construction
Huadian Heavy Industries Co., Ltd. (SHSE:601226)	Engineering/Construction
Huaneng Lancang River Hydropower Inc. (SHSE:600025)	Green & Renewable Energy
Huaneng Renewables Corporation Limited (SEHK:958)	Green & Renewable Energy
Huayu Expressway Group Limited (SEHK:1823)	Engineering/Construction
Hunan Baili Engineering Sci&Tech Co.,Ltd (SHSE:603959)	Engineering/Construction

Hunan Development Group Co.,Ltd (SZSE:000722)	Green & Renewable Energy
Inner Mongolia M-Grass Ecology And Environment (Group) Co., Ltd. (SZSE:300355)	Engineering/Construction
Jangho Group Co., Ltd. (SHSE:601886)	Engineering/Construction
Jiangsu Boxin Investing&Holdings Co.,Ltd. (SHSE:600083)	Engineering/Construction
JiangSu JiuWu Hi-Tech Co., Ltd. (SZSE:300631)	Environmental & Waste Services
Jiangsu New Energy Development Co., Ltd. (SHSE:603693)	Green & Renewable Energy
Jiangsu Seagull Cooling Tower Co.,Ltd. (SHSE:603269)	Engineering/Construction
Jiangsu Zhongshe Group Co., Ltd. (SZSE:002883)	Engineering/Construction
JSTI Group (SZSE:300284)	Engineering/Construction
Jujiang Construction Group Co., Ltd. (SEHK:1459)	Engineering/Construction
Keda Group Co., Ltd. (SHSE:600986)	Engineering/Construction
L&K Engineering (Suzhou) Co.,Ltd. (SHSE:603929)	Engineering/Construction
Lawton Development Co., Ltd (SHSE:600209)	Engineering/Construction
Leader Environmental Technologies Limited (SGX:LS9)	Environmental & Waste Services
LingNan Eco&Culture-Tourism Co.,Ltd. (SZSE:002717)	Engineering/Construction
Long Yuan Construction Group Co.,Ltd (SHSE:600491)	Engineering/Construction
LongiTech Smart Energy Holding Limited (SEHK:1281)	Green & Renewable Energy
Longjian Road&Bridge Co.,Ltd (SHSE:600853)	Engineering/Construction
Metallurgical Corporation of China Ltd. (SEHK:1618)	Engineering/Construction
Misho Ecology & Landscape Co.,Ltd. (SZSE:300495)	Environmental & Waste Services
Ning Xia Yin Xing Energy Co.,Ltd (SZSE:000862)	Green & Renewable Energy
Ningbo Construction Co., Ltd. (SHSE:601789)	Engineering/Construction
Ningxia Jiaze Renewables Corporation Limited (SHSE:601619)	Green & Renewable Energy
Ningxia Qinglong Pipes Industry Co.,LTD. (SZSE:002457)	Engineering/Construction
Norinco International Cooperation Ltd. (SZSE:000065)	Engineering/Construction
Northcom Group Co., Ltd. (SZSE:002359)	Engineering/Construction
Palm Eco-Town Development Co., Ltd (SZSE:002431)	Engineering/Construction
Penyao Environmental Protection Co., Ltd. (SZSE:300664)	Environmental & Waste Services
Poten Environment Group Co., Ltd. (SHSE:603603)	Environmental & Waste Services

Power Construction Corporation of China, Ltd (SHSE:601669)	Engineering/Construction
Qingdao Huicheng Environmental Technology Co., Ltd. (SZSE:300779)	Environmental & Waste Services
RINO International Corporation (OTCPK:RINO)	Environmental & Waste Services
Runjian Co., Ltd. (SZSE:002929)	Engineering/Construction
Saurer Intelligent Technology Co.,Ltd. (SHSE:600545)	Engineering/Construction
Shaanxi Yanchang Petroleum Chemical Engineering Co., Ltd. (SHSE:600248)	Engineering/Construction
Shandong Hi-Speed Road&Bridge Co., LTD. (SZSE:000498)	Engineering/Construction
Shandong Lipeng Co., Ltd. (SZSE:002374)	Environmental & Waste Services
Shandong Meichen Ecology & Environment Co.,Ltd. (SZSE:300237)	Environmental & Waste Services
Shanghai Chengdi Construction Corporation LTD (SHSE:603887)	Engineering/Construction
Shanghai Construction Group Co., Ltd. (SHSE:600170)	Engineering/Construction
Shanghai Emperor of Cleaning Hi-Tech Co., Ltd (SHSE:603200)	Environmental & Waste Services
Shanghai Environment Group Co., Ltd (SHSE:601200)	Environmental & Waste Services
Shanghai Lingyun Industries Development Co., Ltd (SHSE:900957)	Green & Renewable Energy
Shanghai Pudong Road & Bridge Construction Co., Ltd. (SHSE:600284)	Engineering/Construction
Shanghai Tongji Science & Technology Industrial Co.,Ltd (SHSE:600846)	Engineering/Construction
Shanghai Tunnel Engineering Co., Ltd. (SHSE:600820)	Engineering/Construction
Shanghai Yanhua Smartech Group Co., Ltd. (SZSE:002178)	Engineering/Construction
Shenwu Energy Saving Co., Ltd. (SZSE:000820)	Environmental & Waste Services
Shenzhen Asiantime International Construction Co., Ltd. (SZSE:002811)	Engineering/Construction
Shenzhen Bauing Construction Holding Group Co., Ltd. (SZSE:002047)	Engineering/Construction
Shenzhen Ecobeauty Co., Ltd. (SZSE:000010)	Environmental & Waste Services
Shenzhen Glory Medical Co., Ltd. (SZSE:002551)	Engineering/Construction
Shenzhen Grandland Group Co., Ltd. (SZSE:002482)	Engineering/Construction
Shenzhen Hongtao Group Co., Ltd. (SZSE:002325)	Engineering/Construction
Shenzhen Magic Design & Decoration Engineering Co.,Ltd (SZSE:002856)	Engineering/Construction
Shenzhen Minkave Technology Co., Ltd. (SZSE:300506)	Engineering/Construction
Shenzhen Tagen Group Co., Ltd. (SZSE:000090)	Engineering/Construction

Shenzhen Techand Ecology & Environment Co., Ltd. (SZSE:300197)	Engineering/Construction
Shenzhen Wenke Landscape Co., Ltd. (SZSE:002775)	Environmental & Waste Services
Shenzhen Zhongzhuang Construction Group Co.,Ltd (SZSE:002822)	Engineering/Construction
Sichuan Chuantou Energy Co.,Ltd. (SHSE:600674)	Green & Renewable Energy
Sichuan Road & Bridge Co.,Ltd (SHSE:600039)	Engineering/Construction
Sino Great Wall Co., Ltd. (SZSE:200018)	Engineering/Construction
SinoDaan Co., Ltd. (SZSE:300635)	Engineering/Construction
Sinoma Energy Conservation Ltd. (SHSE:603126)	Environmental & Waste Services
Sinoma International Engineering Co., Ltd. (SHSE:600970)	Engineering/Construction
SINOPEC Engineering (Group) Co., Ltd. (SEHK:2386)	Engineering/Construction
Sinosteel Engineering & Technology Co., Ltd. (SZSE:000928)	Engineering/Construction
Spic Yuanda Environmental-Protection Co.,Ltd. (SHSE:600292)	Environmental & Waste Services
Suntar Environmental Technology Co., Ltd. (SHSE:688101)	Environmental & Waste Services
Suzhou Gold Mantis Construction Decoration Co., Ltd. (SZSE:002081)	Engineering/Construction
Suzhou Institute of Building Science Group Co., Ltd. (SHSE:603183)	Engineering/Construction
Telidyne Inc. (OTCPK:TLDN)	Engineering/Construction
Tengda Construction Group Co., Ltd. (SHSE:600512)	Engineering/Construction
TianGuang ZhongMao Co.,Ltd. (SZSE:002509)	Environmental & Waste Services
Tianjin Capital Environmental Protection Group Company Limited (SHSE:600874)	Environmental & Waste Services
Tianjin LVYIN Landscape and Ecology Construction Co., Ltd (SZSE:002887)	Engineering/Construction
Tianjin MOTIMO Membrane Technology Co.,Ltd (SZSE:300334)	Environmental & Waste Services
TianYu Eco-Environment Co.,Ltd (SHSE:603717)	Environmental & Waste Services
Tibet Tianlu Co., Ltd. (SHSE:600326)	Engineering/Construction
Tieling Newcity Investment Holding (Group) Limited (SZSE:000809)	Engineering/Construction
TIL Enviro Limited (SEHK:1790)	Environmental & Waste Services
Times Neighborhood Holdings Limited (SEHK:9928)	Environmental & Waste Services
Tunghsu Azure Renewable Energy Co.,Ltd. (SZSE:000040)	Green & Renewable Energy
TUS ENVIRONMENTAL SCIENCE AND TECHNOLOGY DEVELOPMENT Co., LTD. (SZSE:000826)	Environmental & Waste Services

Watts International Maritime Engineering Limited (SEHK:2258)	Engineering/Construction
Weigang Environmental Technology Holding Group Limited (SEHK:1845)	Environmental & Waste Services
Wuhan Nusun Landscape Co., Ltd. (SZSE:300536)	Environmental & Waste Services
Wuhan Xianglong Power Industry Co.Ltd (SHSE:600769)	Engineering/Construction
Xiamen Lutong International Travel Agency Co. Ltd. (OTCPK:LTGJ)	Environmental & Waste Services
Xinjiang Beixin Road & Bridge Group Co., Ltd (SZSE:002307)	Engineering/Construction
Xinjiang Communications Construction Group Co., Ltd. (SZSE:002941)	Engineering/Construction
Xinte Energy Co., Ltd. (SEHK:1799)	Engineering/Construction
Xinyi Energy Holdings Limited (SEHK:3868)	Green & Renewable Energy
Yonker Environmental Protection Co.,Ltd. (SZSE:300187)	Environmental & Waste Services
Yuancheng Environment Co., Ltd. (SHSE:603388)	Environmental & Waste Services
Yunnan Yuntou Ecology and Environment Technology Co., Ltd. (SZSE:002200)	Environmental & Waste Services
Zhejiang Communications Technology Co.,Ltd. (SZSE:002061)	Engineering/Construction
Zhejiang Reclaim Construction Group Co., Ltd. (SZSE:002586)	Engineering/Construction
Zhejiang Southeast Space Frame Co., Ltd. (SZSE:002135)	Engineering/Construction
Zhejiang Tuna Environmental Science & TechnologyCo.,Ltd. (SHSE:603177)	Environmental & Waste Services
Zhejiang Weiming Environment Protection Co., Ltd. (SHSE:603568)	Environmental & Waste Services
Zheneng Jinjiang Environment Holding Company Limited (SGX:BWM)	Green & Renewable Energy
Zhengping Road & Bridge Construction Co., Ltd. (SHSE:603843)	Engineering/Construction
Zhenhai Petrochemical Engineering CO., LTD (SHSE:603637)	Engineering/Construction
Zhongmin Energy Co., Ltd. (SHSE:600163)	Green & Renewable Energy

Appendix 2

Table A2.1. Test values and probability of r_c and r_q for Italy (simulation performed with Oracle Crystal Ball software)

	r_{1t}					r_{2t}				
Bin di grafici	**Min**	**Max**	**Medio**	**Freq.**	**Prob.**	**Min.**	**Max.**	**Medio**	**Freq.**	**Prob.**
1	-12.31%	-11.89%	-12.10%	1	0.0001	-7.223%	-6.966%	-7.094%	1	0.0001
2	-11.89%	-11.48%	-11.69%	1	0.0001	-6.966%	-6.709%	-6.837%	1	0.0001
3	-11.48%	-11.07%	-11.27%	1	0.0001	-6.709%	-6.452%	-6.580%	1	0.0001
4	-11.07%	-10.65%	-10.86%	0	0	-6.452%	-6.194%	-6.323%	0	0
5	-10.65%	-10.24%	-10.45%	3	0.0003	-6.194%	-5.937%	-6.066%	3	0.0003
6	-10.24%	-9.83%	-10.03%	0	0	-5.937%	-5.680%	-5.809%	0	0
7	-9.83%	-9.41%	-9.62%	1	0.0001	-5.680%	-5.423%	-5.552%	1	0.0001
8	-9.41%	-9.00%	-9.21%	3	0.0003	-5.423%	-5.166%	-5.295%	3	0.0003
9	-9.00%	-8.59%	-8.79%	3	0.0003	-5.166%	-4.909%	-5.037%	3	0.0003
10	-8.59%	-8.17%	-8.38%	3	0.0003	-4.909%	-4.652%	-4.780%	3	0.0003
11	-8.17%	-7.76%	-7.97%	4	0.0004	-4.652%	-4.395%	-4.523%	4	0.0004
12	-7.76%	-7.35%	-7.55%	9	0.0009	-4.395%	-4.137%	-4.266%	9	0.0009
13	-7.35%	-6.93%	-7.14%	6	0.0006	-4.137%	-3.880%	-4.009%	6	0.0006
14	-6.93%	-6.52%	-6.73%	6	0.0006	-3.880%	-3.623%	-3.752%	6	0.0006
15	-6.52%	-6.11%	-6.31%	16	0.0016	-3.623%	-3.366%	-3.495%	16	0.0016
16	-6.11%	-5.69%	-5.90%	13	0.0013	-3.366%	-3.109%	-3.237%	13	0.0013
17	-5.69%	-5.28%	-5.49%	16	0.0016	-3.109%	-2.852%	-2.980%	16	0.0016
18	-5.28%	-4.87%	-5.07%	19	0.0019	-2.852%	-2.595%	-2.723%	19	0.0019
19	-4.87%	-4.45%	-4.66%	22	0.0022	-2.595%	-2.338%	-2.466%	22	0.0022
20	-4.45%	-4.04%	-4.25%	33	0.0033	-2.338%	-2.080%	-2.209%	33	0.0033
21	-4.04%	-3.63%	-3.83%	55	0.0055	-2.080%	-1.823%	-1.952%	55	0.0055
22	-3.63%	-3.21%	-3.42%	59	0.0059	-1.823%	-1.566%	-1.695%	59	0.0059
23	-3.21%	-2.80%	-3.01%	59	0.0059	-1.566%	-1.309%	-1.438%	59	0.0059
24	-2.80%	-2.38%	-2.59%	55	0.0055	-1.309%	-1.052%	-1.180%	55	0.0055
25	-2.38%	-1.97%	-2.18%	91	0.0091	-1.052%	-0.795%	-0.923%	91	0.0091
26	-1.97%	-1.56%	-1.76%	122	0.0122	-0.795%	-0.538%	-0.666%	122	0.0122
27	-1.56%	-1.14%	-1.35%	123	0.0123	-0.538%	-0.280%	-0.409%	123	0.0123
28	-1.14%	-0.73%	-0.94%	162	0.0162	-0.280%	-0.023%	-0.152%	162	0.0162
29	-0.73%	-0.32%	-0.52%	212	0.0212	-0.023%	0.234%	0.105%	212	0.0212
30	-0.32%	0.10%	-0.11%	243	0.0243	0.234%	0.491%	0.362%	243	0.0243
31	0.10%	0.51%	0.30%	274	0.0274	0.491%	0.748%	0.619%	274	0.0274
32	0.51%	0.92%	0.72%	347	0.0347	0.748%	1.005%	0.877%	347	0.0347

33	0.92%	1.34%	1.13%	433	0.0433	1.005%	1.262%	1.134%	433	0.0433
34	1.34%	1.75%	1.54%	506	0.0506	1.262%	1.519%	1.391%	506	0.0506
35	1.75%	2.16%	1.96%	585	0.0585	1.519%	1.777%	1.648%	585	0.0585
36	2.16%	2.58%	2.37%	649	0.0649	1.777%	2.034%	1.905%	649	0.0649
37	2.58%	2.99%	2.78%	726	0.0726	2.034%	2.291%	2.162%	726	0.0726
38	2.99%	3.40%	3.20%	811	0.0811	2.291%	2.548%	2.419%	811	0.0811
39	3.40%	3.82%	3.61%	810	0.081	2.548%	2.805%	2.677%	810	0.081
40	3.82%	4.23%	4.02%	797	0.0797	2.805%	3.062%	2.934%	797	0.0797
41	4.23%	4.64%	4.44%	711	0.0711	3.062%	3.319%	3.191%	711	0.0711
42	4.64%	5.06%	4.85%	693	0.0693	3.319%	3.576%	3.448%	693	0.0693
43	5.06%	5.47%	5.26%	511	0.0511	3.576%	3.834%	3.705%	511	0.0511
44	5.47%	5.88%	5.68%	372	0.0372	3.834%	4.091%	3.962%	372	0.0372
45	5.88%	6.30%	6.09%	240	0.024	4.091%	4.348%	4.219%	240	0.024
46	6.30%	6.71%	6.50%	124	0.0124	4.348%	4.605%	4.476%	124	0.0124
47	6.71%	7.12%	6.92%	50	0.005	4.605%	4.862%	4.734%	50	0.005
48	7.12%	7.54%	7.33%	11	0.0011	4.862%	5.119%	4.991%	11	0.0011
49	7.54%	7.95%	7.74%	7	0.0007	5.119%	5.376%	5.248%	7	0.0007
50	7.95%	8.36%	8.16%	2	0.0002	5.376%	5.633%	5.505%	2	0.0002
				10000					10000	

Table A2.2. Test values and probability of r_c and r_q for China (simulation performed with Oracle Crystal Ball software)

	r_{1t}					r_{2t}				
Bin di grafici	**Min**	**Max**	**Medio**	**Freq.**	**Prob.**	**Min**	**Max**	**Medio**	**Freq.**	**Prob.**
1	-25.70%	-24.36%	-25.03%	1	0.00010	-13.509%	-12.774%	-13.142%	1	0.0001
2	-24.36%	-23.01%	-23.68%	2	0.00020	-12.774%	-12.039%	-12.407%	2	0.0002
3	-23.01%	-21.66%	-22.34%	1	0.00010	-12.039%	-11.304%	-11.671%	1	0.0001
4	-21.66%	-20.32%	-20.99%	0	0.00000	-11.304%	-10.569%	-10.936%	0	0
5	-20.32%	-18.97%	-19.64%	2	0.00020	-10.569%	-9.833%	-10.201%	2	0.0002
6	-18.97%	-17.62%	-18.30%	1	0.00010	-9.833%	-9.098%	-9.466%	1	0.0001
7	-17.62%	-16.28%	-16.95%	3	0.00030	-9.098%	-8.363%	-8.731%	3	0.0003
8	-16.28%	-14.93%	-15.60%	0	0.00000	-8.363%	-7.628%	-7.995%	0	0
9	-14.93%	-13.58%	-14.26%	3	0.00030	-7.628%	-6.892%	-7.260%	3	0.0003
10	-13.58%	-12.24%	-12.91%	5	0.00050	-6.892%	-6.157%	-6.525%	5	0.0005
11	-12.24%	-10.89%	-11.56%	10	0.00100	-6.157%	-5.422%	-5.790%	10	0.001
12	-10.89%	-9.54%	-10.22%	15	0.00150	-5.422%	-4.687%	-5.054%	15	0.0015
13	-9.54%	-8.20%	-8.87%	22	0.00220	-4.687%	-3.952%	-4.319%	22	0.0022
14	-8.20%	-6.85%	-7.52%	27	0.00270	-3.952%	-3.216%	-3.584%	27	0.0027

15	-6.85%	-5.50%	-6.18%	33	0.00330	-3.216%	-2.481%	-2.849%	33	0.0033
16	-5.50%	-4.16%	-4.83%	60	0.00600	-2.481%	-1.746%	-2.114%	60	0.006
17	-4.16%	-2.81%	-3.48%	74	0.00740	-1.746%	-1.011%	-1.378%	74	0.0074
18	-2.81%	-1.46%	-2.14%	100	0.01000	-1.011%	-0.275%	-0.643%	100	0.01
19	-1.46%	-0.12%	-0.79%	152	0.01520	-0.275%	0.460%	0.092%	152	0.0152
20	-0.12%	1.23%	0.56%	200	0.02000	0.460%	1.195%	0.827%	200	0.02
21	1.23%	2.58%	1.90%	271	0.02710	1.195%	1.930%	1.563%	271	0.0271
22	2.58%	3.92%	3.25%	380	0.03800	1.930%	2.665%	2.298%	380	0.038
23	3.92%	5.27%	4.60%	478	0.04780	2.665%	3.401%	3.033%	478	0.0478
24	5.27%	6.62%	5.94%	583	0.05830	3.401%	4.136%	3.768%	583	0.0583
25	6.62%	7.96%	7.29%	785	0.07850	4.136%	4.871%	4.503%	785	0.0785
26	7.96%	9.31%	8.64%	824	0.08240	4.871%	5.606%	5.239%	824	0.0824
27	9.31%	10.66%	9.98%	939	0.09390	5.606%	6.341%	5.974%	939	0.0939
28	10.66%	12.00%	11.33%	890	0.08900	6.341%	7.077%	6.709%	890	0.089
29	12.00%	13.35%	12.68%	862	0.08620	7.077%	7.812%	7.444%	862	0.0862
30	13.35%	14.70%	14.02%	722	0.07220	7.812%	8.547%	8.180%	722	0.0722
31	14.70%	16.04%	15.37%	638	0.06380	8.547%	9.282%	8.915%	638	0.0638
32	16.04%	17.39%	16.72%	498	0.04980	9.282%	10.018%	9.650%	498	0.0498
33	17.39%	18.74%	18.06%	361	0.03610	10.018%	10.753%	10.385%	361	0.0361
34	18.74%	20.08%	19.41%	289	0.02890	10.753%	11.488%	11.120%	289	0.0289
35	20.08%	21.43%	20.76%	227	0.02270	11.488%	12.223%	11.856%	227	0.0227
36	21.43%	22.78%	22.10%	168	0.01680	12.223%	12.958%	12.591%	168	0.0168
37	22.78%	24.12%	23.45%	104	0.01040	12.958%	13.694%	13.326%	104	0.0104
38	24.12%	25.47%	24.80%	72	0.00720	13.694%	14.429%	14.061%	72	0.0072
39	25.47%	26.82%	26.14%	59	0.00590	14.429%	15.164%	14.796%	59	0.0059
40	26.82%	28.16%	27.49%	46	0.00460	15.164%	15.899%	15.532%	46	0.0046
41	28.16%	29.51%	28.84%	29	0.00290	15.899%	16.635%	16.267%	29	0.0029
42	29.51%	30.86%	30.18%	21	0.00210	16.635%	17.370%	17.002%	21	0.0021
43	30.86%	32.20%	31.53%	22	0.00220	17.370%	18.105%	17.737%	22	0.0022
44	32.20%	33.55%	32.88%	6	0.00060	18.105%	18.840%	18.473%	6	0.0006
45	33.55%	34.90%	34.22%	7	0.00070	18.840%	19.575%	19.208%	7	0.0007
46	34.90%	36.24%	35.57%	4	0.00040	19.575%	20.311%	19.943%	4	0.0004
47	36.24%	37.59%	36.92%	0	0.00000	20.311%	21.046%	20.678%	0	0
48	37.59%	38.94%	38.26%	2	0.00020	21.046%	21.781%	21.413%	2	0.0002
49	38.94%	40.28%	39.61%	1	0.00010	21.781%	22.516%	22.149%	1	0.0001
50	40.28%	41.63%	40.96%	1	0.00010	22.516%	23.251%	22.884%	1	0.0001
				10000						

Appendix 3

Table A3.1. Detailed Cost Estimates by Financier (source: ADB, 2018)

		ADB		Government		Total	
Item		**Amount**	**%**	**Amount**	**%**	**Amount**	**% of Total**
A.	**Investment Costs**						
1	Civil works, loan-based	140.23	85.70%	23.39	14.30%	**163.62**	39.56%
	TVET	24.13	76.27%	7.51	23.73%	**31.64**	7.65%
	Others	116.09	87.96%	15.89	12.04%	**131.98**	31.91%
	Civil works, non-loan (TVET)	0.00	0.00%	6.04	100.00%	**6.04**	1.46%
2	Equipment, loan-based (Others)	55.55	100.00%	0.00	0.00%	**55.55**	13.43%
	Equipment, non-loan (TVET)	0.00	0.00%	1.24	100.00%	**1.24**	0.30%
3	Land acquisition, compensation, and resettlement	0.00	0.00%	100.55	100.00%	**100.55**	24.32%
4	Survey, design, and supervision	0.00	0.00%	23.74	100.00%	**23.74**	5.74%
5	Consulting services	4.23	100.00%	0.00	100.00%	**4.23**	1.02%
	Subtotal (A), Total Base Cost	**200.00**	**56.34%**	**154.97**	**44.20%**	**354.98**	85.84%
B.	**Contingencies**						
1	Physical contingencies	0.00	0.00%	12.72	100.00%	**12.72**	3.1%
2	Price contingencies	0.00	0.00%	21.30	100.00%	**21.30**	5.2%
	Subtotal (B)	**0.00**	**0.00%**	**34.02**	**100.00%**	**34.02**	8.23%
C.	**Interest and Commitment Charges**						
1	Interest during implementation	0.00	0.00%	23.81	100.00%	**23.81**	5.76%
2	Commitment charges	0.00	0.00%	0.73	100.00%	**0.73**	0.18%
	Subtotal (C)	**0.00**	**0.00%**	**24.54**	**100.00%**	**24.54**	5.94%
	Total Project Cost (A+B+C)	**200.00**	**48.00%**	**213.54**	**52.00%**	**413.54**	100.00%

Table A3.2. Detailed Cost Estimates by Outputs (source: ADB, 2018)

		Output 1		**Output 2**		**Output 3**		**Project Management**	
	Total Cost	Amount	% of Cost Category	Amount	% of Cost Category	Amount	% of Cost Category	Amount	% of Cost Category
A. Investment Cost									
1 Civil works, loan-based	**163.62**	131.98	80.66%	31.64	19.34%	0.00	0.00%	0.00	0.00%
TVET	**31.64**	0.00	0.00%	31.64	100.00%	0.00	0.00%	0.00	0.00%
Others	**131.98**	131.98	100.00%	0.00	0.00%	0.00	0.00%	0.00	0.00%
Civil works, non-loan (TVET)	**6.04**	0.00	0.00%	6.04	100.00%	0.00	0.00%	0.00	0.00%
2 Equipment, loan-based (Others)	**55.55**	0.00	0.00%	41.09	73.97%	14.46	26.03%	0.00	0.00%
Equipment, non-loan (TVET)	**1.24**	0.00	0.00%	1.24	100.00%	0.00	0.00%	0.00	0.00%
3 Land acquisition, compensation, and resettlement	**100.55**	85.88	85.41%	14.67	14.59%	0.00	0.00%	0.00	0.00%
4 Survey, design, and supervision	**23.75**	19.56	82.36%	3.02	12.72%	1.17	4.93%	0.00	0.00%
5 Consulting services	**4.23**	0.00	0.00%	0.91	21.51%	0.85	20.09%	2.47	58.39%
Subtotal (A)	**354.98**	**237.42**	**66.88%**	**98.61**	**27.78%**	**16.48**	**4.64%**	**2.47**	**0.70%**
B. Contingencies									
1 Physical contingencies	**12.72**	7.57	59.53%	4.20	33.03%	0.82	6.47%	0.12	0.97%
2 Price contingencies	**21.30**	16.84	79.08%	3.24	15.22%	1.04	4.89%	0.17	0.81%
Subtotal (B)	**34.02**	**24.42**	**71.77%**	**7.44**	**21.88%**	**1.87**	**5.48%**	**0.30**	**0.87%**
C. Interest and Commitment Charges									
1 Interest during construction	**23.81**	11.32	47.55%	10.47	43.97%	1.77	7.44%	0.25	1.05%
2 Commitment charges	**0.73**	0.54	73.84%	0.13	17.35%	0.06	7.54%	0.01	1.27%
Subtotal (C)	**24.54**	**11.86**	**48.33%**	**10.60**	**43.18%**	**1.83**	**7.44%**	**0.26**	**1.05%**
Total Project Cost	**413.54**	**273.70**	**66.18%**	**116.65**	**28.21%**	**20.17**	**4.88%**	**3.02**	**0.73%**

Table A3.3. Detailed Cost Estimates by years (source: ADB, 2018)

		2019	2020	2021	2022	2023	2024	Total
A	**Base Costs**							
1	Civil works, loan-based	3.16	42.42	49.01	43.31	21.07	4.64	**63.62**
	TVET	3.16	22.15	6.33	0.00	0.00	0.00	**31.64**
	Others	0.00	20.27	42.69	43.31	21.07	4.64	**131.98**
	Civil works, non-loan (TVET)	0.60	4.23	1.21	0.00	0.00	0.00	**6.04**
2	Equipment, loan-based (Others)	16.43	28.99	5.79	4.34	0.00	0.00	**55.55**
	Equipment, non-loan (TVET)	0.12	0.87	0.25	0.00	0.00	0.00	**1.24**
3	Land acquisition, compensation, and resettlement	14.45	36.49	27.40	12.72	6.84	2.65	**100.55**
4	Survey, design, and supervision	3.76	5.87	6.95	4.13	1.94	1.08	**23.74**
5	Consulting services	0.34	1.21	0.79	0.79	0.85	0.25	**4.23**
	Subtotal (A), Total Base Cost	**38.88**	**120.09**	**91.40**	**65.29**	**30.70**	**8.63**	**354.98**
B.	**Contingencies**							
1	Physical contingencies	1.22	4.18	3.20	2.63	1.19	0.30	**12.72**
2	Price contingencies	0.49	4.45	5.68	5.83	3.60	1.25	**21.30**
	Subtotal (B)	**1.71**	**8.63**	**8.88**	**8.46**	**4.79**	**1.55**	**34.02**
C	**Interest and Commitment Charges**							
1	Interest during implementation	0.32	1.74	3.65	5.20	6.25	6.65	**23.81**
2	Commitment charges	0.29	0.22	0.13	0.07	0.02	0.00	**0.73**
	Subtotal (C)	**0.61**	**1.96**	**3.79**	**5.27**	**6.27**	**6.65**	**24.54**
	Total Project Cost (A+B+C)	**41.20**	**130.67**	**104.06**	**79.02**	**41.76**	**16.83**	**413.54**
	% of Total Project Cost	**9.96%**	**31.60%**	**25.16%**	**19.11%**	**10.10%**	**4.07%**	

Table A3.4. Historical Revenues and Expenditures for Ziyang

Item	2012	2013	2014	2015	2016	%	Compound Annual Growth Rate (%)
Revenues (CNY, million)							
1. General budget revenue	4,073	4,844	5,546	6,177	4,684	18.5	3.3
2. Upper-level government allocations	10,849	11,576	13,011	13,700	11,583	45.8	1.8
3. Balance of last year	608	254	419	451	339	1.3	(2.3)
4. Other revenue	432	563	572	6,114	8,667	34.3	22.6
Total Revenues	**15,963**	**17,237**	**19,548**	**26,443**	**25,272**	**100**	**4.0**
Expenditures (CNY, million)							
1. General budget expenditures	15,404	16,490	18,868	21,608	18,836	76.3	2.6
2. Other expenditures	305	328	229	4,469	5,865	23.7	22.9
Total Expenditures	**15,709**	**16,818**	**19,097**	**26,077**	**24,701**	**100**	**4.0**

( ) = negative, CNY = Chinese yuan.
Note: Numbers may not sum precisely and percentages may not total 100% because of rounding. Source: Asian Development Bank estimates.

Table A3.5. Financial Projection of the Ziyang Municipal Government

Item	2019	2020	2021	2022	2023	2024	2025	2026
Revenues (CNY, million)	33,954	37,970	42,812	48,664	55,753	64,356	74,813	87,542
Expenditures (CNY million)	33,333	37,331	42,155	47,988	55,058	63,641	74,077	86,785
Annual counterpart funds (CNY million)	72	289	434	506	145			
Counterpart funds as a share of revenues (%)	0.20	0.80	1.00	1.00	0.30			
Annual debt service, and O&M for subprojects						107	105	103
Annual debt service, subsidy, and O&M for subprojects as revenue share (%)						0.17	0.14	0.12

CNY = Chinese yuan, O&M = operation and maintenance.

Source: Asian Development Bank estimates.

Table A3.6. Economic analysis of Eco-embankment (years 2019-2058, UNIT: CNY 10.000)

	Project Cost				Project Benefit				Hypotesis on critical variabiles					
Year	Capital Cost	O&M Cost	Total Cost	Cost discounted	Cost Saving of Flood Damage	Benefits of Increme ntal Green Space	Total Benefit	Total Benefit Discount ed	Min Capital Cost	Max Capital Cost	Min O&M Cost	Max O&M Cost	Min Tot Benefits	Max Benefits
2019	3124.7	-	3124.7	2815.045	-	-	-	-	2975.905	3437.17	-	-	-	-
2020	5917.62	-	5917.62	4802.873	-	-	-	-	5635.829	6509.382	-	-	-	-
2021	10949.51	-	10949.51	8006.187	-	-	-	-	10428.1	12044.46	-	-	-	-
2022	16092.47	-	16092.47	10600.61	-	-	-	-	15326.16	17701.72	-	-	-	-
2023	13299.56	-	13299.56	7892.642	-	-	-	-	12666.25	14629.52	-	-	-	-
2024	5363.68	-	5363.68	2867.642	-	-	-	-	5108.267	5900.048	-	-	-	-
2025	-	326.18	326.18	157.1073	258.97	-	258.97	172.2298	-	-	310.6476	358.798	235.4273	271.9185
2026	-	326.18	326.18	141.5381	258.97	-	258.97	162.481	-	-	310.6476	358.798	235.4273	271.9185
2027	-	326.18	326.18	127.5118	258.97	-	258.97	153.2839	-	-	310.6476	358.798	235.4273	271.9185
2028	-	326.18	326.18	114.8755	258.97	-	258.97	144.6075	-	-	310.6476	358.798	235.4273	271.9185
2029	-	326.18	326.18	103.4915	258.97	-	258.97	136.4222	-	-	310.6476	358.798	235.4273	271.9185
2030	-	326.18	326.18	93.23556	258.97	1480.6	1739.57	864.513	-	-	310.6476	358.798	1581.427	1826.549
2031	-	326.18	326.18	83.996	258.97	1480.6	1739.57	815.5783	-	-	310.6476	358.798	1581.427	1826.549
2032	-	326.18	326.18	75.67207	258.97	1480.6	1739.57	769.4135	-	-	310.6476	358.798	1581.427	1826.549
2033	-	326.18	326.18	68.17304	258.97	1480.6	1739.57	725.8618	-	-	310.6476	358.798	1581.427	1826.549
2034	-	326.18	326.18	61.41715	258.97	1480.6	1739.57	684.7753	-	-	310.6476	358.798	1581.427	1826.549
2035	-	326.18	326.18	55.33077	258.97	1480.6	1739.57	646.0144	-	-	310.6476	358.798	1581.427	1826.549
2036	-	326.18	326.18	49.84754	258.97	1480.6	1739.57	609.4475	-	-	310.6476	358.798	1581.427	1826.549
2037	-	326.18	326.18	44.90769	258.97	2961.2	3220.17	978.7151	-	-	310.6476	358.798	2927.427	3381.179
2038	-	326.18	326.18	40.45738	258.97	2961.2	3220.17	923.3162	-	-	310.6476	358.798	2927.427	3381.179
2039	-	326.18	326.18	64.79753	258.97	2961.2	3220.17	1174.967	-	-	310.6476	358.798	2927.427	3381.179
2040	-	326.18	326.18	59.99771	258.97	2961.2	3220.17	1124.37	-	-	310.6476	358.798	2927.427	3381.179
2041	-	326.18	326.18	55.55344	258.97	4441.8	4700.77	1708.025	-	-	310.6476	358.798	4273.427	4935.809
2042	-	326.18	326.18	51.43837	258.97	4441.8	4700.77	1634.474	-	-	310.6476	358.798	4273.427	4935.809

2043	-	326.18	326.18	47.62812	258.97	4441.8	4700.77	1564.09	-	-	310.6476	358.798	4273.427	4935.809
2044	-	326.18	326.18	44.10011	258.97	4441.8	4700.77	1496.737	-	-	310.6476	358.798	4273.427	4935.809
2045	4106.066	228.326	4334.392	542.6087	258.97	7403	7661.97	2334.536	3910.539	4516.672	217.4533	251.1586	6965.427	8045.069
2046	4106.066	228.326	4334.392	502.4154	258.97	7403	7661.97	2234.006	3910.539	4516.672	217.4533	251.1586	6965.427	8045.069
2047	4106.066	228.326	4334.392	465.1995	258.97	7403	7661.97	2137.805	3910.539	4516.672	217.4533	251.1586	6965.427	8045.069
2048	4106.066	228.326	4334.392	430.7403	258.97	7403	7661.97	2045.746	3910.539	4516.672	217.4533	251.1586	6965.427	8045.069
2049	-	228.326	228.326	21.00966	258.97	7403	7661.97	1957.652	-	-	217.4533	251.1586	6965.427	8045.069
2050	-	228.326	228.326	19.45339	258.97	7403	7661.97	1873.351	-	-	217.4533	251.1586	6965.427	8045.069
2051	-	228.326	228.326	18.01239	258.97	7403	7661.97	1792.68	-	-	217.4533	251.1586	6965.427	8045.069
2052	-	228.326	228.326	16.67814	258.97	7403	7661.97	1715.484	-	-	217.4533	251.1586	6965.427	8045.069
2053	-	228.326	228.326	15.44272	258.97	7403	7661.97	1641.611	-	-	217.4533	251.1586	6965.427	8045.069
2054	-	228.326	228.326	14.29882	258.97	7403	7661.97	1570.92	-	-	217.4533	251.1586	6965.427	8045.069
2055	-	228.326	228.326	13.23965	258.97	7403	7661.97	1503.272	-	-	217.4533	251.1586	6965.427	8045.069
2056	-	228.326	228.326	12.25893	258.97	7403	7661.97	1438.538	-	-	217.4533	251.1586	6965.427	8045.069
2057	-	228.326	228.326	11.35086	258.97	7403	7661.97	1376.592	-	-	217.4533	251.1586	6965.427	8045.069
2058	-	228.326	228.326	10.51006	258.97	7403	7661.97	1317.313	-	-	217.4533	251.1586	6965.427	8045.069
													ENPV	**809.535**

CNY = Chinese yuan, O&M = operation and maintenance.

Table A3.7. Economic analysis of Eco-embankment post mitigation interventions (years 2019-2044, UNIT: CNY 10.000, SDR = 9 %)

	Project Cost			Project Benefit					
Year	Capital Cost	O&M	Total cost	Cost Saving of Flood Damage	Ben. of Increm. Green Space	Improvement of the cultural offer	Territorial enhanc.	Total Benefit	Net Benefit
2019	3124.70		3124.70	-	-	-	-	-	-3124.70
2020	5917.62		5917.62	-	-	-	-	-	-5917.62
2021	10949.51		10949.51	-	-	-	-	-	-10949.51
2022	16092.47		16092.47	-	-	-	-	-	-16092.47
2023	13299.56		13299.56	-	-	-	-	-	-13299.56
2024	5544.34		5544.34	-	-	-	-	-	-5544.34
2025	-	339.70	352.57	258.97	7403.00	2442.33	2111.54	12294.54	11941.96
2026	-	339.70	352.57	258.97	7403.00	2442.33	2111.54	12294.54	11941.96
2027	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2028	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2029	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2030	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2031	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2032	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2033	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2034	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2035	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2036	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2037	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2038	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2039	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2040	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2041	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2042	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2043	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
2044	-	339.70	352.57	258.97	7403.00	2442.33	-	10183.00	9830.42
							ENPV (9%)		16069.81

Table A3.8. Economic analysis of Eco-embankment post mitigation interventions (years 2019-2058, UNIT: CNY 10.000, DDR)

	Project Cost				Project Benefit					
Year	Capital Cost	O&M	Total Cost	Cost discounted	Cost Saving of Flood Damage	Ben. of Increm. Green Space	Improvement of the cultural offer	Territorial enhanc.	Total Benefit	Total Benefit Discounted
2019	3124.70	-	3124.70	2815.05	-	-	-	-	-	-
2020	5917.62	-	5917.62	4802.87	-	-	-	-	-	-
2021	10949.51	-	10949.51	8006.19	-	-	-	-	-	-
2022	16092.47	-	16092.47	10600.61	-	-	-	-	-	-
2023	13299.56	-	13299.56	7892.64	-	-	-	-	-	-
2024	5363.68	-	5363.68	2867.64	-	-	-	-	-	-
2025	-	339.70	339.70	163.62	258.97	-	2442.33	2111.54	4812.84	3200.81
2026	-	339.70	339.70	147.41	258.97	-	2442.33	2111.54	4812.84	3019.63
2027	-	339.70	339.70	132.80	258.97	-	2442.33	-	2701.30	1598.89
2028	-	339.70	339.70	119.64	258.97	-	2442.33	-	2701.30	1508.39
2029	-	339.70	339.70	107.78	258.97	-	2442.33	-	2701.30	1423.01
2030	-	339.70	339.70	97.10	258.97	1480.60	2442.33	-	4181.90	2078.27
2031	-	339.70	339.70	87.48	258.97	1480.60	2442.33	-	4181.90	1960.64
2032	-	339.70	339.70	78.81	258.97	1480.60	2442.33	-	4181.90	1849.66
2033	-	339.70	339.70	71.00	258.97	1480.60	2442.33	-	4181.90	1744.96
2034	-	339.70	339.70	63.96	258.97	1480.60	2442.33	-	4181.90	1646.19
2035	-	339.70	339.70	57.62	258.97	1480.60	2442.33	-	4181.90	1553.01
2036	-	339.70	339.70	51.91	258.97	1480.60	2442.33	-	4181.90	1465.10
2037	-	339.70	339.70	46.77	258.97	2961.20	2442.33	-	5662.50	1871.53
2038	-	339.70	339.70	42.13	258.97	2961.20	2442.33	-	5662.50	1765.59
2039	-	339.70	339.70	67.48	258.97	2961.20	2442.33	-	5662.50	2246.81
2040	-	339.70	339.70	62.49	258.97	2961.20	2442.33	-	5662.50	2150.05
2041	-	339.70	339.70	57.86	258.97	4441.80	2442.33	-	7143.10	2595.45
2042	-	339.70	339.70	53.57	258.97	4441.80	2442.33	-	7143.10	2483.68
2043	-	339.70	339.70	49.60	258.97	4441.80	2442.33	-	7143.10	2376.73
2044	-	339.70	339.70	45.93	258.97	4441.80	2442.33	-	7143.10	2274.38
2045	4106.07	237.79	4343.86	543.79	258.97	7403.00	2442.33	-	10104.30	3078.69

2046	4106.07	237.79	4343.86	503.51	258.97	7403.00	2442.33	-	10104.30	2946.12
2047	4106.07	237.79	4343.86	466.22	258.97	7403.00	2442.33	-	10104.30	2819.25
2048	4106.07	237.79	4343.86	431.68	258.97	7403.00	2442.33	-	10104.30	2697.85
2049	-	237.79	237.79	21.88	258.97	7403.00	2442.33	-	10104.30	2581.67
2050	-	237.79	237.79	20.26	258.97	7403.00	2442.33	-	10104.30	2470.50
2051	-	237.79	237.79	18.76	258.97	7403.00	2442.33	-	10104.30	2364.11
2052	-	237.79	237.79	17.37	258.97	7403.00	2442.33	-	10104.30	2262.31
2053	-	237.79	237.79	16.08	258.97	7403.00	2442.33	-	10104.30	2164.89
2054	-	237.79	237.79	14.89	258.97	7403.00	2442.33	-	10104.30	2071.67
2055	-	237.79	237.79	13.79	258.97	7403.00	2442.33	-	10104.30	1982.45
2056	-	237.79	237.79	12.77	258.97	7403.00	2442.33	-	10104.30	1897.09
2057	-	237.79	237.79	11.82	258.97	7403.00	2442.33	-	10104.30	1815.39
2058	-	237.79	237.79	10.95	258.97	7403.00	2442.33	-	10104.30	1737.22
								ENPV (DDR)		33008.24

Table A3.9. Economic analysis of wetland area development (years 2019-2048, UNIT: CNY 10.000, DDR)

	Project Cost		Project Benefit		Hypotesis on critical variabiles			
					1		2	
Year	Capital Cost	Cost Discounted	Water Quality Improvement	Total Benefit Discounted	Min Capital Cost	Max Capital Cost	Min Tot Benefit	Max Benefit
2019	4,284.72	3,860.11	-	-	3,856.25	4,713.19	-	-
2020	12,917.68	10,484.28	-	-	11,625.91	14,209.45	-	-
2021	1,353.82	989.90	-	-	1,218.44	1,489.20	-	-
2022	398.18	262.29	-	-	358.36	438.00	-	-
2023	398.18	236.30	-	-	358.36	438.00	-	-
2024	238.91	127.73	-	-	215.02	262.80	-	-
2025	-	-	2,979.26	1,981.38	-	-	2,681.33	3,277.19
2026	-	-	2,979.26	1,869.22	-	-	2,681.33	3,277.19
2027	-	-	2,979.26	1,763.42	-	-	2,681.33	3,277.19
2028	-	-	2,979.26	1,663.60	-	-	2,681.33	3,277.19
2029	-	-	2,979.26	1,569.44	-	-	2,681.33	3,277.19
2030	-	-	2,979.26	1,480.60	-	-	2,681.33	3,277.19
2031	-	-	2,979.26	1,396.79	-	-	2,681.33	3,277.19
2032	-	-	2,979.26	1,317.73	-	-	2,681.33	3,277.19
2033	-	-	2,979.26	1,243.14	-	-	2,681.33	3,277.19
2034	-	-	2,979.26	1,172.77	-	-	2,681.33	3,277.19
2035	-	-	2,979.26	1,106.39	-	-	2,681.33	3,277.19
2036	-	-	2,979.26	1,043.77	-	-	2,681.33	3,277.19
2037	-	-	2,979.26	984.68	-	-	2,681.33	3,277.19
2038	-	-	2,979.26	928.95	-	-	2,681.33	3,277.19
2039	-	-	2,979.26	876.37	-	-	2,681.33	3,277.19
2040	-	-	2,979.26	826.76	-	-	2,681.33	3,277.19
2041	-	-	2,979.26	779.96	-	-	2,681.33	3,277.19
2042	-	-	2,979.26	735.81	-	-	2,681.33	3,277.19
2043	-	-	2,979.26	694.16	-	-	2,681.33	3,277.19
2044	-	-	2,979.26	654.87	-	-	2,681.33	3,277.19
				ENPV	**8,129.21**			

Table A3.10. Economic analysis of ecological preservation of bare hills (years 2019-2048, UNIT: CNY 10.000, DDR)

Year	Project Cost			Project Benefit		Hypotesis on critical variabiles					
	Capital Cost	O&M	Total Cost	Cost Saving of Traffic Interruption	Total Benefit Discounted	Min Capital Cost	Max Capital Cost	Min Operating Cost	Max Operating Cost	Min Tot Benefit	Max Tot Benefit
2019	99.78	-	89.89	-	-	95.03	114.75	-	-	-	-
2020	1245.67	-	1011.01	-	-	1186.35	1432.52	-	-	-	-
2021	1245.67	-	910.82	-	-	1186.35	1432.52	-	-	-	-
2022	99.78	-	65.73	-	-	95.03	114.75	-	-	-	-
2023	-	19.05	11.31	360.30	269.24	0.00	0.00	18.14	20.96	313.30	378.32
2024	-	19.05	10.18	360.30	254.00	0.00	0.00	18.14	20.96	313.30	378.32
2025	-	19.05	9.18	360.30	239.62	0.00	0.00	18.14	20.96	313.30	378.32
2026	-	19.05	8.27	360.30	226.06	0.00	0.00	18.14	20.96	313.30	378.32
2027	-	19.05	7.45	360.30	213.26	0.00	0.00	18.14	20.96	313.30	378.32
2028	-	19.05	6.71	360.30	201.19	0.00	0.00	18.14	20.96	313.30	378.32
2029	-	19.05	6.04	360.30	189.80	0.00	0.00	18.14	20.96	313.30	378.32
2030	-	19.05	5.45	360.30	179.06	0.00	0.00	18.14	20.96	313.30	378.32
2031	-	19.05	4.91	360.30	168.92	0.00	0.00	18.14	20.96	313.30	378.32
2032	-	19.05	4.42	360.30	159.36	0.00	0.00	18.14	20.96	313.30	378.32
2033	-	19.05	3.98	360.30	150.34	0.00	0.00	18.14	20.96	313.30	378.32
2034	-	19.05	3.59	360.30	141.83	0.00	0.00	18.14	20.96	313.30	378.32
2035	-	19.05	3.23	360.30	133.80	0.00	0.00	18.14	20.96	313.30	378.32
2036	-	19.05	2.91	360.30	126.23	0.00	0.00	18.14	20.96	313.30	378.32
2037	-	19.05	2.62	360.30	119.08	0.00	0.00	18.14	20.96	313.30	378.32
2038	-	19.05	2.36	360.30	112.34	0.00	0.00	18.14	20.96	313.30	378.32
2039	-	19.05	2.13	360.30	105.98	0.00	0.00	18.14	20.96	313.30	378.32
2040	-	19.05	1.92	360.30	99.99	0.00	0.00	18.14	20.96	313.30	378.32
2041	-	19.05	1.73	360.30	94.33	0.00	0.00	18.14	20.96	313.30	378.32
2042	-	19.05	1.56	360.30	88.99	0.00	0.00	18.14	20.96	313.30	378.32
2043	-	19.05	1.40	360.30	83.95	0.00	0.00	18.14	20.96	313.30	378.32
2044	-	19.05	1.26	360.30	79.20	0.00	0.00	18.14	20.96	313.30	378.32
								ENPV (UNIT = 10,000 UNIT)			1256.51

Table A3.11. Economic analysis of ecological preservation of bare hills (years 2019-2044, UNIT: CNY 10.000, SDR, including trees benefits)

	Project Cost			Project Benefit			
Year	Capital Cost	Operation and Maintenance	Total Cost	Cost Saving of Traffic Interruption	Trees Benefits	Total Benefit	Net Benefit
2019	99.78	-	99.78	-	-	-	-99.78
2020	1245.67	-	1245.67	-	-	-	-1245.67
2021	1389.59	-	1389.59	-	-	-	-1389.59
2022	243.70	-	243.70	-	-	-	-243.70
2023	-	40.06	40.06	360.30	-	360.30	320.24
2024	-	40.06	40.06	360.30	-	360.30	320.24
2025	-	40.06	40.06	360.30	-	360.30	320.24
2026	-	40.06	40.06	360.30	-	360.30	320.24
2027	-	40.06	40.06	360.30	-	360.30	320.24
2028	-	40.06	40.06	360.30	61.13	421.43	381.37
2029	-	40.06	40.06	360.30	61.13	421.43	381.37
2030	-	40.06	40.06	360.30	61.13	421.43	381.37
2031	-	40.06	40.06	360.30	61.13	421.43	381.37
2032	-	40.06	40.06	360.30	61.13	421.43	381.37
2033	-	40.06	40.06	360.30	122.27	482.57	442.51
2034	-	40.06	40.06	360.30	122.27	482.57	442.51
2035	-	40.06	40.06	360.30	122.27	482.57	442.51
2036	-	40.06	40.06	360.30	122.27	482.57	442.51
2037	-	40.06	40.06	360.30	122.27	482.57	442.51
2038	-	40.06	40.06	360.30	122.27	482.57	442.51
2039	-	40.06	40.06	360.30	122.27	482.57	442.51
2040	-	40.06	40.06	360.30	122.27	482.57	442.51
2041	-	40.06	40.06	360.30	122.27	482.57	442.51
2042	-	40.06	40.06	360.30	122.27	482.57	442.51
2043	-	40.06	40.06	360.30	122.27	482.57	442.51
2044	-	40.06	40.06	360.30	122.27	482.57	442.51
						EIRR (%)	9.55%
						ENPV (9%)	127.99

Table A3.12. Economic analysis of ecological preservation of bare hills (years 2019-2058, UNIT: CNY 10.000, DDR, including trees benefits)

	Project Cost			Project Benefit			
Year	Capital Cost	Operation and Maintenance	Total Cost Discounted	Cost Saving of Traffic Interruption	Trees Benefits	Total Benefit	Total Benefit Discounted
2019	99.78	-	89.89	-	-	-	-
2020	1245.67	-	1011.01	-	-	-	-
2021	1389.59	-	1016.05	-	-	-	-
2022	243.70	-	160.53	-	-	-	-
2023	-	40.06	23.77	360.30	-	-	-
2024	-	40.06	21.42	360.30	-	-	-
2025	-	40.06	19.30	360.30	-	-	-
2026	-	40.06	17.38	360.30	-	-	-
2027	-	40.06	15.66	360.30	-	-	-
2028	-	40.06	14.11	360.30	61.13	360.30	269.24
2029	-	40.06	12.71	360.30	61.13	360.30	254.00
2030	-	40.06	11.45	360.30	61.13	360.30	239.62
2031	-	40.06	10.32	360.30	61.13	360.30	226.06
2032	-	40.06	9.29	360.30	61.13	360.30	213.26
2033	-	40.06	8.37	360.30	122.27	421.43	235.33
2034	-	40.06	7.54	360.30	122.27	421.43	222.01
2035	-	40.06	6.80	360.30	122.27	421.43	209.44
2036	-	40.06	6.12	360.30	122.27	421.43	197.58
2037	-	40.06	5.52	360.30	122.27	421.43	186.40
2038	-	40.06	4.97	360.30	122.27	482.57	201.36
2039	-	40.06	7.96	360.30	122.27	482.57	189.96
2040	-	40.06	7.37	360.30	122.27	482.57	179.21
2041	-	40.06	6.82	360.30	122.27	482.57	169.07
2042	-	40.06	6.32	360.30	122.27	482.57	159.50
2043	-	40.06	5.85	360.30	122.27	482.57	200.09
2044	-	40.06	5.42	360.30	122.27	482.57	191.48
2045	-	40.06	5.02	360.30	122.27	482.57	183.23
2046	-	40.06	4.64	360.30	122.27	482.57	175.34
2047	-	40.06	4.30	360.30	122.27	482.57	167.79

2048	-	40.06	3.98	360.30	122.27	482.57	160.57
2049	-	40.06	3.69	360.30	122.27	482.57	153.65
2050	-	40.06	3.41	360.30	122.27	482.57	147.03
2051	-	40.06	3.16	360.30	122.27	482.57	140.70
2052	-	40.06	2.93	360.30	122.27	482.57	134.64
2053	-	40.06	2.71	360.30	122.27	482.57	128.85
2054	-	40.06	2.51	360.30	122.27	482.57	123.30
2055	-	40.06	2.32	360.30	122.27	482.57	117.99
2056	-	40.06	2.15	360.30	122.27	482.57	112.91
2057	-	40.06	1.99	360.30	122.27	482.57	108.05
2058	-	40.06	2.68	360.30	122.27	482.57	103.39
					ENPV(DDR)		482.57

UNIONE EUROPEA
Fondo Sociale Europeo

Ministero dell'Istruzione, dell'Università e della Ricerca

PON RICERCA E INNOVAZIONE 2014 - 2020

SOCOMER GRANDI LAVORI srl

This research was financed with ministerial funds within the framework of the National Operational Programme Research and Innovation 2014-2020 (CCI 2014IT16M2OP005), European Social Fund, Action I.1 "Innovative doctorates with an industrial character".
The PhD Thesis derives from research activities carried out at the Department of Civil Engineering of the University of Salerno (tutor: Prof. Antonio Nesticò), at the School of Economics of Shanghai University (tutor: Prof. Shuquan He), at the company Socomer Grandi Lavori based in Battipaglia, Salerno (company tutor: Dr. Rosa Maria Caprino).