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Simulation methods for quantifying ESG risks

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ABSTRACT

ESG risks and opportunities are highly relevant as causes and drivers for positive or negative scenarios with a significant impact on a company's reputation or intangible assets. The following article deals with the relevance and assessment of ESG risks in practice. Special emphasis is placed on explaining the importance of stochastic simulation methods that enable a quantitative assessment of complex systems, such as environmental systems or social systems. The quantification of the financial impact of an environmental risk is illustrated using the currently particularly important topic of CO_2 emissions. The article shows that advanced tools of stochastics and probabilistics makes our knowledge more multifaceted and diverse, but not inaccurate.

ESG-Risiken und -Chancen sind wesentliche Ursachen und Treiber für sowohl positive als auch negative Szenarien und können erhebliche Auswirkungen auf die immateriellen Vermögenswerte und die Reputation eines Unternehmens haben. Der folgende Artikel befasst sich mit der Relevanz und Bewertung von ESG-Risiken in der Praxis. Ein besonderer Schwerpunkt liegt auf der Bedeutung stochastischer Simulationsmethoden, die eine quantitative Bewertung komplexer Systeme, wie z.B. Umweltsysteme oder soziale Systeme, ermöglichen. Die Quantifizierung der finanziellen Auswirkungen eines Umweltrisikos wird anhand des derzeit besonders wichtigen Themas der CO_2-Emissionen illustriert. Der Artikel zeigt, dass fortgeschrittene Werkzeuge der Stochastik und Probabilistik unser Wissen vielfältiger und abwechslungsreicher, aber nicht ungenauer machen.

KEYWORDS

Stochastic simulation, risk aggregation, quantification, probabilistics, ESG risks

Stochastische Simulation, Risikoaggregation, Quantifizierung, Probabilistik, ESG-Risiken

Introduction

The acronym ESG stands for Environment, Social and (Corporate) Governance. General examples for the area of Environment are the amount of energy used, the share of renewable energy sources, climate change strategy and emissions. Social includes aspects such as respect for human rights, prohibition of child and forced labour, equal opportunities and diversity, workplace design and further development. The criterion Governance aims at the extent to which sustainability is structurally anchored within the company. This includes, for example, topics such as sustainability management, anti-corruption measures, environmental & quality management systems, financial sustainability and risk management systems.

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In January 2018 BlackRock CEO Larry Fink proclaimed in his annual letter that, "To prosper over time, every company must not only deliver financial performance, but also show how it makes a positive contribution to society." [1]. In his latest 2021 letter to CEOs he could show that sustainability also drives better financial returns: "Over the course of 2020, we have seen how purposeful companies, with better environmental, social, and governance (ESG) profiles, have outperformed their peers. During 2020, 81% of a globally-representative selection of sustainable indexes outperformed their parent benchmarks." [2]. Fink predicted that in the near future, all investors will be using ESG metrics to determine the value of a company.

ESG risks and opportunities are highly relevant as a cause for risk scenarios, as they can have a significant impact on a company's reputation or intangible assets [3, 4]. In this context, it is shown that ESG risks also often have financial effects, which must be quantified as such and taken into account in the assessment of the overall scope of risk (aggregation of risk), the cost of capital and the degree of "threats to the existence" of a company.

The following article deals with the relevance and assessment of ESG risks in practice. Special emphasis is placed on explaining the importance of simulation methods that enable a quantitative assessment of complex systems, such as environmental systems or social systems.

ESG criteria as a cause for multiple impact mechanisms

The ESG criteria and the ESG risks resulting from them have multiple effects. First of all, effects – direct and indirect – on the company must be distinguished from those that affect society or the environment. Relevant for the company are first effects of a financial nature, i.e. changes in (1) expected amount or (2) volatility of cash flows, because these together determine the fundamental earnings value of a company (earnings risks, expressed for example in the coefficient of variation of earnings, determine the cost of capital and, in addition to risk bearing capacity, also influence insolvency risk). The assessment and quantification of the potential financial impact of ESG effects is already necessary today due to the legal requirements for an early risk detection system (see section 91 German Stock Corporation Act, AktG). It is important to note that the financial impact of ESG risks is often "indirect". For example, the expected level and risk of cash flows is influenced by first affecting a company's reputation, which in turn can result in a variety of financial impacts (e.g. loss of sales due to loss of customers as a result of a damaged reputation).

It is a truism that a good corporate reputation is the essential and dominant intangible asset of a company. Building and developing a "good reputation" often takes years or decades. Conversely, however, reputation can be damaged or even completely destroyed in no time at all. When the rumor mill is bubbling, it is high time for companies to intervene before issues in the public eye develop their own momentum [5, 6].

The link between brand and reputation creates a special form of symbiotic dependence. The fragile and multi-faceted structure of reputation can be destroyed within a few moments. Therefore, it must be the goal of every company to recognize reputational threats in good time and to preserve its reputation in the long term through prevention. Because the "domino rally" when reputational risks occur can be rapid.

Today, the future economic success or failure of a company is not only determined by its real physical capital, but also by its intangible assets [2]. In this context, corporate reputation is one of the most important intangible assets. Reputation is ideal for building and expanding strategic competitive advantages.

In 2012, the competence portal RiskNET conducted a study in cooperation with the Graz University of Technology on the causes and drivers of reputation losses / gains [5, 6]. 430 people participated in the study. The aim of the scientific analysis was to determine the main reputation drivers. To determine the impact of the individual drivers on the fragile construct of corporate reputation, the path coefficients, in particular their strengths and significances, represent the essential assessment criterion.

As the result of the regression analysis shows (see Figure 1), the perception of corporate attractiveness has the largest positive influence on corporate reputation with a regression coefficient of 0.333. The company's innovativeness as perceived by the public ($\beta = 0.280$) and the perceived quality of products and services (β = 0.219) occupy the second and third highest coefficients, respectively. With regard to corporate social responsibility (CSR), the empirically collected result can be interpreted in such a way that the perceived attractiveness as an employer of a company is three times more significant with regard to corporate reputation than the perceived CSR activities of a company (β = 0.116). The lowest influence on corporate reputation is exerted by the perceived financial performance of a company (β = 0.069) [6].

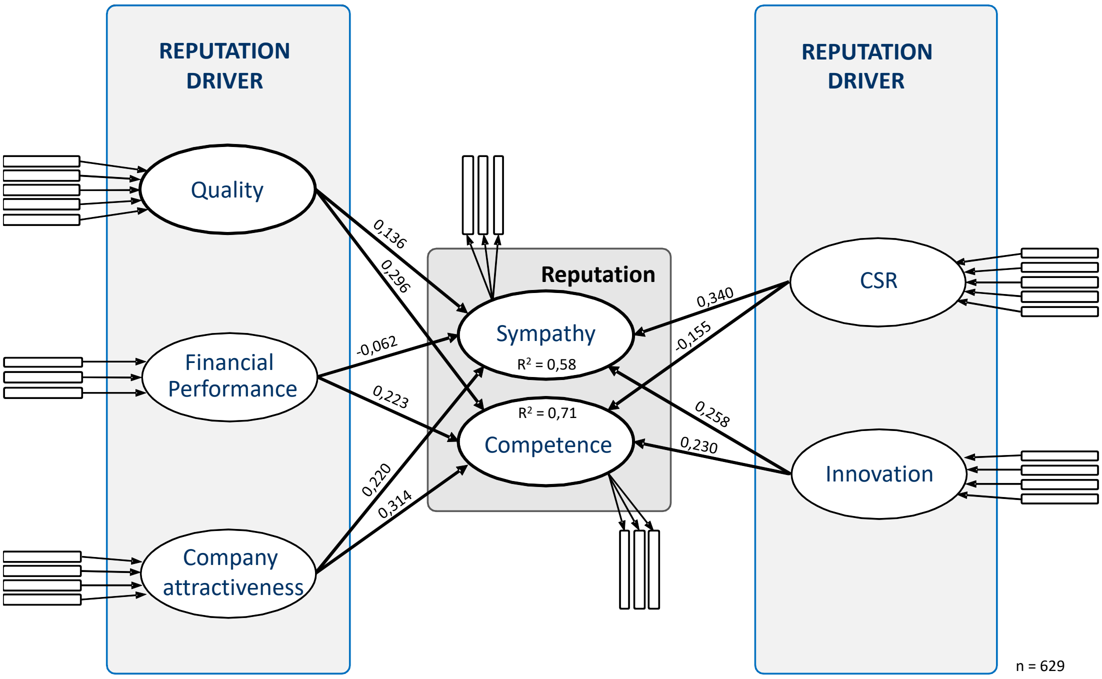

Figure 1: Effect of CSR risks in the reputation driver model (Source: own illustration based on [6])

The aggregated result of the driver analysis is shown in Figure 1. In the model set up, 58 per cent and 71 per cent of the two reputation constructs, sympathy and competence, can be explained by their five drivers. The sympathy dimension is positively influenced by the drivers quality, attractiveness, innovative strength and corporate social responsibility (CSR). The overlap between the two terms CSR and ESG is obvious. The main difference between ESG and CSR lies in the fact that institutional investors in particular are more oriented towards ESG criteria in order to assess the condition of an asset.

Figure 2 shows that sympathy is negatively affected by financial performance, although this relationship is the only one in the model that cannot be described as significant. The competence dimension can be assigned positive effects from the drivers financial performance, quality, attractiveness and innovative strength. The negative influence via the CSR driver proves to be significant.

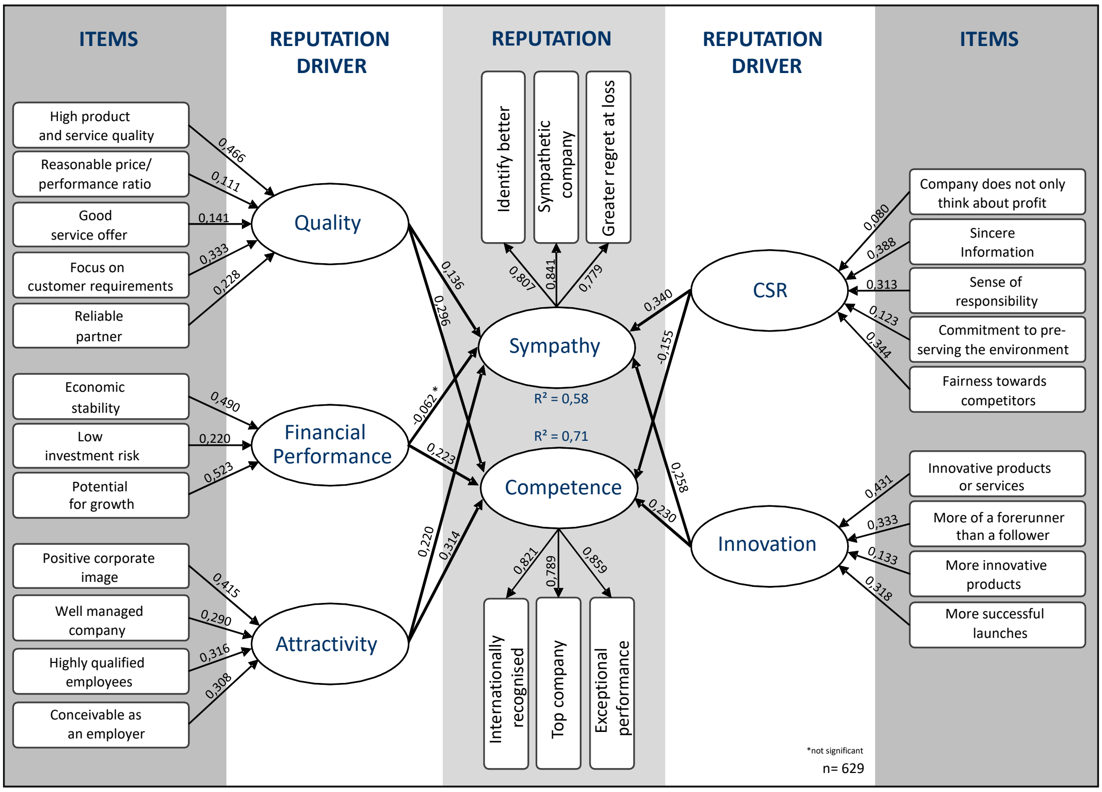

Figure 2: Early warning indicators in the reputation driver model (Source: own illustration based on [6])

ESG criteria should therefore be considered in a driver model and as a subsystem of an overall system to measure reputation. In this context, it is particularly important that the effect on financial performance is mapped in a quantitative form.

Quantification of ESG risks and stochastic simulation models

System Dynamics for modelling complex systems

System dynamics (SD) is a methodology and mathematical modeling technique to frame, understand, and discuss complex issues and problems. Originally developed in the 1950s, SD helps decision makers improve their understanding of complex systems.

The first use of simulation methods in connection with ESG risks took place as early as the 1980s in the World3 model. The project was led by Dennis L. Meadows of the Massachusetts Institute of Technology (MIT), supported by 16 scientists from various disciplines.

Meadows used the SD simulation method and modified the original World2 model by adding a larger number of variables and links.

Two problem complexes in particular were to be analyzed with the simulation:

- The possible discrepancy between population and economic growth as well as the limitedness of the earth in terms of resources and sinks were to be shown.
- The interdependence and the effects of essential factors that determine the physical behavior of the global system were to be analyzed.

In March 1972, after 18 months of study, the report was presented to the public in a popular scientific form under the title "The Limits to Growth" [7]. In 1973, a collection of 13 individual reports on the structure of the subsystems [8] was published as a supplement, and one year later the "technical report" [9] – presentations on methodology, systems of equations and the data basis.

The Limits to Growth provoked controversy and criticism worldwide; the model builders were derided as progress pessimists and prophets of doom.

In response to the critics, Meadows et al. pointed out that the objective of the World3 model is not to make a precise forecast in the narrow statistical sense, but to show typical patterns of behavior by means of a projection (an imprecise forecast in the broader sense). And precisely here lies the root of the critics' misinterpretation of the model approach. Many critics have simply not understood the difference between forecasts and scenarios [10].

"We had to limit ourselves to conditional and imprecise questions, rather than precise predictions, for two reasons. First social systems are by their nature unpredictable in the absolute sense. Since any prediction made about the future of a social system becomes an influence on social policy, the prediction itself may change the system's behavior. Second, the incomplete and inaccurate world data base currently available does not permit precision, even for conditional long-term prediction of social systems." [9]

With the help of the World3 model, the MIT scientists have described and simulated the interdependencies and complexity of a system. The MIT team describes World3 as a formal mathematical model of a complex social system. It attempts to analyze the long-term growth behavior of the world economy for 70 years ex ante and to simulate scenarios over a period of 130 years. The aim was not to make an exact forecast, but rather to enable "learning from the future".

System dynamics methods can be seen as a preliminary stage of a stochastic simulation (Monte Carlo simulation). System dynamics models are helpful to analyze and map essential interrelationships and to think through possible "individual scenarios" [3]. In addition, however, information is required about the range of certain developments, and thus also the probability of scenarios (probability density). A conceivable transition is possible if uncertain assumptions set in the model are described by probability distributions.

Consequently, it makes sense to supplement the SD model with a stochastic simulation. With the help of a stochastic simulation, realizations are generated for all random variables included in a model (based on random numbers drawn), which asymptomatically obey a previously specified distribution assumption (per variable). In the following chapter, we discuss the use of stochastic simulation models for the assessment of ESG risks.

Stochastic simulation as a method for risk assessment and aggregation

This central section deals with the quantification of ESG risks. The necessity of quantifying ESG risks, especially their financial impact, the challenges that exist here (for example, due to deficits in the available data) and methodical solutions are addressed. In particular, the importance of simulation methods (stochastic simulation or Monte Carlo simulation) is also referred to in this context.

The "Natural Capital Protocol" and the "Social & Human Capital Protocol" offer possible points of reference for quantifying ESG risks.

As concrete methods, COSO and WBCSD recommend, for example, carrying out a Delphi analysis, a deterministic scenario analysis, a stochastic simulation and ESG-specific methods.

Further methods are listed in the documentation ([11], p. 60):

- Greenhouse Gas Protocol: The Greenhouse Gas Protocol Corporate Accounting and Reporting Standard provides guidance to companies on calculating greenhouse gas inventories.
- WBCSD Water Tool: The WBCSD Water Tool is a multi-functional resource for identifying and calculating a company's water risks and opportunities, including a workbook, (for site investors, key reporting indicators and metrics), mapping functionality and Google Earth compatibility.
- InVEST: The Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) is a suite of open source software models. InVEST enables decision makers to evaluate the impacts of management decisions on future climate and identify where investments can sustainably enhance human development and ecosystems.

- WRI Aqueduct: WRI Aqueduct is a risk mapping tool that helps companies understand where and how water risks and opportunities arise around the world. The atlas uses a peer-review methodology to create customizable global maps of water risks.
- World Bank Climate Change Knowledge Portal: The Climate Change Knowledge Portal is a central hub for information, data and reports on climate change worldwide. It allows users to query, map, compare, display and summarize key climate and climate-related information.
- B Analytics, Global Impact Investment Rating System (GIIRS): GIIRS uses the B impact assessment methodology to measure the impact of an investment portfolio on workers, clients, groups and the environment.
- Impact Measurement Framework: This collection of sector-specific frameworks identifies relevant socio-economic impacts, indicators and metrics.
- Organisation for Economic Co-operation and Development (OECD) Guidelines on Measuring Subjective Well-being: These guidelines provide advice on the collection and use of measures of subjective well-being. They are intended to assist national statistical offices and other stakeholders in designing, collecting and publishing measures of subjective well-being.

In the document "Enterprise Risk Management: Applying enterprise risk management to environmental, social and governance-related risks", critical reference is also made to assessment errors (availability bias, confirmation bias, groupthink bias, illusion of control, overconfidence effect, status quo bias) [12, 13, 14].

The frequently read reference that some risks are not quantifiable does not apply [15, 16]. If one does not start from a traditional "frequentist" approach and – sensibly – allows the quantification of risks based on the best available information, every risk is quantifiable and Knight's distinction of uncertainty [17] between uncertainty and a quantifiable risk is obsolete. Using the best available information, every risk can be quantified by an expert estimate, but this must be explained transparently.

Risk quantification is useful and important for the following reasons:

1. Quantifying individual risks enables their prioritization and comparison with other risks of a company. For this purpose, it is necessary to define a risk measure and/or calculate the consequence of a risk for the company's measure of success (ultimate goal, e.g. enterprise value). If risks are also measured in several impact dimensions, an offsetting between the dimensions must take place (time, money, reputation, human health, etc.); only then is the comparison possible. In the case of companies, it is ultimately the effect on profit, earnings, cash flow or company value that counts.

2. The quantitative description of individual risks is also an indispensable basis for subsequently calculating an overall risk position by means of risk aggregation and for identifying the impact mechanisms through the combined effect of several individual risks.

3. Only through risk quantification can risk management be placed in the context of planning and controlling in order to assess planning reliability.

4. With such risk aggregation, which requires risk quantification, statements are possible regarding the necessary assessment of risk bearing capacity or liquidity reserves. Statements on the appropriate rating – i.e. the probability of insolvency or survival – can then also be derived directly from corporate planning in conjunction with the quantified risks. In addition, the consequences of the risks can also be presented in an easily understandable way as "imputed equity costs".

As the above examples show, the well-known principle "If you can measure it, you can manage it" also applies to risk management. The necessity of a clear quantitative description of risks becomes clear from the fact that a mere verbal description results in a very broad spectrum of interpretation [18].

Hillson conducted a study in 2004. He asked more than 5.000 persons interested in risk management (members of the Risk Doctor Network) to define selected probability-related terms. Fifteen terms were offered to respondents. Thirteen terms which appeared in more than one of the previous studies were chosen, and these were supplemented with „definite“ and „impossible“. These latter two were added as control end-points, since in theory they do not represent any form of uncertainty: one might expect „definite“ to be interpreted as 100% probability, and „impossible“ as 0%. The fifteen terms included in this survey were therefore: A good chance; Almost certain; Better than even; Definite; Highly probable; Highly unlikely; Impossible; Improbable; Likely; Possible; Probable; Quite likely; Rare; Seldom; Unlikely (see Figure 3).

Terms are often used instead of concrete numbers to communicate frequencies or impacts. Especially in discussions on risk assessment between risk managers and those responsible for risk or board members, typical terms such as high, low or rare are regularly used for this purpose. Studies show that even with supposedly unambiguous terms such as excluded or safe, it is obviously not clear for many people what is meant by them, or these terms are not clearly assigned a probability that corresponds to the meaning of these terms. This problem becomes even more serious with terms that do not have clear connotations, such as possible, frequent or most likely.

Hillson was able to show, in addition to other studies: if natural language is used to describe probability, it is highly probable that errors will be introduced into the assessment of risk.

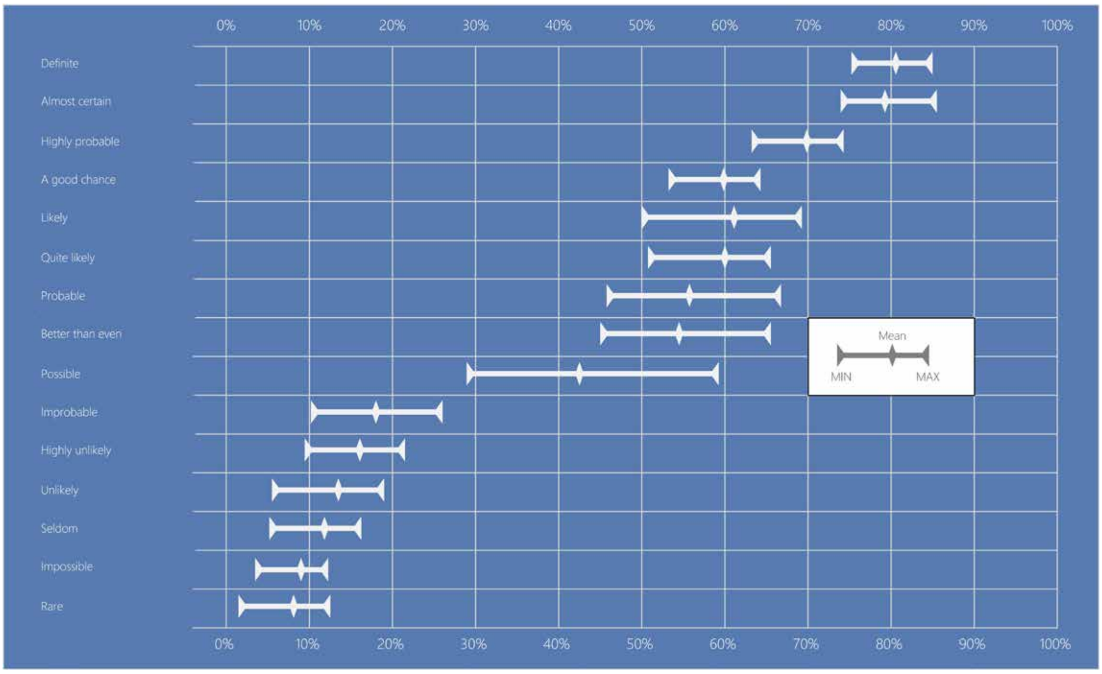

Figure 3: Can there even be a risk assessment without quantification? (Source: Own illustration based on [18])

Risk Assessments should therefore at least be able to deal with the above-mentioned bandwidths and take them into account. It is not about whether something is inaccurate, but the statement that a verbal statement is inaccurate, but can be mapped within a certain range, that contributes to the evaluation. It is up to the risk manager or the person responsible for the risk to decide whether a „highly unlikely” rating of between 5 to 21% should be used, whether it is important to set a focus within the bandwidth in the form of a mean value, or whether the mean value alone is sufficient for quantification. In any case, a transfer of a vague qualitative statement to a quantitative, stochastic-based one is possible in any case.

Non-quantification means quantification with zero

The fact that risks are nevertheless frequently not quantified has various causes. In particular, there are problems with available data on risks, knowledge deficits regarding the methodology for risk quantification and the aversion of many people to deal with numbers and mathematics (and thus to commit themselves comprehensibly and clearly, see the empirical studies on the risk attitude of managers in [19] and [20]). The most frequent reason given by companies is that a quantitative description of the risk is dispensed with because no adequate (historical) data is available on the quantitative effects and the probability of occurrence or frequency of a risk. The risk is then not quantified and only "managed" as a "verbal note" in risk management. Accordingly, it is neither included in the assessment of the threat to the company as a going concern, nor in the calculation of equity capital requirements by means of risk aggregation nor in the derivation of risk-appropriate capital cost rates for corporate management.

Does poor data quality justify dealing with a risk in this way? Certainly not. What is decisive above all is that with the neglecting of a risk described here, a "non-quantification" is not achieved at all. In fact, the risk is not taken into account in any of the calculations mentioned, i.e. it was in fact quantified with zero (i.e. with a probability of occurrence/frequency and an amount of zero damage).

This makes it clear: there is no such thing as non-quantification of risks; non-quantification means quantification with zero. And this is certainly often not the best estimate of a risk.

Instead of such a "zero quantification" of a risk, it is obvious to quantify it with the best available information and this can be – if neither historical data nor comparative values or other information are available – even subjective estimates of the quantitative level of the risk by "experts" from the company or external "experts". An acceptable quality of such estimates can certainly be ensured through suitable procedures, for example a commitment to a comprehensible derivation. The use of subjectively estimated risks and their use in risk management is also methodologically permissible and necessary, which Sinn already pointed out in 1980 in the context of his dissertation "Economic Decisions under Uncertainty" [16].

Subjectively estimated risks can also be processed in the same way as (supposedly) objectively quantified risks. One must always be clear about the alternatives: Estimating the quantitative effects of a risk with the best available knowledge (subjectively if necessary), or implicitly setting the quantitative effects to zero and thus underestimating the scope of the risk. Overall, it is thus clear: only the quantification of risks creates a significant part of the economic benefit of risk management to support decisions under uncertainty. Effective risk management requires quantification of all relevant risks [21, 22].

After the process step of risk identification, all material risks must be quantified. This also applies to ESG risks, at least their financial impacts. Only with quantified risks can one calculate, compare and assess them, for example, with regard to the consequences for rating or company value. Risk assessment comprises – as already mentioned – the quantitative description of a risk by means of a suitable probability distribution and the calculation of risk measures. Since the determination of a suitable quantitative description for a risk can certainly be associated with considerable work, for example statistical analyses, in practice one will usually limit oneself here to the risks that are important for the company. In order to be able to focus in this way, however, at least a rough estimate of the quantitative level of a risk is necessary.

Describe risks with probability distributions

For the quantitative description of a risk, a probability distribution can be used that describes the impact of a risk on results within a period (something related to a year). A more differentiated view is possible if a risk is described by (1) a probability distribution for the frequency of risk occurrence within a period and (2) a probability distribution for the amount of loss per risk event that occurs.

A distinction must be made between "gross effects" and "net effects" of a risk. For risk quantification, the net effects are ultimately relevant, in which all currently realized risk management procedures (e.g. insurance) are already taken into account. Instead of "gross effects" and "net effects", it would be more appropriate to speak of a status quo risk and a target risk. The status quo analysis takes into account all measures already implemented in the past. The target risk, on the other hand, defines the targeted level after implementation of further and new risk management measures. The calculation of a "true gross risk" will not be possible in practice, as there is usually no information on all measures that have already been implemented in the past.

The most important distribution functions in the context of risk management are binomial distribution, normal distribution, triangular distribution, Poisson distribution and the compound distribution [22, 23, 24]. These distributions describe either the frequency or the impact of a risk. Or they integrate the frequency of occurrence and the level of impact of the risk.

Traditionally, the simplest binomial distribution is often used in practice, which describes a risk only by the amount of damage and the probability of occurrence. This is appropriate when considering "event-oriented risks". With these, one can approximately assume that the corresponding risk occurs exactly once in a year with probability p and then results in a loss. Typical use cases are the loss of a key customer, a fire in a factory or the failure of a critical machine.

Risks that represent upside and downside risk at the same time can be described by the normal distribution, for example. For its specification, one needs the expected value, which as a situation parameter says what happens "on average", and the standard deviation, which specifies the scope of "usual" positive or negative deviations. The normal distribution is used in particular to describe risks that can be understood as a compression of many individual small (and independent) single events, such as for demand fluctuations, turnover fluctuations, interest rate and currency risks, stock returns and commodity price changes (specifically, therefore, for "market-related" risks).

In the simplest case, the so-called triangular distribution can be used to describe asymmetric risks that have either an excess of opportunities or an excess of downside risk. In this, a risk-related variable under consideration (for example, the costs of a project) is described by (a) minimum value, (b) most probable value and (c) maximum value. Examples: risk-related possible range of market share, personnel costs or amount of investment.

Frequencies can be described very pragmatically and soundly with a Poisson distribution. The Poisson distribution is mainly used where the frequency of an event is considered over a certain time. The Poisson distribution is also sometimes called the "distribution of rare events". The generalized Poisson distribution and the mixed Poisson distribution are mainly used in the field of actuarial mathematics, where it is also a question of estimating the frequency of loss events. If a random variable X is Poisson distributed, then λ is both the expected value and the variance.

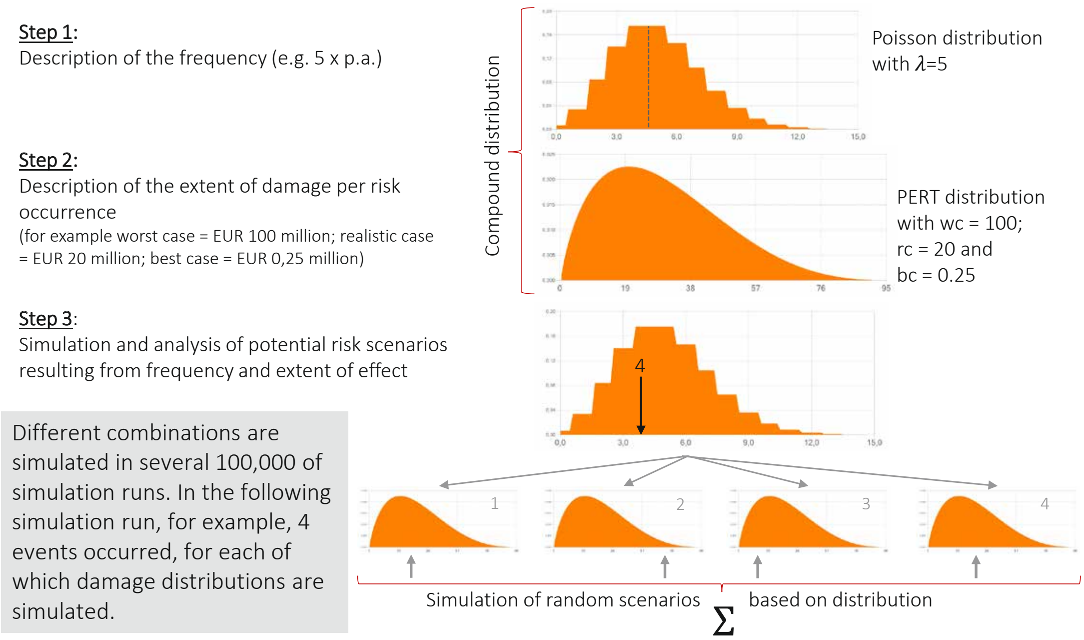

Figure 4: Compound distribution (Source: own illustration)

The compound distribution results naturally from practical applications where a random number of claims, each with a random amount, add up to a total claim. Figure 4 shows an example of the evaluation based on a compound distribution. In the example, the damage scenario was modelled based on the parameters "best case", "realistic case" and "worst case" in the form of a PERT distribution. The PERT distribution is based on a transformation of the four-parameter beta distribution with the assumption that the expected value results as a weighted average of the minimum, the maximum and the most probable value. In the standard PERT distribution, four times the weight is applied to the most likely value. By adjusting the shape parameter, the uncertainty of the expert estimates can be reflected.

Especially for the assessment of ESG risks and a "serious" consideration of uncertainty, the compound distribution offers a solid basis.

Often, only a combination of probability distributions allows an adequate description of a risk. This combination is represented by the compound distribution. Consider, for example, the case where a certain probability of occurrence or frequency can be assigned to an event-oriented risk, but the amount of damage itself is uncertain and can only be described by a range (minimum value, most probable value or maximum value).

Particularly when quantifying ESG or CSR risks, one is often confronted with the problem that the available data appear to be insufficient (and one obviously has to rely on expert estimates). Very often, one is faced with the challenge that an ESG risk consists of many "facets". The various sub-aspects or individual risks have to be aggregated accordingly. The aggregation of risks generally requires a stochastic simulation (Monte Carlo simulation), except in a few special cases (e.g. when all risks are normally distributed, see [21]). The method of stochastic simulation is explained in more detail in the following subsection.

Stochastic simulation as a methodology for risk aggregation

Stochastic scenario analysis (often called Monte Carlo simulation in practice) is based on the idea of considering the input parameters of a simulation as random variables. Thus, problems that cannot be solved analytically or can only be solved at great expense may be solved numerically with the help of probability theory (which is part of stochastics, which combines probability theory and statistics). In general, two groups of problems can be distinguished for which stochastic scenario analysis can be applied. On the one hand, it can be used to deal with problems of a deterministic nature that have a unique solution. On the other hand, questions that can be assigned to the group of stochastic problems are also a suitable field of application for a stochastic simulation [10]. The basis for the simulation is a very large number of similar random experiments.

From a business point of view, all questions can be investigated that

- either cannot (be) analyzed exactly due to the large number of their influencing variables and for which therefore a random sample is used for the analysis;
- or for which the input parameters are random variables (the optimization of processes or decisions with parameters that are not exactly known also belong to this group).

The application of stochastic scenario analysis is broad and ranges, among other things, from the stability analysis of algorithms and systems, the aggregation of individual risks of a company to an overall entrepreneurial risk, the prediction of developments that are themselves influenced by random events (stochastic processes), the optimization of decisions based on uncertain assumptions to the modelling of complex processes (weather / climate, production processes, supply chain processes, reconstruction processes in nuclear medicine) or the estimation of distribution parameters.

Against this background, stochastic simulation is also suitable for mapping uncertainty in the area of ESG risks.

The development of the method is closely associated with the names of the two mathematicians Stanislaw Ulam and John von Neumann. They are said to have used this method during their work on the Manhattan Project at the Los Alamos Scientific Laboratory to solve highly complex physical problems numerically using a simulation. According to anecdotal evidence, the code name used was "Monte Carlo". The first scientific publications on this method appeared in the late 1940s. With the emergence of electronic computers, which happened at the same time, Monte Carlo simulation first became widespread in science and later also in business. Today, stochastic simulation is an established method in many subject areas and for solving a wide range of problems.

The basic idea of stochastic simulation is to determine the corresponding result or target variables for randomly selected parameters via the corresponding correlations (cause-effect network). The model used to determine the target variables is usually deterministic in nature, i.e. the target variables are unambiguously determined when the parameters are set. However, due to the random character of the parameters, the target variables are in principle again random variables. However, it can generally be assumed that a sufficiently large number of target variables determined in this way represents a good approximation of the actual values of these target variables (strictly speaking, it is not the actual values but the expected values of the target variables that are meant). The mathematical foundation of this procedure is the law of large numbers, the fundamental theorem of statistics (theorem of Gliwenko-Cantelli) and the central limit theorem [25]. The method is thus a sampling procedure. Due to the random selection of parameters, the term stochastic simulation or stochastic scenario analysis has also become established for Monte Carlo simulation.

The Monte Carlo simulation procedure was described by Metropolis and Ulam in an article published in 1949 in the Journal of the American Statistical Association. In it, both scientists describe the procedure for the Monte Carlo method in two steps: "(1) production of 'random' values with their frequency distribution equal to those which govern the change of each parameter, (2) calculation of the values of those parameters which are deterministic, i.e., obtained algebraically from the others." [26].

This procedure described by Metropolis and Ulam has not changed much in the last 80 years. Today Monte Carlo simulation constitutes an indispensable method in risk management and is used for risk aggregation [10, 22].

Specifics of quantifying ESG / CSR risks: financial and non-financial impacts

The connection between the so-called "non-financial" risks and the financial risks should be considered in more detail below. It should be noted that the so-called "non-financial" risks, such as ESG or CSR risks in particular, can very well have financial effects that must be taken into account in risk management.

As a result of the Global Reporting Initiative (GRI), the management reports of companies have also included sustainability reporting (Corporate Social Responsibility, CSR) since 2017. A relationship to risk management arises from the fact that material non-financial risks must also be addressed here.

However, only risks that – taking risk management measures into account – are very likely to have serious negative effects (for example on the company, employees, customers, nature or society) are to be disclosed in the annual report. The materiality threshold is so high that ESG or CSR risks have hardly been reported so far. Nevertheless, "internally" these CSR risks are also a topic for risk management. It is recommended to first structure them (see Figure 5).

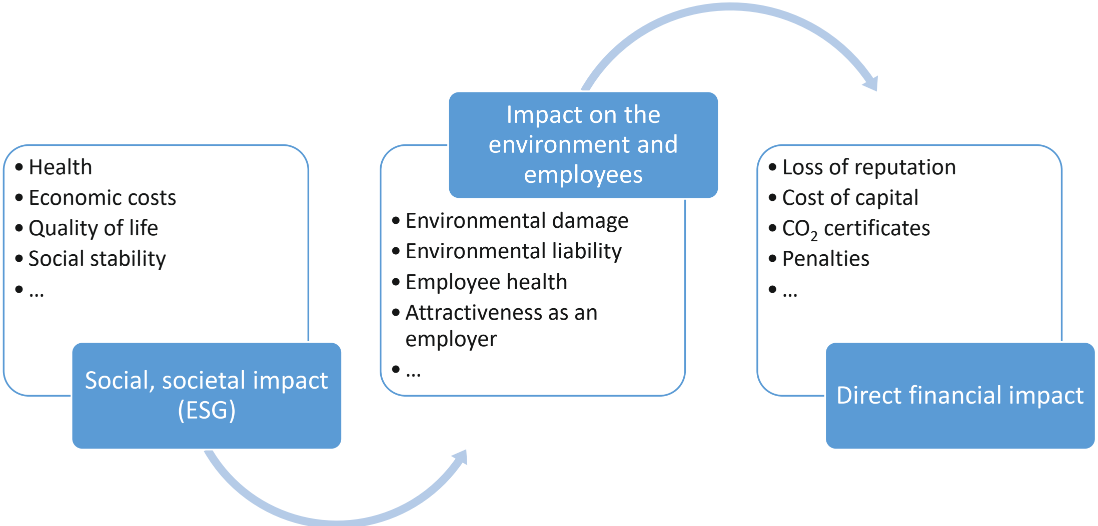

Figure 5: Impact areas of ESG and CSR risks [Source: own illustration]

Direct financial effects have, for example, "CO_2emission risks", which may require an expensive purchase of CO_2 certificates in the future. Section 91 of the German Stock Corporation Act (AktG) requires that possible "developments threatening the existence of the company", including those resulting from the combined effects of individual risks, be recognized at an early stage. However, a threat to the company's existence is only to be assumed if a "CSR risk" also has financial effects and can thus lead to illiquidity. Such risks must also be included in the risk-bearing capacity concept.

In the case of risks belonging to the first box in Figure 5 (Social, societal impact), legal requirements must be adhered to; a topic for "compliance". Whether a company should do more than this is debatable. The economist and statistician and winner of the Nobel Memorial Prize in Economic Sciences Milton Friedman has argued that companies should generate the highest possible profits for their owners in a sustainable manner – in compliance with the law – and leave it up to the owners to decide whether they want to use profits for social, environmental or other goals (shareholder value approach) [27].

The bottom line is that risk management must also deal with non-financial risks, especially "CSR risks", i.e. develop methods for identifying, quantifying and monitoring risks that primarily have an impact on employees, customers, nature or society. One needs measurement concepts, also for the non-financial impacts (for example like the DALY [Disease-Adjusted Life Years] to capture possible negative health impacts). Furthermore, for every CSR risk – as for any other risk – the financial impact on the company must always be recorded (including indirect impacts, for example, through a negative reputational impact). As always, it should be noted: in addition to the frequency / probability of occurrence, the uncertainty of the effects must also be quantified. This means that the effects are to be described with the help of a suitable statistical probability distribution, and not, for example, by a "certain amount of damage". It is therefore a matter of bandwidths to avoid false accuracies. Such considerations are also relevant for the models for measuring risk-bearing capacity and risk tolerance.

An example of the possibility of quantifying an ESG risk is the risks from the CO_2 emissions of an industrial company, which are considered in the next section.

Case study on the quantitative assessment of ESG risks using the example of CO_2 emissions

The quantification of the financial impact of an environmental risk ("E-component" in ESG) is illustrated below using the currently particularly important topic of CO_2 emissions.

	2021	2022	2023	2024	2025
Production units (planned)	1000	1050	1103	1158	1216
Planned increase p.a.		5%	5%	5%	5%
Standard deviation (uncertainty)	4%	4%	4%	4%	4%
Simulated production units	1011	1035	1106	1177	1307
CO_2/production unit (in tonnes)	1000	1000	1000	1000	1000
Total CO_2 (in tonnes)	1011208	1034665	1106148	1177360	1307474
Planned reduction CO_2 p.a.	-10%	-10%	-10%	-10%	-10%
Standard deviation (uncertainty)	5%	5%	5%	5%	5%
Simulated CO_2 reduction (in tonnes)	-99683	-104080	-112239	-119327	-126497
Total CO_2 after reduction (in tonnes)	911525	930585	993909	1058034	1180977
Cost of CO_2 certificates / tonne (realistic case)	20 €	20 €	20 €	20 €	20 €
worst case (PERT distribution)	23 €	24 €	26 €	28 €	30 €
best case (PERT distribution)	16 €	17 €	17 €	18 €	18 €
Simulated costs CO_2 certificates / tonne	21 €	21 €	19 €	22 €	21 €
Total costs of CO_2 certificates (simulation)	18.824.592 €	19.078.845 €	19.337.614 €	22.845.399 €	25.306.378 €
Expected value p.a.	17.871.421 €	19.081.426 €	20.352.336 €	21.884.509 €	23.339.266 €
VaR 99%	20.971.914 €	23.092.915 €	25.837.378 €	28.536.611 €	31.600.413 €
Expected Shortfall 99 %	21.343.149 €	23.613.091 €	26.769.732 €	29.841.663 €	32.975.643 €

Table 1: Parameters of the CO_2 simulation model

Assume that a company currently emits 1,000 tonnes of CO_2 per production unit, directly and indirectly [3].[1] In 2021, 1,000 production units are planned. Furthermore, production is planned to increase at a rate of 5% per year (in real terms) over the five-year planning period under consideration (uncertainty: 4%).[2] The CO_2 intensity of production is planned to be reduced by 10% per year (uncertainty: 5% per year). How does this data represent the financial risk of the company, which also has to be taken into account in risk aggregation and the determination of the overall risk scope (equity capital requirement)? And how does the ESG risk present itself from the perspective of the stakeholder "society", i.e. how relevant are the negative effects of the company's CO_2 emissions as a result of the associated increase in temperature?

Table 1 shows the basic parameters and the structure of the stochastic simulation model. Both the chosen parameters and the structure of the model should be interpreted against the background of a didactic example. For example, stochastic processes were not taken into account in the example.

First, the financial risks of the company are calculated. The starting point is the measurement of the additional costs that the company may

1 The heterogeneous products are converted into a uniform measure, whereby even the (price-adjusted) turnover can be used for simplification.

2 A normal distribution with a standard deviation of the growth rate of 4% is assumed. In addition, a martingale is assumed, i.e. deviations from the plan that occur in year t lead to an adjustment of the plan in the corresponding amount in the following years. In probability theory, a martingale is a sequence of random variables for which, at a particular time, the conditional expectation of the next value in the sequence is equal to the present value, regardless of all prior values.

incur due to an unplanned development of CO_2 emissions.[3] It is assumed that CO_2 certificates are purchased for the CO_2 emission, which currently have a price of 20 EUR per tonne. The future price development is uncertain. This uncertainty is represented in the simulation model with the help of a PERT distribution (see Figure 6). The uncertain costs of CO_2 emissions therefore result from the uncertain price of the CO_2 certificate on the one hand and the uncertain CO_2 emission quantity on the other. With a stochastic simulation, the corridor for the future costs "CO_2 emission risk" shown in Figure 7 can easily be specified.

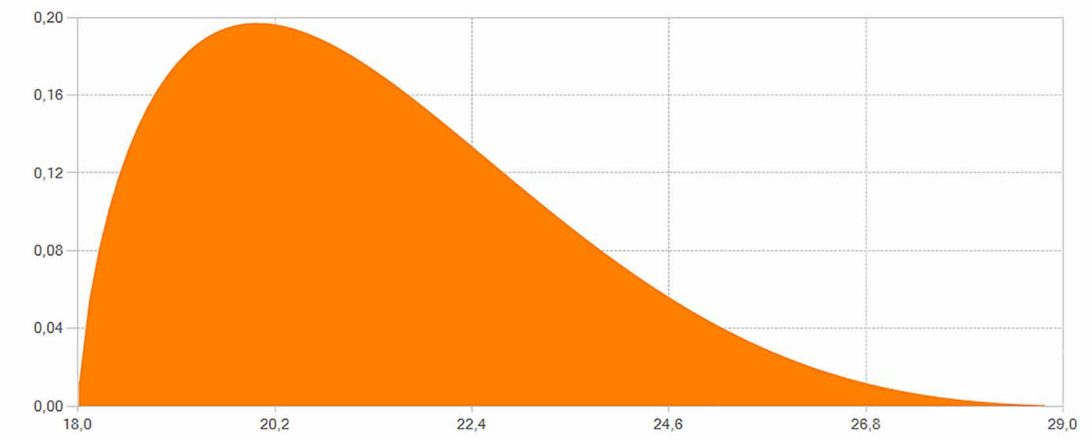

Figure 6: Uncertainty of CO_2 certificate prices was taken into account with a PERT distribution

As already mentioned, the expected value of the costs is taken into account in the planning. As a risk measure, the Value at risk (VaR) and Expected Shortfall (ES) is additionally calculated, initially for each individual year. In addition, the " CO_2 emission cost risk" is given for the entire planning period of five years. Specifically, it is determined that, for example, with a certainty of 99%, from the company's point of view the "CO_2 emission costs" of around 31.6 million EUR will not be exceeded in 2025. In Figure 5 (histogram) and Figure 6 (cumulative density function), both the expected values and the value at risk as well as the expected shortfall [22, 28] can be read.

Here one has a quantification of the CO_2 emission risk "stand alone". In the context of risk management, CO_2 emission costs that deviate from the planning are directly taken into account in the risk aggregation in order to adequately consider the interaction between uncertain production volume and uncertain CO_2 emission costs.[4]

3 The costs for planned CO_2 emissions are of course taken into account in the "realistic case" planning, as are other costs, especially also for CO_2-reducing measures through investment and technology change.

4 Uncertainty regarding the planned costs of the CO_2 emission reduction measures have been neglected in the didactic example for the sake of simplicity. Other aspects of risk that are still relevant here, e.g. from the uncertainty of the political environment and climate policy, are also neglected.

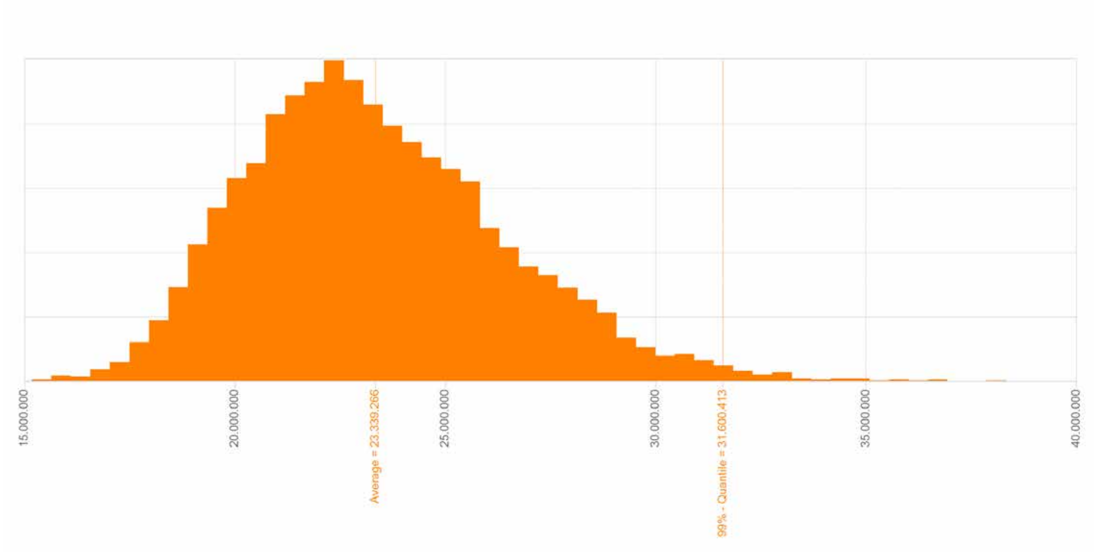

Figure 7: Histogram of the simulation results

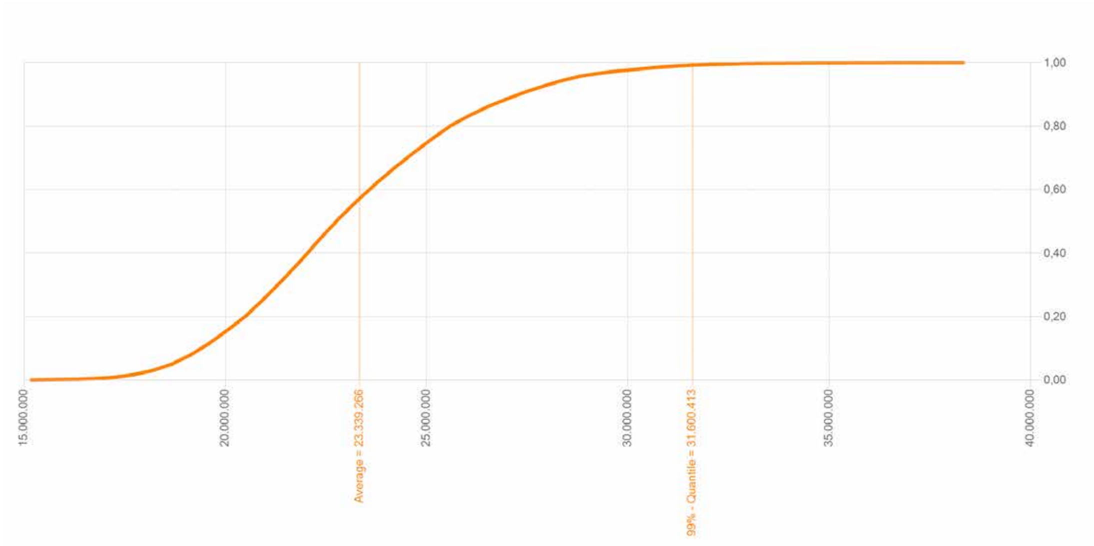

Figure 8: Cumulative distribution function (CDF) of the simulation results

How does the constellation look from the level of society? Of course, one can first understand the CO_2 emission risk as a "non-financial" risk and state the CO_2 emission data, e.g. "in tonnes". But in many cases it is not even necessary to remain at this level. One can also indicate the financial impact here, which makes it possible to compare even different risks – within certain limits. For example, the damage caused by CO_2 emissions has already been quantified in various scientific studies [29].

Let us assume that the global damage caused by the increase in temperature as a result of CO_2 emissions would be around 30 EUR per tonne. By combining the uncertain CO_2 emission amount of the company and the uncertain damages caused by the CO_2 emission, one can now quantify the ESG risk "CO_2 emission" from a global perspective, again with a simulation model. It should be noted that part of the damage caused by CO_2 emissions is already "compensated" by the company through the purchase of CO_2 certificates. Without going into the details of the model here, the economic costs can also be quantified – in the form of expected values over time and as a "bandwidth".

Summary and outlook: Probabilistics make our knowledge more multi-faceted and diverse

The term ‘stochastics’ comes from the Greek word στοχαστικὴ τέχνη, meaning assumption and presumption. The mathematician Jakob Bernoulli discovered the value of stochastics for evaluating risks back in the 17th century. In his major work, "Ars Conjectandi", he describes that assuming anything is fundamentally the same as measuring its probability. Bernoulli refers to the art of assumption and presumption (ars conjectandi sive stochastice) as the probability to measure things with the purpose that we can select and follow whatever seems to be more accurate, safe and recommendable in our actions. And that is what effective risk management is all about. Risk management is the art to professionally anticipate risks and opportunities and safely sail through stormy seas. This requires a serious way of dealing with uncertainty. If we know very little, we should not presume that we can label a risk with a price tag or an exact probability.

A well-founded risk analysis avoids false accuracies and individual scenarios and instead offers realistic bandwidths of future development. In the simplest case, a worst-case, a realistic-case and a best-case scenario are assessed. The world of stochastics and probabilistics makes our knowledge more multifaceted and diverse, but not inaccurate [30, 31].

Stochastic statements provide a range of potential scenarios. We simply do not know the potential surprises in the future. Therefore, risks should be assessed in an interdisciplinary discourse across a range of potential scenarios.

It is not relevant here whether the information is perfect or not. Perfect information is never available in reality and therefore risk analyses can deal with bad data and help to optimally evaluate the information that is actually available.

Stochastic scenario simulation combines expert knowledge (also in the form of intuition and gut feeling) with the power of statistical tools in an intelligent way. This is because statistical thinking leads to greater competence in dealing with uncertainty as a result. Understanding statistics is a necessary skill (not only for risk managers) to be able to classify and evaluate the world we live in and to make decisions under uncertainty. The Indian statistician C.R. Rao puts it in a nutshell: Secure knowledge emerges in a new way of thinking from the combination of uncertain knowledge and knowledge about the extent of uncertainty [32].

Analogous to a statistician, a risk manager should also have four competencies:

- they can distinguish the essential from the insignificant,
- they can deal with risk and uncertainty,
- they can structure problems and translate them into methodologically sound models,
- they can structure data and translate them into solutions.

It is essential to note that ESG risks also have financial implications, which must be quantified in any case. If one were to ignore the financial components of ESG risks for the company, one would underestimate the "degree of threat to the company's existence" and the aggregated total risk scope (equity and liquidity requirements).

The possibilities for quantifying such risks are available if one sensibly allows quantification from the best available information in each case (i.e. also transparent quantification based on expert estimates). The extent to which the non-financial aspects, the effects on society and the environment, are quantified must be discussed independently.

The didactic example of CO_2 emissions outlined in the article shows that such quantification is certainly possible. Basically, it should be noted that the consequences of ESG risks for society and the environment can also be quantified in accordance with the general explanations on the quantification possibilities of risks.

The alternative of non-quantification, on the other hand, would be the creation or invention of alternative facts that we just like. Politicians, the media and, unfortunately, "scientists" are increasingly providing us with such simple (explanatory) pictures of the world.

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