3.3.3 Industry and energy

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1 Introduction and background

This section focuses on the secondary sector, namely manufacturing and energy industries. These industries produce goods and services that are consumed as final or intermediate goods and services, and that are necessary for activities in a society, while they also employ labour and provide wages to households. Physical damage to these industries not only leads to a shortage of goods and services that they produce, but also causes declines in income to their labour forces. In addition, because of the globalised production networks as well as the lean production system employed in various manufacturing industries, the damage and business interruptions brought about in one region could spread to other regions in the same countries and potentially across the world. Some recent empirical observations, for example the declines in production of car-manufacturing companies at various countries in the aftermath of the 2011 east Japan earthquake and tsunami, proved that the modern manufacturing network appears vulnerable to such catastrophic disasters (Reuters, 2016). In this context, the production networks, such as intra- and interindustry linkages, should be encompassed to understand a comprehensive picture of disaster effects.

In this section, damage to physical facilities, resulting from internal causes or external forces, is called 'damage', while the decline in production level caused by the damage is called '(first-order) losses' of production (Okuyama, 2007). While the terminology used in the United Nations (2016) refers to damage and losses as 'direct economic losses' and 'indirect economic losses' respectively, the use of the words 'direct' and 'indirect' creates some confusion, such as adding these two different measures together, which is theoretically incorrect and potentially leads to the double counting of impacts. In addition, the methodologies to measure higher-order effects use the term 'indirect' with a different definition (Rose, 2004). The most up-to-date Handbook for Disaster Assessment by the Economic Commission for Latin American and the Caribbean (ECLAC, 2014), known as the ECLAC methodology, also employs definitions of damage and loss similar to Rose's. Therefore, in this section, 'damage', 'losses' and 'higher-order effects' are utilised, instead. These two numbers of damage and losses should be clearly distinguished, because adding them together would double-count the impacts, and Rose (2004) suggested listing both of them separately to paint an inclusive picture. A few methodologies are available for the quantification of damage and losses, and their details are discussed below.

2 Risks in industry and energy industries

Manufacturing and energy industries inherently involve risks that can be classified into internal and external, and/or can lead to broader effects on the macroeconomy and the natural environment.

Manufacturing and energy industries inherently involve risks that could lead to accidents that might result in a disaster, or could experience a catastrophic natural hazard, such as earthquake, flooding, severe weather, or drought, that would bring about damage or losses to the production facilities. These risks can be classified into internal (within the industry) and external (from other industries), and/or can lead to broader effects on the macroeconomy and natural environment. For example, internal risks include the malfunctioning of production equipment, software bugs, faulty operation of production systems by humans, financial risks, reputational risks if the company does not address climate change and so on. External risks can be threats of catastrophic natural (and man-made) hazards, which can cause physical damage to production facilities and/or networks, and increased climate variability leading to hazards. Internal risks can be dealt with by technological and behavioural means, while external risks may be responded to by prevention and preparedness, such as a business continuity plan (BCP).

In particular, modern manufacturing and energy industries rely heavily on supply chains (value chains) because of the increasing globalisation of production processes, through which a company purchases parts (intermediate inputs) provided by other companies (upstream industries) for its products and sells its products to other companies (downstream industries) or to consumers as final products. Specifically, upstream industries are mainly mining, material production (chemical, steel, etc.) and energy industries, and downstream industries include product-assembling industries (automobile, electrical and electronic products, etc.) and service industries. In this way, manufacturing and energy industries form complex and interwoven interindustry networks. Given this, one company's stoppage of production due to damage to its production facility resulting from internal or external causes would create a negative ripple effect on a wide range of industries and on the economy, as well as positive opportunities to other companies that can provide substitutable products. The impacts of such an event can be classified into the following five types: (1) production (supply) disruptions due to damage to production facilities; (2) forward effects of the supply disruptions to the downstream industries; (3) technical and/or spatial substitution effects for replaceable goods and services; (4) decline in both intermediate and final demands due to the decreased production and earnings; and (5) backward and positive effects from intensive demand injection of reconstruction activities (Oosterhaven, 2017). It is expected that the interindustry

2.1 Risks within industries

Manufacturing and energy industries inherently involve risks within their operations, and the realisation of such risks may cause damage to their facilities. These risks include faulty design of production processes, malfunction of the production facility and/or equipment, software problems, mismanagement of the company, or other human errors. Each company in these industries tries to minimise these risks using redundancy, backup facilities, periodical maintenance and so on. Because all the production systems, facilities, and equipment are designed and installed by humans, it is inevitable by our nature that they will contain some major or minor errors or drawbacks. While these risks originate internally in the production system in question, the systems are also exposed to external risks. Some natural hazards, for example earthquakes, flooding, severe storms, and drought, can damage or even destroy part or all of the production facilities, creating the similar impacts to the internal risks above. This risk will create production disruptions, as in type 1, and would trigger a ripple effect on the economy and society as described above.

2.2 Risks among industries

Modern manufacturing and energy industries require a set of intermediate inputs for producing their products, creating interwoven interindustry linkages. For example, car manufacturers require thousands of intermediate inputs, such as tyres, glass, seats, plastic materials, paints, electrical parts, electronic circuits and, water, from their suppliers. Even though a car-manufacturing company did not have any physical damage to its production facility, it would eventually halt or delay its operations if one of the suppliers that produces critical intermediate input were damaged and could not supply its products. This type of cascading impact on an undamaged company is called 'higher-order effects' (Rose, 2004), which can potentially produce the ripple effect of impacts through interindustry linkages (supply chains) to many other industries, described as types 2, 3, and 4 above.

This ripple effect would propagate not only to the downstream industries through the supply chain but also to the upstream industries. If one company (A) needs to pause its production because of severe damage to one of its critical suppliers (B), this is called the impact on downstream industry. Meanwhile, another company (C), which provides its product as an intermediate input to B, will need to decrease its production because B cannot produce its product therefore does not need intermediate inputs from C. This is an upstream propagation of the impact. Moreover, company A uses other intermediate inputs from another company (D) as well as from B. When company A halts production as a result of damage to B, it influences the production of company D, since A also stops purchasing D's product. This is also an upstream propagation of impact. Company A's production stoppage can also potentially lead to a downstream propagation of the impacts, if other companies purchase company A's product as their intermediate inputs. The ripple effect of impacts spreads through the web of supply chains that modern manufacturing industries have formulated and utilised. Some industries, such as car manufacturing and construction, require a wide range of intermediate inputs; if even a small supplier that provides a critical input to major companies is damaged by a disaster, it can create extensive ripple effects on many other industries.

Higher-order effects are quite entangled and complex to measure empirically by using usual macroeconomic indices, such as changes in gross domestic product, due to other macroeconomic disturbances and so on. Therefore, the quantification of higher-order effects requires economic models, such as input–output (IO), computable general equilibrium (CGE) or econometric models. Some of these models are briefly discussed below.

2.3 Effects on macroeconomy and environment

Since the higher-order effects can propagate across a broad range of industries, there is a concern that a catastrophic disaster, such as the 2005 Hurricane Katrina in the United States and the 2011 east Japan earthquake and tsunami, could affect negatively the regional or national economy. While a disaster caused by internal or external risk to manufacturing or energy industry would lead to localised damage and losses and could spread the higher-order effects further to other industries elsewhere, the economic impact of such a disaster, even a catastrophic one, may not affect the national economy of developed countries negatively in both the short and longer terms (Albala-Bertrand, 2007). This is because developed countries should have sufficient financial, technological, and other resources to better manage disaster risk through the implementation of countermeasures against the adverse impacts of disasters. In other words, if they did not prepare thoroughly against such events, there would be substantial and long-lasting negative effects in and around the country, such as after the 1986 Chernobyl nuclear accident and the 2011 Fukushima nuclear accident.

The timing of a disaster occurrence could influence the overall impact of a disaster in a macroeconomic context. When economies exhibit higher growth during a boom period, they may be more vulnerable to disasters than those with slower or declining growth in a bust period. This is because during a bust period idle and unused production capacity can serve to absorb the production shortage induced by the disaster, whereas during a boom period production capacity in economies is fully utilised and hence cannot deal with the production shortage (Hallegatte and Ghil, 2008). Having an inventory of intermediate inputs and final products can also serve as a buffer against the forward (downstream) effect of supply shortage, whereas modern manufacturing industry has been exercising the lean production system, under which it minimises or eliminates such inventories, embedding increased vulnerability to the forward effects. However, many manufacturing companies consider that such risk would last for a short period so they maintain the lean production system, even after experiencing prolonged production stoppage due to forward effects created by a catastrophic disaster (Reuters, 2016).

It is a somewhat common misconception that disasters might cause renewal or update of assets and facilities, leading to upward macroeconomic trends in the long term, which is sometimes referred to as the Schumpeterian creative destruction or fertilisation effect. Empirical investigations of the relationship between disasters and economic growth/trends indicate otherwise (Okuyama, 2019). The studies using socioeconomic disaster indicators, such as those by Noy (2009), Cavallo et al. (2013), and Fomby et al. (2013), provide somewhat mixed results for such a relationship, whereas the studies employing physical intensity indicators of disasters, for example those of Hsiang and Jina (2014), Felbermayr and Gröshcl (2014), and Berlemann and Wenzel (2016), found clear negative effects between them. Hallegatte and Dumas (2009) analysed this relationship that damage caused by hazards and subsequent reconstruction with renewed assets only increase production levels but cannot lead to overall technological progress, therefore they may not boost long-term economic growth.

Some industries, especially upstream industries (mining and energy industries), characteristically contain risks with the potential to trigger environmental damage due to their use of hazardous resources and materials. Some accident in such a company, with a natural or human cause, may result in a leakage of hazardous materials into the surrounding area, which contaminates the natural environment of the area. This may lead to an environmental disaster, such as the Exxon Valdez oil spill in 1989 in Alaska, the United States. While downstream industries (assembling products) also hold the similar risks to a lesser degree, they are not immune to causing environmental damage by fire in factories and/or inventory facilities, leading to temporary air pollution from the burning of their intermediate and final products.

3 Risks from climate change

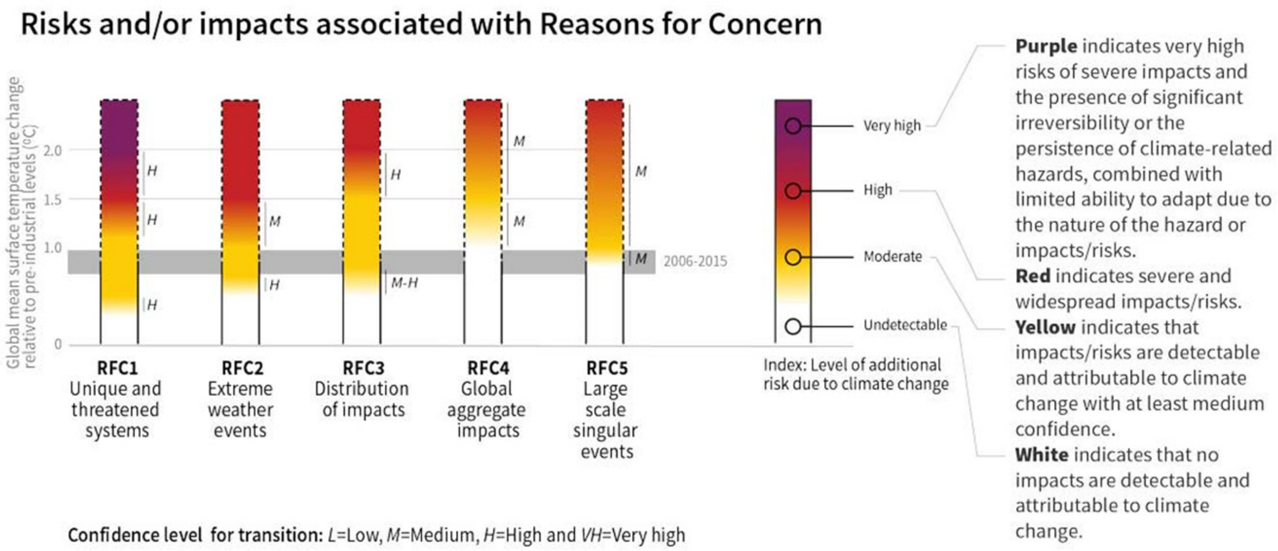
Uncertainties related to climate change risks (e.g. time of occurrence and level of increase in risk) prevent industry from organising optimal (timely and measured) and proactive preparedness.

Climate change is expected to increase both the frequency of occurrence and the magnitude of natural hazards, and this will increase the risks (exposure and consequences) to manufacturing and energy industries. The similarity of these hazards to already existing threats (i.e. extreme weather events) makes it easier for the industry to assess, prepare for and mitigate the risks. However, the uncertainties related to the issues, such as the time of occurrence and level of increase in the risk, prevent industry from organising optimal (timely and measured) proactive preparedness.

Premature and/or excessive adaptation presents risk itself. Additional uncertainty is related to regional impacts. A special report from the Intergovernmental Panel on Climate Change (IPCC) analyses the risks from various climate change scenarios between 2 °C and 1.5 °C warming above pre-industrial levels and related global greenhouse gas emission pathways (Hoegh-Guldberg et al., 2018). That report estimates the impacts and risks as high from extreme weather events, and moderate from large-scale singular events at 1.5 °C warming, with a moderate level of confidence, as shown in Figure 1.

However, the estimates of coastal flooding risk are very high, with a high level of confidence. The following two subsections discuss industry and government actions related to climate change risk assessment, adaptation and mitigation measures.

Figure 1. *Estimated impacts and risks from different levels of global warming associated with reasons for concern (RFCs)*
Source*: Figure 3.21 in Hoegh-Guldberg et al., 2018.*



3.1 Climate change risk management for the manufacturing and energy industries

The manufacturing and energy industries have been facing climate change risks to their market ratings and regulation requirements. Dealing with these risks is essential because the government regulations, financial market, and insurance companies force and/or expect them to implement timely reactions to such risks.

Goldstein et al. (2018) reviewed more than 16 000 corporate adaptation strategies and significant blind spots found in the assessments of climate change impacts and their management. CDP (2019) summarises the following findings from the companies reporting about climate change risks and opportunities: significant risks are identified as needing expanded analysis; the largest companies report major financial implications; the risks are smaller than the opportunities; some striking regional differences exist; many industries expect to experience fewer implications than the financial industry; management costs outweigh the benefits; the energy industry is a source of lessons to be learned because of early and wide-ranging impacts.

Industry could prepare better for climate change risks by incorporating its assessment into an overall risk management (RM) strategy. Continuous updating with the best available data and methodology is necessary for tackling all the related uncertainties.

3.2 Governance for reduction of climate change risk

Regulators and investors had already motivated the industry to transition towards a sustainable and low-carbon economy, even before climate-change-related risks were considered transitional risks and became highly publicised. All these various governance measures are imperative because they are designed to prepare for increased climate change risks in a socially optimal way. However, there are ongoing debates about what regulations should be imposed and which best practices should be encouraged. Considering the extensive uncertainties related to climate change risks, finding the best approaches is a daunting task. In this context, research and development to reduce uncertainties, and to improve risk assessment for efficient industry applications and effective regulations, are indispensable to tackle the climate change risks. Without the knowledge and insights from the best available sciences, all those involved would be more likely to underestimate or overestimate the future climate change risks. Either way, this would result in significant waste of resources.

4 Estimation methods

It is imperative to understand what assessment models/methods can or cannot cover based on their assumptions.

As argued in the 2017 report (Poljanšek et al., 2017), more consistent and systematically gathered data for the damage and losses to manufacturing and energy industries, and other industries, are needed for assessing the impacts of events. While the OECD governance of critical risks initiative has compiled the data[1] for the policies, processes and practices through which OECD Member countries govern critical risks, the data for damage and losses, as well as higher-order effects, have not been collected consistently or systematically. Because the definitions of damage and loss in a disaster situation, such as the spatial and temporal extent and the valuation methodology, have not been set, nor is there any consensus among stakeholders (Okuyama, 2007), it is a good idea to start with the definitions proposed in the widely used ECLAC assessment methodology (UN ECLAC, 2014), which has been employed to assess damage and losses in recent major disaster cases in developing countries. Terminology used in this subsection – damage, losses and higher-order effects – follows the definitions in the introduction above.

4.1 Assessment of damage

In the ECLAC methodology, damage is defined as the effects that a disaster has on the assets of each industry, expressed in monetary terms. The assets here include physical assets such as buildings, machinery, equipment, furnishing, roads and ports, land, and inventory of final goods and intermediate inputs. Two pieces of information are required to evaluate damage: the level of destruction of each asset and their monetary value (UN ECLAC, 2014). While the ECLAC methodology uses the replacement cost of damaged assets for the conversion from physical quantity to monetary value, it becomes occasionally problematic, especially in a disaster situation (Rose, 2004). When a machine is partly damaged in a disaster, it does not have to be replaced but can be repaired; in this case, the cost should be the repair cost. In addition, even in a case of replacing the damaged equipment, it would not be replaced with the same machine; rather, newer equipment can be installed to replace the damaged old one. In this case, the replacement cost (the cost of new equipment) is not equal to the value of the

[1] See https://qdd.oecd.org/subject.aspx?Subject=GOV_RISK

old one before the disaster. In an extreme case, if a company's factory were damaged by a disaster and it went bankrupt, there would be no replacement cost. Information on estimated damage is indispensable for industries to evaluate their preparedness and mitigation measures and to respond to the damage. Recent increased data collection capabilities and advanced information and communication technologies in many developed countries make it possible to estimate property damage immediately after a natural hazard hit. One such method has been proposed by Heatwole and Rose (2013); it can estimate property damage, including the damage to land, livestock, buildings, equipment, etc., from major US earthquakes based on a regression model. This model consists of 'exposure-related predictors', such as population, income, and land area of hazard-affected region, and 'hazard-related predictors', such as earthquake magnitude, distance from epicentre and so forth, to derive a set of property damage estimates (lower bound, average, and upper bound) in monetary value. While this model is only for earthquakes in the United States, this framework can be applied to other types of hazard and to other countries. This type of method can be useful to assess the damage that a natural hazard has caused and to assist timely disaster response and recovery activities.

4.2 Assessment of losses

Production or business interruptions caused by damage to production facilities lead to declines in production flows of goods and services. Losses are defined as goods and services that go unproduced during a period running from the time the hazard occurs until full recovery of the damaged assets is achieved.

By and large, different methods have been employed for the estimation of business interruption costs. The popular approaches are (1) applying an industry-specific reference value per unit affected or per day of interruption to estimate the production losses; (2) comparing production output between years with and without hazard; and (3) calculating production losses as a proportion of damaged production capital (Meyer et al., 2013). Furthermore, loss estimates can be obtained by fitting statistical models to available historical data (e.g. originating from the insurance industry) (Hogg and Klugman, 1984) by using methods such as parametric curve fitting based on extreme value theory, and generalised Pareto distribution due to the heavy-tailed and skewed nature of the data (McNeil, 1997; Jindrová and Pacáková, 2016). It is cautioned, however, that the hypothetical baseline (without disaster) case must be projected from the best information available, in order to avoid losses being over- or underestimated (UN ECLAC, 2014). Losses here are sometimes called first-order losses, to distinguish them clearly from higher-order effects, discussed below.

Like the frameworks to estimate damage discussed above, a few models have been proposed to estimate losses from hazard intensity index and socioeconomic data that are readily available. One such model is the estimation model for 'production capacity loss rate' by Kajitani and Tatano (2014).

Conventional approaches to production loss estimate require damage data on production facilities and equipment, whereas this model evaluates the production capacity loss rate through functional fragility curves and lifeline resilience factors. While their methodology is tailored to earthquakes and Japanese cases, the framework can be applied to other types of hazards and to other countries where similar data are available. One of the advantages in this methodology is that, once the ground motions of a particular earthquake are given, the estimated changes in the production capacity rate can be derived in the damaged area. This type of rapid assessment method for evaluating production loss is advantageous to timely decision-making in industry for managing response and recovery strategies as well as analysing the higher-order effects.

4.3 Assessment of higher-order effects [2]

As discussed in the introduction, the first-order losses stemming from the business disruptions caused by the damage to production facilities set off a chain reaction, or ripple effect, through interindustry linkages (supply chains). For instance, if a power station were damaged by an accident, electric power would not be available to some or all of the power grids that the power station covered, and manufacturing industries in the affected power grids would have to halt their production until power was restored, even if they were not damaged at all. Moreover, due to the lost production of those industries without power, the suppliers to and the customers of those industries would need to either decrease or pause their production, too. How the ripples of such effect spread across other industries in economies is rather complex, because of intertwined supply chains across industries and over space and even across countries.

In order to assess such higher-order effects of a disaster, one needs to use economic models, such as input-output (IO), computable general equilibrium (CGE), econometric, non-linear optimisation or some other macroeconomic models. These models are highly sophisticated and need some lengthy descriptions. In short, IO models highlight interindustry transactions to derive ripple effects from changes in demand to one or more industries, while CGE models simulate changes in demand and/or supply in various markets to replicate how an economy responds (or economies respond) to a shock. Econometric models are regression models based on historical data about an economy. Readers interested in this topic are encouraged to consult the relevant literature, such as Rose (2004), Okuyama (2007), Okuyama and Santos (2014) and Okuyama and Rose (2019). While these models have been popular and employed for numerous recent cases, they are not without criticisms (e.g. Albala-Bertrand, 2013). Because economic models are representations of specific aspects of the real world, they intrinsically neglect some other aspects, such as psychological impacts on the labour force. It is imperative to understand what assessment models/methods can or cannot cover. At the same time, there are also considerable ambiguities in the estimates, especially for higher-order effects from the cascading impacts, due to uncertainties in a disaster situation that might be amplified by these methods. Further studies on this topic are essential, given the importance of unbiased estimates of the economic impacts (Girgin et al., 2019).

5 Countermeasures against risks

Prevention, preparedness, mitigation, response and recovery measures are the most common countermeasure strategies.

In order to avoid an incident becoming a disaster, strategies for dealing with existing and emerging risks are necessary. These strategies, also known as countermeasures against risks, include prevention, preparedness, mitigation, and recovery measures. Particularly in manufacturing and energy industries, their production activities establish a complex system, which covers production, logistics networks, and budget constraints, and this complexity and the internal and external risks that they face burden their management decisions about how to formulate and implement countermeasures. For example, a company's production process relies heavily on the use of electric power, which is produced by a power company. If the power company could not produce and/or transmit power, causing a blackout, this company's production would be suspended as a higher-order effect of the power shutdown. If the accident were caused internally within the power company, the loss of revenue of

[2] The 2017 report (Disaster Risk Management Knowledge Centre, 2017) discussed the methodologies assessing higher-order effects ('indirect economic damage') to some extent, such as simultaneous equation econometric models, input–output models, and computable general equilibrium models. The issues with these models raised in the 2017 report, for example dynamic adjustment features such as recovery, resilience, interregional substitution, inventory adjustments, and changes in labour supply, have been dealt with by the recent models. In particular, Okuyama and Rose (2019) provide state-of-the-art modelling practices and examples of the recent advances.

this company could be contractually divided between the two companies and potentially compensated for by the power company. On the other hand, if the accident were caused by an external source, such as a natural hazard, it would often be out of the scope of contractual matters. As one of the preparedness measures, this company would want to install backup generators for such a case; however, the cost of generators and fuels is added to the production cost (the larger the backup generators become, the more they cost the company), whereas the occurrence of such blackouts is quite infrequent.

The countermeasure strategies against risks try not only to avoid an incident becoming a disaster but also to limit the impacts of such an event once it occurs. Usually, prevention, preparedness, and mitigation measures are identified during the pre-disaster phase, and the response and recovery measures are set up in the post-disaster phase. Measures to reduce or limit the impact of a risk are not arranged in isolation but are put in place along with strategic medium- and long-term plans, and always within the enterprise-wide RM, i.e. the overall management of the risks that organisations take, to make decisions about how to formulate and implement countermeasures and how to achieve their strategic objectives.

5.1 Risk management

Risk management is a 'combination of organisational systems, processes and procedures that identify, assess, evaluate and mitigate risks in order to protect the organisation, its strategies and objectives (Martínez Torre-Enciso, 2007). An effective RM system plays a significant role in reducing exposure to potentially unfavourable events. Many organisations follow RM frameworks([3]) and models for enterprise risk management (ERM), business continuity (BC), disaster management (DM) or crisis and emergency management (CEM), among others. Each of these models establishes its own processes and procedures; however, in certain respects they overlap regarding the identification and evaluation of risks and the control and financing of both the risks and the measures established to limit their effects. Moreover, these overlaps among different strategies (ERM, BC, DM, CEM) are allowed in many cases – and especially in regard to operational risks, which are the most important in manufacturing and energy industries – in order to obtain important synergies (Laye and Martinez Torre-Enciso, 2001). For example, a company that aims to develop ERM and BC plans should carry out the identification, assessment and evaluation of risks for both. If the same team deals with ERM and BC plans, significant savings in personnel costs and time are achieved, as processes will only be carried out once.

The Committee of Sponsoring Organisations of the Treadway Commission (COSO) ERM model and other risk management frameworks, such as International Organization for Standardization (ISO) 31.000, develop comprehensive identification, assessment and evaluation of risks through risk mapping, matrix, etc.(ISO, 2018). Once risks are determined by the company's risk tolerance levels, the ERM model and frameworks allow it to decide how the risks are treated: control, finance and transfer them. If the risk has been identified, there are several ways to deal with it, including acceptance, transference, and mitigation. To transfer the risk, the company may purchase insurance or outsource the activity to a third party. Mitigating the risk might mean that it is reduced in some way. By applying these processes, it is possible to reduce the inherent risk until only residual risk remains. ERM not only calls for corporations to identify all risks they face, so that they can decide which risks to manage actively, which helps companies in the complex decision-making process on establishing countermeasures against risks; it also involves making that plan of action available to all stakeholders, shareholders and potential investors, as part of their annual reports (e.g. figure 2).

([3]) Around the world, a number of risk management standards have been published in order to guide the application of risk management. These standards include (but are not limited to) Enterprise risk management – Integrated framework (Committee of Sponsoring Organisations of the Treadway Commission [COSO]–USA, 2017); ISO 31000:2009 Risk management – Principles and guidelines (International Organization for Standardization, 2009); BS 6079-3:2000 Project management – Guide to the management of business related project risk (British Standards Institute, 2000); King IV report on governance (Institute of Directors in Southern Africa, 2016).

Figure 2. *Enterprise risk management process* ***Source***: *© COSO, 2017.*

For manufacturing and energy industries, these risks may entail consideration of supply chain delays/disruption, third-party vendors, information technology (IT), staffing and succession planning, emerging markets, and productivity and quality issues, among others. Controls can be directed to all exposures to risk (hazard, operational, strategic and financial) and can be achieved by implementing policies, standards, procedures and physical changes to a workplace. For example, when there is an identified risk of fire, organisations may employ physical control measures such as good housekeeping, fireproof materials, sprinkler systems or a no-smoking policy. For security risks, control measures may include physical barriers and locks. For IT breaches, there are measures such as firewalls, increasing password complexity or moving to two-factor authentication. For fraud risks, control measures could include background checks on staff members, segregation of incompatible duties or implementing system security to limit access.

5.2 Business continuity management

Each company has a number of critical business functions that must not be interrupted and, if they are, must be recovered as quickly and at the lowest possible cost. For such situations, companies develop BC plans whose countermeasures against risks are planned in the pre-disaster phase, but have their full development in the post-disaster phases. Business continuity management (BCM) is a 'holistic management process that is used to ensure that operations continue and that products and services are delivered at predefined levels, that brands and value-creating activities are protected, and that the reputations and interests of key stakeholders are safeguarded whenever disruptive incidents occur' (ISO, 2012).

Implementing the business continuity plan (BCP) of a company can help sort out this complex decision-making and can direct it to establish sufficient countermeasures against risks as a result. A BCP is a 'document that describes how a firm intends to continue carrying out critical business processes in the event of disasters (American Bar Association, 2011: page 1). BC planning is also the process of creating systems of prevention and recovery to deal with a disaster situation (Elliott et al., 1999). It consists of three stages: (1) risk assessment, including 'risk evaluation' and 'business impact analysis'; (2) developing and documenting BCP, including 'develop recovery strategy' and 'document plan'; and (3) testing, approving, and implementing BCP, including 'test plan', 'approve and implement plan', and 'maintain plan' (AIG, 2013: Page 3). BC planning appears closer to preparation for how to recover from and/or respond during a disaster (including impact from higher-order effects); however, business impact analysis at the first stage can highlight weakness in production processes that are vulnerable to disaster scenarios. Therefore, constructing and implementing a BCP is not only critical for minimising the impacts during recovery from a disaster but also imperative for determining prevention, preparedness and mitigation strategies before such a disaster occur'

Two notes on BCP components (Martínez Torre-Enciso and Casares, 2011) are worth discussing here. Crisis and disaster situations usually result in the loss or temporary disruption of one or more of the following necessary key business resources: facilities, infrastructure, IT applications/systems, people and supply chain. Developing a correct and deep business impact analysis is a key element for a BCP's success, as it identifies the impact of a sudden loss of business functions, and evaluates which are the core and critical business activities that must not be disrupted. On other hand, some people think a disaster recovery plan is the same as a BCP, but a disaster recovery plan focuses mainly on restoring IT infrastructure and operations after a crisis. It is actually just one part of a complete BCP, as a BCP looks at the continuity of the entire organisation. In this way, BCP documentation may include (1) a disaster recovery plan, including the loss prevention and control measures and the emergency plan; (2) a crisis management plan; and (3) contingency plans.

Manufacturing and energy industries need to have strategic plans in place to ensure that disruptions are avoided in the areas of staffing, supplies and machinery; the aim is to recover plant operations. They focus their BCPs on recovery strategies and mitigation measures, given the difficulty in finding continuity solutions. On the one hand, setting aside alternative sites for them is usually avoided because of the costs involved. In the absence of alternative production sites, there are few recovery strategies available to manufacturers. When custom construction equipment and assembly lines used cannot be easily replaced, recovery options available are (1) slowing down when they feel the impact, by using inventory/buffer storage; (2) selective recovery of production lines; and (3) ensuring that the recovery/repair operations are performed quickly. Alternatively, if some equipment in their production lines is similar to that of their suppliers, manufacturers that assemble semi-finished products may try to resume limited production capacities at their suppliers' premises.

On the other hand, the ability of having redundancies of production process as a backup for efficiency is a key objective for manufacturers, and mitigation strategies are often prioritised. Those measures should focus on either preventing or limiting the impact of a disruption, taking into account the production of goods or energy. For instance, if there is a fire, the sprinkler system might be activated as a whole, and could damage production equipment that were otherwise unaffected by the fire. This can be avoided through the use of localised sprinkler discharges so that each sprinkler needs to be independently activated, or the use of a dry delivery sprinkler system so that, upon activation, fluids are directed to only the discharge point.

Healy and Malhotra (2009) studied public spending on disaster relief measures and countermeasures, and found that every USD 1 spent on preparedness saves the equivalent of USD 15 on relief measures for all future disasters. While their study concerns only government spending and its consequences, this tendency for pre-disaster preparedness to be less costly than post-disaster recovery applies to the private sector, especially the manufacturing and energy industries, considering the amount and extent of the higher-order effects on a society. At the same time, as discussed above, because the lean production system inherently comprises the risk of supply chain disruptions, careful preparation in the BCP for alternative suppliers or supply chain, instead of having and/or increasing inventory, should be seriously considered.

6 Case studies

The impacts related to industries and energy production systems are not limited to direct physical damage, but also include business interruptions and cascading events hazardous to human life and the environment. This is especially the case for the aftermath of natural disasters that affect multiple industries at once.

6.1 The 2013 floods of the Danube and Elbe rivers in Germany

The June 2013 flood was the severest large-scale flood in Germany for the last six decades for which a hydrological flood severity had been estimated (Merz et al., 2014). In May 2013, rainfall above the long-term average in many parts of central Europe caused severe flooding. In that month, 178 % of the long-term monthly precipitation fell across the whole of Germany. The flood began after some areas of Germany experienced a total of over 400 mm of rain within a few days. While there was only moderate flooding in the south-west of Germany, the authorities in parts of southern Bavaria and Austria declared a full-scale emergency.

In Upper Bavaria, some areas had to be evacuated after embankments were breached. Eastern Germany, such as the states of Saxony, Saxony-Anhalt and Thuringia, was also severely affected, and some rivers flooded towns and villages, causing damage to houses and vehicles and forcing the evacuation of almost 100 000 people (Munich Re, 2014) (Figure 3).

The floods caused damage to a railway bridge, and the important high-speed rail connection between Berlin and the western part of Germany was cut off for several months (Schulte in den Bäumen et al., 2015). Manufacturing companies were severely affected: Krones, a global market leader in manufacturing bottling machines, shut down production in two plants in Upper Bavaria, because its workers were unable to commute to work on inundated roads. Volkswagen in Zwickau had to stop its vehicle production, since its suppliers were unable to deliver the parts in time owing to the damage to the transport infrastructure (Wenkel, 2013). Thieken et al. (2013) interviewed 557 flood-affected companies in order to investigate impacts on economic activities.

Of those companies, 88 % answered that they were affected by 'interruption of operations' by flooding, followed by 'building and/or equipment damage' and 'turnover losses'. Manufacturing companies reported more frequently than other industries that 'their own delivery problems' and 'delivery problems by suppliers' affected their operations. Because manufacturing companies rely heavily on supply chains for intermediate inputs (parts and products), also known as vertical specialisation, once any transportation links and/or nodes are disrupted, suppliers cannot reach their customers to deliver their products. This leads to business interruptions to the downstream companies/industries, propagating higher-order impacts.

The economic cost of the flooding was estimated at EUR 10 billion in Germany alone (EUR 11.7 billion in the entire affected area), while the insured amount was EUR 1.8 billion in Germany (Munich Re, 2014). These numbers are estimates of damage, not losses, nor do they include higher-order effects over the surrounding regions. For a more comprehensive and broader assessment of the socioeconomic impacts of river floods, Alferi et al. (2016) proposed an integrated framework to estimate the economic damage and population affected by river floods at a continental scale, in which pan-European river flow simulations are linked with a high-resolution impact assessment framework.

Figure 3. *Wust-Fischbeck (Saxony-Anhalt) submerged by the river flood in June 2013.*
Photographer: *Jens Wolf. © European Union, 2020*

They applied this framework to the 2013 central Europe floods and derived aggregated estimates of (direct) damage in Czechia, Germany, and Austria amounting to EUR 10.9 billion and 360 000 people affected by this event. Their framework focuses mainly on simulating physical events (floods) and assessing physical damage, but not losses or higher-order effects. Nevertheless, this framework is quite useful to simulate events and monitor floods in severe weather conditions. For a more comprehensive evaluation of the event, especially covering a larger area, the losses and higher-order effects of the event need to be evaluated.

Employing a multi-regional IO model of Germany (including the 16 Länder of Germany and the rest of the world, with 41 types of industry) to simulate the supply chain disruptions, Schulte in den Bäumen et al. (2015) estimated that the higher-order effects of this event in Germany, which affected not only the motor vehicle and food industries in Germany but also foreign production, amounted to EUR 6.2 billion. The higher-order effects on regions and industries outside the flooded areas were around EUR 400 million. Their estimates suggest that losses of production in the damaged Länder were EUR 3.1 billion in Bavaria, EUR 750 million in Saxony, EUR 423 million in Saxony-Anhalt, EUR 398 million in Brandenburg and EUR 394 million in Thüringen. Outside the damaged Länder, it is estimated that other economies suffered production losses (higher-order effects) through supply-chain interruptions: for example, EUR 171 million in North Rhine-Westphalia, EUR 151 million in Lower Saxony, EUR 80.2 million in Baden-Württemberg and EUR 42.2 million in Hessen. In addition, economies outside Germany lost EUR 33.8 million in forgone production as the higher-order effects through supply-chain interruptions. The industries in Bavaria most severely affected by production losses were estimated to be real estate services (EUR 218 million), transport equipment production (EUR 181 million), 'other business services' (EUR 154 million) and motor vehicle production (EUR 80.2 million). On the other hand, the industries suffering the largest higher-order effects were motor vehicle production in Baden-Württemberg (EUR 85.7 million), and food industries in North Rhine-Westphalia (EUR 84.3 million) and Lower Saxony (EUR 34 million). As their results suggest, the impacts (higher-order effects) of the event spread geographically and across industries, especially among manufacturing industries, through interindustry supply chain networks.

As the globalised production system and the integrated economy, such as in EU Member States and regions, expand, it is essential to consider and evaluate the economic values not only of damage and losses but also of higher-order effects, which are becoming more extensive and crucial than before. As discussed in the previous subsections, standardising the definition and establishing the extent of higher-order effects are essential for implementing effective strategies and countermeasures to minimise such broad impacts. At the same time, because of the interconnected production systems of these industries, cooperative measures among related firms and with the public sector need to be promoted on a wider geographical scale.

6.2 Industrial accidents triggered by natural hazards

The impacts of natural catastrophes on the industries and energy production systems are not limited to direct physical damage and business interruption, but may also involve cascading events hazardous to human life and the environment, such as fires, explosions, and toxic or radioactive spills. Such cascading events may amplify the overall economic loss with further physical damage, injuries, fatalities, medium- or long-term health problems, environmental damage, loss of ecosystem services, business interruption, public unrest and social costs. These consequences can be quite substantial, and cost even more than the damage directly caused by the natural hazard. For example, the earthquakes of 5 March 1987 in Ecuador (Ms 6.9) caused the destruction of more than 40 km of the Trans-Ecuadorian Oil Pipeline in massive landslides triggered by the seismic activity. Approximately 100 000 barrels of oil spilled into the environment and the loss of revenue during the 5 months required for repair was USD 800 million, equal to 80 % of the total earthquake losses (NRC, 1991). Furthermore, if persistent or radioactive hazardous materials are also involved, environmental clean-up and restoration activities may require an exceptionally long time and enormous resources, as seen at the Fukushima nuclear power plant accident caused by the 2011 east Japan earthquake and tsunami.

Known as natural-hazard-triggered technological (natech) accidents, such cascading events are a recurring feature in many natural disasters, which affect industries and energy systems that store, handle, or transport hazardous substances. One noteworthy example in Europe is the 17 August 1999 Kocaeli earthquake (Mw 7.4), which resulted in many natech accidents with significant economic and environmental consequences. The earthquake, which was one of the most devastating natural disasters in the modern history of Turkey, caused about 17 500 fatalities, injured about 44 000 people, affected 15 million people and resulted in property damage totalling over USD 15 billion.

The affected area is one of the industrial heartlands of the country and is densely populated and heavily industrialised, accounting for 35 % of the gross national product (Özmen, 2000; Durukal and Erdik, 2008). The earthquake caused significant damage at numerous industrial facilities (Johnson et al., 2000; Rahnama and Morrow, 2000; Suzuki, 2002; Sezen and Whittaker, 2006; Durukal and Erdik, 2008), which led to many natech accidents ranging from small hazardous substance releases to enormous fires (Steinberg et al., 2001; Steinberg and Cruz, 2004). Among these events, two were especially noteworthy owing to their consequences: the huge fire at the Tüpraş İzmit Refinery in Korfez, Kocaeli, and the acrylonitrile spill at the Aksa acrylic fibre production plant in Ciftlikkoy, Yalova (Girgin, 2011).

Founded in 1961, the Tüpraş İzmit Refinery had 40 % of the refining capacity in Turkey and was one of the most advanced refineries in the Mediterranean region (Tüpraş, 2010). The fire at the refinery lasted for 5 days and could only be extinguished with international support (Danış and Görgün, 2005).

The Aksa plant, which was constructed in 1971 with a capacity of 5 000 tons per year, had a production capacity of 230 000 tons per year in 1999. Currently, it is the only acrylic fibre producer in Turkey and it is also the largest in the world, with a global market share of 18 % and an annual production capacity of 315 000 tons (Aksa, 2019). The spill of 6 500 tons of acrylonitrile, a highly flammable, toxic and carcinogenic substance, harmed domestic animals, affected agricultural activities, endangered public health and resulted in environmental pollution that required 5 years of continuous treatment for reclamation (Bayer, 1999; Zanbak, 2008).

Both events required the evacuation of the nearby settlements and hampered earthquake search and rescue operations. There were also considerable economic losses. In the case of the Tüpraş İzmit Refinery, the majority of the units were put back into operation within 3 months after the earthquake, but it required 1 year for all units to be functional. The total cost of restoration, including the oil spill cleanup, was about USD 58 million. However, the refinery also lost roughly 6 months of its crude oil processing capacity (4.6 million tons) during this period as operational losses (Girgin, 2011).

The Tüpraş and Aksa incidents showed that preparedness for large external events, considering the extraordinary and highly resource-limited conditions they cause, is critical to prevent and reduce the impacts on industries and energy production systems. Existing risk should be assessed taking into account temporal change due to factors such as climate change and ageing of the equipment; structural (e.g. strengthening of buildings) and organisational (e.g. training of personnel) measures should be implemented properly; and response and recovery plans should be prepared, periodically reviewed and practised. Sharing of information and involvement of public and other stakeholders in decision-making process are also crucial to limit consequences and increase resilience.

As for the lessons learned from the past natech incidents, analysis of historical incident data for selected industries shows that, although natech accidents occur less frequently than accidents from other causes, their economic consequences are more severe (Girgin and Krausmann, 2016). In fact, owing to synergistic and cascading effects among natural and technological hazards, natech accidents may result in complex consequences involving numerous hazardous events over large areas, damaging safety systems and barriers, and destroying lifelines needed for emergency management purposes. Therefore, it is essential to quantify the losses not only considering the direct damage, but also considering the cascading impacts. This can be challenging even for a single facility; hence, dealing with multiple facilities and mutual dependencies is a difficult task.

The main economic damage potential is attributable to fires and explosions, as they cause direct physical property damage. However, depending on the market dynamics, serious losses may also occur through business interruption even if the property damage is relatively minor. Occasionally, even the proximity of a hazard without any direct impact may lead to losses. For example, wildfires in British Columbia, Canada, in 2017 led the operators to temporarily shut down natural gas wells, pipelines and other facilities as a precautionary measure where wildfires came dangerously close to operations, leading to costly business interruptions (Marsh, 2018). The industry can transfer these risks to third parties using financial tools, such as insurance that covers the losses related to natural hazard impacts or business interruptions. But the coverage is usually limited and varies with estimated risk and existing RM practices (Olson and Wu, 2010). Safety expenditures are often not self-financing for low-probability high-impact risks such as natech risk. Therefore, in order to fill the existing gaps, some legislative or financial support might be necessary from the public authorities for the required prevention and mitigation measures (Girgin et al., 2019).

7 Conclusions and key messages

Disaster risks that manufacturing and energy industries face are rather wide-ranging. They can potentially trigger a disaster from internal causes, such as an industrial accident leading to air or water pollution, while they are also threatened by external risks, such as natural hazards and/or other companies' and/or industries' accidents. Furthermore, in some cases these industries can exacerbate disaster processes, resulting in natech events as discussed in the case studies above. Internal risks can be mostly treated through management strategies and technological means, whereas external risks are often difficult to predict. Integrating RM and BCM with their business operations can potentially reduce and/or mitigate risks, but it is still difficult and costly to prepare practically for infrequent but catastrophic events and their consequences. This type of event should be dealt with and prepared for by the public sector, i.e. various levels of government, through several means, such as regulations, subsidies, taxation, and so forth.

Some risk transfer mechanisms, for instance disaster insurance, should be considered together with RM and BCM. In the EU, disaster finance has been increasingly linked with insurance regulations (Botzen, 2013), climate change adaptation strategies (van Renssen, 2013) and a joint compensation scheme between Member States (Hochrainer et al., 2010). For developing such insurance mechanisms and joint compensation schemes for future disaster situations, detailed information on the probabilities of natural hazard occurrence and estimates of potential damage are essential (Jongman et al., 2014).

Because manufacturing and energy industries are a vital part of economies and because of the intersections of broad production factors (resources, intermediate inputs, labour, land, and money) across industries and over space, the implementation of RM and BCM requires a multidisciplinary perspective, involving engineers, management, finance, economists, and environmentalists. Since the higher-order effects could spread over an entire economic system in different ways, and in case environmental damage also results, it is vital to define, and potentially legislate about, to what extent these companies should be responsible in a disaster situation.

Policymakers

Policymakers should legislate and implement the countermeasures against disaster risks that these industries face both in the pre-event phase (regulations for handling hazardous material, pre-arrangement of compensation schemes, mandatory insurance, mandatory RM and BCM, etc.) and in the post-event phase (disaster relief, macroeconomic stabilisation, evacuation strategy, etc.), based on the findings and insights from scientific findings of disaster research.

Practitioners

Practitioners of risk management should support the efforts of these industries to install and maintain RM and BCM in each firm, encourage and help drills in the pre-event phase, and assist the operation of RM and BCM in .the post-event phase

Scientists

Scientists should work together in a multidisciplinary way to understand and anticipate the risks in these industries and provide perspectives and/or devise countermeasures that mitigate the risks and the consequences. More importantly, these four groups of stakeholders should work together to achieve the creation of a sustainable society and economy.

Citizens

Citizens need to be aware of the risks that these industries face and their impacts on society, and to understand how they can be affected both as workers (supply side) and as consumers (demand side).

In conclusion, each stakeholder has the following roles for dealing with the disaster risks that manufacturing and energy industries face.

More importantly, these four groups of stakeholders should work together to achieve the creation of a sustainable society and economy.

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Introduction

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3.3.2 Agriculture

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