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Whitepaper

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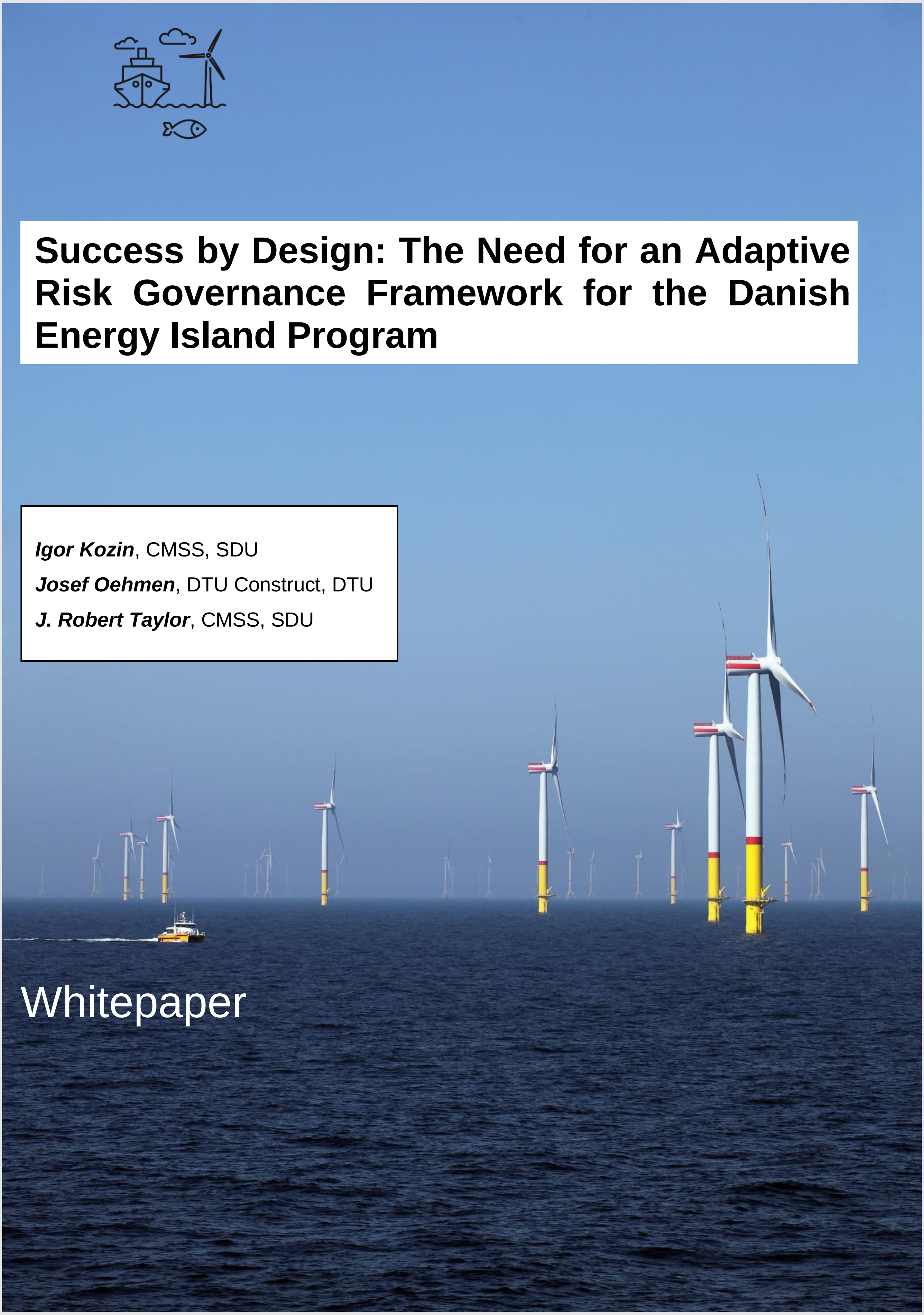

# Success by Design: The Need for an Adaptive Risk Governance Framework for the Danish Energy Island Program


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# Contents

# 1 The Danish Energy Islands are one of the world's most ambitious clean energy program

The construction of the Energy Islands on Bornholm in the Baltic Sea and in the North Sea, approximately 80 km from Thorsminde, a town on the cost of western Jutland, are one of the world's most ambitious green energy programs. The Islands will serve as hubs for connecting and distributing power from the surrounding offshore wind farms (OWF) to several countries. It is expected to have an initial capacity of 3 GW of offshore wind and later reach full capacity at 10 GW for the island in the North Sea, which will be the first of several hubs in the North Sea that is planned to be put into operation in 2033 [1].

Given the scale of the new system and outstanding challenges, the time window of 10 years is rather narrow to design, build and guarantee that risks to health, safety, environment, assets, cost, and uninterrupted electricity supply are under control for the whole lifetime of +80 years. The consequences of failing to predict and manage the risks of complex global systems, like the Energy Island and connected to it systems, can be immense. The Island will have broad social impact and deficits in risk governance that, in particular, do not properly account for the diversity of different values of involved stakeholders may result in loss of credibility in management institutions.

Insufficiently managed risks - from health & safety to cost - can bring the largest engineering programs to a sudden halt: For good reason, injuries, and deaths on construction sites and during operations are unacceptable – both from an ethical as well from a legal and reputational point of view. And we can expect significant public scrutiny regarding promised budgets, schedules, and technical performance.

The technology to build the Energy Island and the whole offshore wind power system is largely available. However, the scale of the new system, the interconnectivity of activities taking place on the island and around it, the planned upscaling of the system, deployment of innovation activities (like Power-To-X) rase challenges to designers, engineers, risk managers, environmentalists, and society as a whole.

As stated in the report [2]: "Many of the necessary solutions required to enable a cost efficient, stable, reliable and resilient operation of the energy islands have not yet been demonstrated at commercial scale. The standards and grid codes are not developed, and we see a series of potential 'chicken and egg' issues where the developer of the energy islands needs to know the potential solutions from suppliers while suppliers await further specification from the developer."

The Island will be constructed as a 'flexible island', which provides technological flexibility and serves as a platform for future additional technological solutions [1]. It will also include infrastructure for logistics such as a helipad and a service port, the area for personnel of transmission operator Energinet and other companies having facilities on the Island. It is flexible also in the sense that its capacity to support energy production will grow from 3 GW to a total connection of 10 GW from the OWFs. It will be a dynamic socio-technical system in constant development.

The dynamic nature of the Island and connected to it systems also means that during some prolonged periods of time there will be simultaneous activities taking place. While the first 3 GW facilities get operational, the construction of the second phase of scaling up the Island up to 10 GW will commence later. The simultaneous operation and construction on a limited area will result in an increased number of operating companies and people on site. At some points and additionally, new technological activities may be deployed on the Island as well. Thus, it will be the evolving landscape of stakeholders, stakeholder expectations, safety cultures and associated objectives.

The control of the system will be enabled by a cyber-layer. In this view, the designed system can be classified as a cyber-physical system, which imposes special requirements to security and safety. It will be a multi-layered system (physical layer, cyber-physical and cyber-layer), which will come with new risks that must be identified and kept under control.

The Island and connected to it OWFs will form part of the Danish and international critical infrastructure. It will have broad social impact nationally and internationally. Hence, there is potential for social mobilization and risk of political or public pressure on risk regulatory agencies and loss of credibility in management institutions.

In this White Paper, we outline the unique challenges that professional risk management face in the Energy Island program, and present a best-practice based Adaptive Safety Risk Governance Framework as the basis for discussing our approach to making the Energy Islands and the whole offshore power system a global inspiration - not only commercially viable and green, but also safe and resilient to shocks of different nature.

# 2 The Energy Island program faces a unique combination of challenges that we can only master with a thoughtful risk governance approach

## 2.1 The Energy Island program must control risks in a wide range of domains

As a visionary and transformative engineering program, the Energy Island program must manage and control risks in a range of related impact categories. These include:

### 2.1.1 Health and safety risks


There are health and safety risks in any large industrial activity. Guidelines for safety management in electrical systems operation and maintenance have been published by many organizations. For example, UK HSE gives access to a whole set of guidelines for electrical safety[1]. These or others provided by different organizations will need some modification for the Energy Island because of the remote location, particularly in the area of medical treatment and medical transport. Some of the aspects of safety management developed for offshore oil and gas installations would be worth adopting.

Construction will continue on the Island for a long period, and a construction safety management program will be needed. One of the good existing guidelines for construction safety management would be a useful starting point.

Several companies will be active concurrently in building and testing the installations on the Energy Island, presenting problems which are well known for other island-based facilities such as oil and gas installations. Some conformity in safety management practices will be needed. This could be achieved by having one standard safety management system to be adopted by all. This would require significant training for each company. An alternative would be to provide a standard audit of contractor company safety management.

Two aspects of safety management which are essential to coordinate is simultaneous operations analysis/management and permit to work systems.

[1] https://www.hse.gov.uk/electricity

### 2.1.2 Unavailability risks

There is already an extensive literature concerning unavailability analysis for offshore wind farms, with adequate collection of failure rate/repair time data and several methods demonstrated. Failure rate data are available at the major subsystem level e.g. transformers, and cables. There is much academic work currently active, but for practical engineering purposes these developments can be regarded as “interesting” rather than “essential”. The main issues here are to select the most effective current methods and to develop them to a point where the methods can be applied quickly i.e. at a rate where they can contribute effectively to design.

Existing failure rate data are by definition quite old since they must be collected over a period of years. An area which will need attention is the collection or estimation of failure rate data for increasingly large wind turbines, and for the rapidly developing high voltage direct current (HVDC) systems. Methods exist, such as reliability physics approaches used in electronic systems design, which could allow more precise reliability predictions.

### 2.1.3 Project cost and schedule risks

In any major project schedule and cost risks need to be analyzed and as far as possible managed. For a project involving many companies this is even more important.

Methods for such analyses have over the years been standardized, but estimating the impact of threats in novel construction presents a challenge. This is an area where current knowledge is inadequate, or at least exists only in spread studies. This in an area in need of new research.

### 2.1.4 Reputational risks

The impact of power failure on public impression of electric power companies is well known. Generally, if power loss is short lived and rare, there is little loss of reputation, especially if the cause of loss is known and perceived to be unavoidable. Longer losses would cause a loss of reputation, but cynically speaking, the impact of this on a project can only end in requirements to do better and repair faster.

A significant problem with loss of reputation from long downtimes or from blackout would be that of loss of trust by client companies, authorities and governments which could in turn result in curbs on dependency on offshore wind energy, and requirements for upgrades, or cancellation of later stages in the Energy Island program. Unfortunately, loss of reputation for the concept as a whole could arise through failure in other projects.

There is a need for research in this area. There is a basis for such research in the form of earlier incidents around the world. Studies of these issues should lead to improved contingency planning.

### 2.1.5 Major accident and catastrophic risk

There have been a number of studies carried out on the analysis of different topologies of electrical systems and OWFs. However, they conceptualize reliability in terms of subsystem failure in a binary way, i.e. failed or not failed. The spectrum of failure modes of the electrical components is much broader and their influence on the reliability and recovery of the system with different topologies should be studied in depth. The existing studies on the topologies do not take protection systems into account explicitly, just as part of the overall subsystem failure rates. This means in practice that the analyses do not deal properly with major failures such as those arising from large fires, external events such as lightning storms, flooding and tsunami, cascade failures and total blackout. These types of incidents are relatively rare, but with a total production capacity of 10 GW in a concentrated location, this means that such failures imply significant risk. The problems of cascade failure, failure propagation and blackout situations are not captured either.

To provide a good basis for design, risk assessment of major accidents is needed. This requires much more detail in analysis than that for availability studies, and this should take into account system's robustness, analysis of protective system, detailed hazard and failure mode analysis, and common cause failure analysis. Some studies at this level have been made e.g. for circuit breakers by the US Nuclear Regulatory Commission and by CIGRE, but a more holistic approach covering the range of threats is needed.

Note that major hazards risks in electrical installations such as switch yards and transmission system do not imply a major risk to employees except for the case of air transport by helicopter. Major hazards and cascade risks do present a significant risk for the island and wind farm assets and production.

### 2.1.6 Legal and compliance risks

The Energy Island will be constructed, built and operated in the Danish Exclusive Economic Zone, applying the existing Danish legal frame. The Danish Energy Agency is responsible for planning and permitting large pipelines and offshore wind facilities under the Continental Shelf Act and the Promotion of Renewable Energy Act. Categorizing the Energy Island is essential, and failure to do so could pose a risk concerning identifying relevant legislation. For example, considering the Energy Island a Danish port may entail e.g., the implementation of the ISPS code, customs regulations, and occupational health regulations.

Legal assessments have been performed earlier by third-party companies, nonetheless, they focus on the permit process and do not consider, e.g., export cables from the Energy Island intended to transport power to other countries with individual sets of legal frames and requirements for reliability and security of supply. A gap analysis of legal requirements, standards and best industry practices could be beneficial to ensure alignment of involved national and international authorities and their expectations.

## 2.2 The Energy Island program must confront risks at different levels of knowledge

Any new technological development comes with new risks and there is often a lack of knowledge about these risks. There could be lacking knowledge about the causality between causes and consequences, or the likelihood of consequences and their extent. Lacking knowledge about human behavior and actions, values, corporate cultures, and interests of stakeholders can also contribute to the risk landscape. Ultimately, there could simply be unpredicted hazards and hazard scenarios.

Up to date knowledge is required to properly manage risks, and the understanding of a degree of ignorance about risks helps to choose an adequate and most appropriate risk management strategy. Assessing the quality of existing knowledge, degrees and types of uncertainty are largely part of the scientific method. In this view, close collaboration of companies, authorities, public institutions, and research community is the necessary prerequisite of having risk controls in place.

There are four distinct characteristics of the risk requiring different risk management strategies [3]: 1) **simplicity**, 2) **complexity**, 3) **uncertainty**, and 4) **ambiguity**.

*Simplicity* is the characteristic of the risk that requires a routine-based strategy that is well-covered by existing good practice, standards, and regulations. This strategy is well applicable when the dominating type of uncertainty is the so-called *aleatory* uncertainty that is differently referred to as *stochastic* uncertainty or the one originated from *variability* in times to failure and extent of consequences.

However, we should not expect that all risks of the Energy Island and connected to it OWFs can be managed by a routine-based strategy. We may even cautiously and justifiably accept the pessimistic stance expressed by Perrow [4]: "Nothing is perfect: every part of every system, industrial or not, is liable to failure. […] The more complicated or tightly coupled the plant the more attention is paid to reducing the occasion for failures, but [. . .] this can never be enough." This warning prompts to go beyond the risk management framework and to work out a strategy to cope with the unexpected. **Resilience management** can be the strategy to be prepared and mitigate risks that have come through all existing barriers.

### 2.2.1 Complexity

Complexity refers to difficulties in identifying and quantifying the causes of specific adverse effects and understanding a sociotechnical system [3]. Disruption of interconnected infrastructures, such as large electricity grids or the internet, are examples of complex risks.

Complex system's topology (connections between wind turbines, HVDC converters, transformers, the Island, onshore facilities, feedback control loops via the SCADA system and the internet), its multi-layereness or physical and cyber-physical interconnectivity (physical layer, cyber-physical and cyber-layer), evolving technological landscape, humans in control loops and operation are all that what makes the Energy Island and connected elements a complex system.

Identifying complex risks is a challenge risk analysts face. Given adequate resources allocated for risk identification, a majority of risks can be predicted, and barriers set in place to either prevent them or mitigate consequences. Methods exist to carry out this job, however, **no one of the existing methods will be enough to do this job well**, and a well-selected set of methods should be determined to reduce the number of uncontrollable residual risks. Existing standards on risk management do not provide a representative sample of the methods to choose from. The-state-of-the-art offers a much richer palette of the methods that have not entered any standard yet despite being proven to possess good predictive power. These should be invoked and evaluated against their appropriateness for the Energy Island program.

Complexity gives rise to another class of complex risks and hazards that cannot be predicted by examination of system's individual parts. They are called "**emergent hazards**" that are causes for "**systemic risks**". They become increasingly an important contributor to the risk landscape, which introduces problems for the designer and the risk analyst.

An emergent complex system hazard can be defined as a "pathological" (often unpredictable) failure behavior that is manifested in complex, highly coupled systems, possibly in catastrophic ways [5].

In design for safety, we can recognize the following classes of phenomena and behaviors that we can term as emergent hazards [5]:

- Hazardous behaviours which arise from complex systems in unexpected ways, due to limitations in our analysis methods;
- Emergent hazards due to creative and possibly hitherto unseen malign action;
- Completely new and hitherto unseen or unrecognised hazardous phenomena;
- Hazardous behaviours which arise from systems in the absence of component failures or errors of individual user or maintenance actions.

### 2.2.2 Uncertainty

Uncertainty refers to a lack of scientific or technical data, or a lack of clarity or quality of the data [3]. Uncertainty is meant here to be *epistemic* that arises due to lack of knowledge either about the severity of consequences of unwanted events or the likelihood of those or both. This type of uncertainty is *reducible*, as it can be reduced by acquiring knowledge about the consequences and likelihoods. Epistemic uncertainty generates **epistemic risks**.

The strategy for the management of epistemic risks is much different from that for known risks, for which the severity of consequences and their likelihoods are rather well established and that can be controlled by routine-based risk management. Epistemic risks call for a strategy that allows more time or/and resources for acquiring needed data and knowledge; they call also for precaution up to its extreme that can hamper innovation. To avoid hampering innovation, trade-offs to be made between enabling innovation, minimizing risk to people and the environment, and balancing the interests and values of all relevant stakeholders. The policy must not simply prohibit or restrict any development for which uncertainty exists but should seek the right balance between potential benefits and threats [3]. This last point brings up the issue of determining the risk appetite of the Danish state and all relevant stakeholders as well as the connected issue of determining risk acceptance criteria.

Both complexity and uncertainty give rise to **emerging risks** that are either new risks or familiar risks that become apparent in new or unfamiliar conditions. Emerging risks are issues that are perceived to be potentially significant, but which may not be fully understood and assessed, thus not allowing risk management options to be developed with confidence [3]. To prepare and cope with systemic or emerging risks marked by uncertainty and complexity many organizations explicitly call for **resilience-based strategies** that are considered as either a supplement or an alternative to conventional risk management. Given potentially mammoth adverse consequences due to loss of energy production, it may be worth investing in resilience building as part of risk governance of the Energy Island.

### 2.2.3 Ambiguity

Ambiguity results from divergent perspectives on risks, including the likelihood and severity of potential adverse outcomes. Risks that are subject to high levels of ambiguity include issue for which economic and ethical issues matter and where controversies and polemics can emerge [3]. There could be disagreement on the risk appetite as, for example, environmentalists and engineers may have different views and perspectives on the risks and acceptance criteria. As the Energy Island program is international, there may be different views on risk sharing between the international partners.

Proactive assessment of social concerns and perceptions should be practiced to responsibly sustain the Program. As an example, the ‘appraisal guidance’ was published by the UK Treasury Department [6] that suggests an estimation procedure to control this type of risks.

### 2.2.4 Binding the characteristics of risk together

Figure 1 gives a conceptual visualization of how the characteristics of risk are bound together and how ignorance about the risks diminishes with knowledge acquisition. In the early phase of system’s design, ambiguity can be the dominating characteristic gradually dissipating and letting uncertainty and complexity champion. Finally, the system can reach the point when the irreducible (aleatory) uncertainty becomes dominating that requires a routine-based management strategy.

All this suggests that different levels of knowledge should require different strategies for risk management, which is one of the key points of the Risk Governance Framework described in [3, 7]. Figure 2 visualizes the dependence of risk management strategies on the quality and extent of knowledge about the risks.

Details on the different risk management strategies can be found in [3, 7] and are well presented by the escalation model of risk management strategies described in these reports.

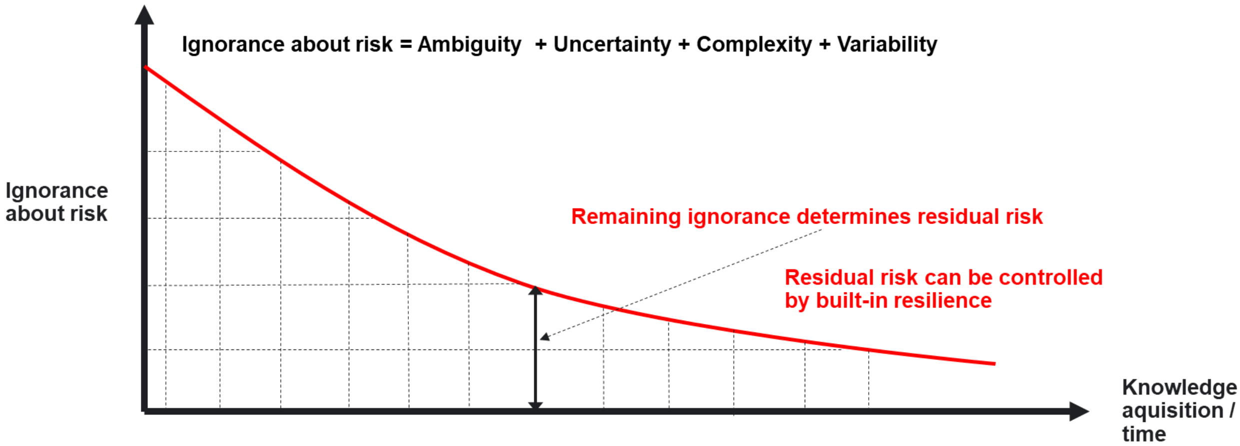


*Figure 1. Bound characteristics of risk*


*Figure 2. Knowledge about risks determines risk management strategy*

## 2.3 The Energy Island program must combine and adapt proven risk management practice from a wide range of domains

### 2.3.1 Moving risk management from compliance to standards to value-adding for the program

Existing HSE regulations, standards and good practices do their work well, however, as we know, accidents - and among them major accidents - do take place. It is important to recognize that conformance with statutory codes of practice and standards typically provide a minimum acceptable level of safety. Regulatory risk analyses cannot at present answer many questions and self-regulation and a greater use of voluntary standards and codes of practice is the existing reserve for improving HSE. The state-of-the-art in risk management, risk assessment, and risk governance of complex socio-technical and cyber-physical systems has much more to offer as a value-added complement to standards and practices. It is worthwhile to study which models, approaches, methods and tools can add value to the Energy Island Program.

### 2.3.2 Design for flexibility and adaptability

Technological flexibility of the Island, upscaling of its capacity and the long lifetime call for imbedding enhanced **adaptive capability** into the functionality of the Hub. Given its dynamic nature, scale, economic and societal importance, and long lifetime, "**slow-developing catastrophic risks**" may become an imminent threat that can abruptly take over to produce far reaching adverse consequences. Being prepared and able to respond and adapt rapidly to sudden change, is the best (and often the only) way to cope effectively with slow-developing catastrophic risks. New thinking and processes may be needed in order to develop such resilient structures [8].

### 2.3.3 Front-loading for risk management: the example of health and safety by design

Health and safety by design is the process of managing health and safety (HS) risks throughout the lifecycle of structures, plant, substance or other products [9]. Studies have shown that design-related issues contributed to approximately a 1/3 of workplace fatalities and a similar ratio of serious non-fatal injuries [10]. It is rather common sense that it is more efficient and effective to manage risks in the design phase than to retrofit HS solutions. Figure 3 shows the decrease in ability to influence safety that stakeholders have over the lifecycle of a system.

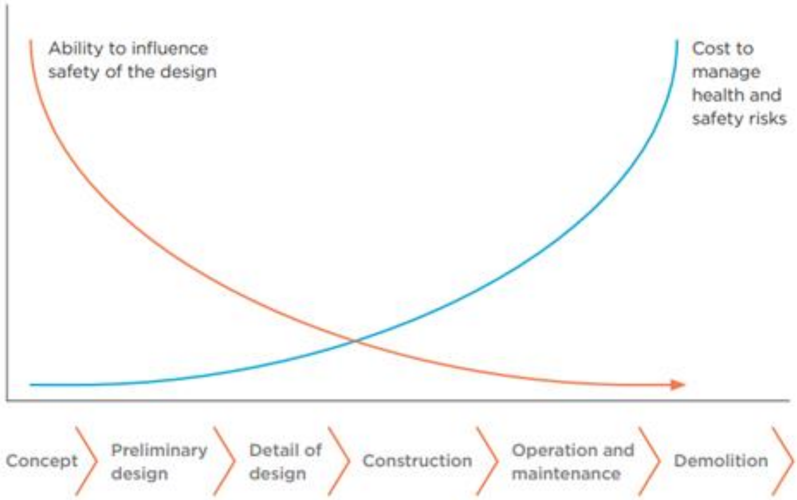


*Figure 3. Szymberski chart of influence over a product's lifecycle (adapted from Szymberski, R. 1997. Construction Project Safety Planning. TAPPI Journal, 80 (11), 69-74)*

Literature on the topic of safety by design is limited. However, there is a noticeable trend in establishing a robust framework for designing for safety, and principles for doing so exist and guidelines on good practice can be found as well. Guidelines on health and safety by design [9] are adopted on voluntary basis in New Zealand, while the government of Singapore made regulations for design for safety mandatory (*Workplace Safety and Health (Design for Safety) Regulations 2015* [10]). Safe-by-design – also referred to as Safe at the Front - forms part of the government's environmental policy in The Netherlands [11].

Safe-by-Design seeks to make safety aspects a permanent consideration in design choices, and it seeks to design materials, products and processes that throughout their entire lifecycle do not pose risks to human health and the environment. This can be achieved by considering safety as early as possible in the innovation process. It is precisely at this stage that crucial choices are made about materials, processes, basic techniques and applications, while there is still time to make adjustments.

Making safe-by-design part of government's policy or mandating guidelines on its implementation should not be separate from other policies aimed at safe and healthy operations and environments. It should encourage researchers, designers and companies to take their responsibility in preventing risks. Safety by Design should be incorporated into investment criteria and responsible investment practices. Safety requirements should be formulated in such a way that they do not limit the possibilities for new, smart solutions, while at the same time innovation is accompanied by a focus on safety from the start. In this way, opportunities for improving safety can also serve more effectively as a driver for innovation.

Safe-by-Design is more than inherently safer design that seeks to eliminate or significantly reduce hazards instead of developing protective systems and procedures. The principles of inherently safer design are well-known and are the pillars on which system safety is built up. However, design alternatives that appear obviously safer for simple systems may create or increase the magnitude of other hazards. Recognition and understanding of these conflicts call for the so-called **risk-risk** and **risk-benefit trade-offs** to make intelligent decisions to optimize the design.

For example, the placement of the innovation area with PtX conversion on a platform separated spaciously from the Energy Island seems a sensible option to prevent domino effects. However, risks introduced by this solution should be well-studies to justify this option.

### 2.3.4 Resilience

As visualized in Figure 1, the more knowledge is gained on associated risks, the less residual ignorance about them is. Continuous work on gaining the knowledge will make the system safer and most risks can be kept under control. However, “this can never be enough”. Given the complexity of the system, it is time and resource prohibited to identify all possible risk scenarios. There will always be residual risks, that may dominate the risk landscape and there must be an adequate management strategy to cope with these risks.

Traditional risk management approaches can hardly address unpredicted risks. To do so, “decision-makers and policymakers have utilized the **concept of resilience** to evaluate the capability of various complex systems to maintain safety, security and flexibility, and recover from a range of potential adverse events. Further, resilience offers the capability to better review how systems may continually adjust to changing information, relationships, goals, threats, and other factors in order to adapt in the face of change […].” [12].

The more uncertainty, the higher complexity and ambiguity, the greater urgency is in having resilience management strategy in place. Figure 1 suggests that it is important to adequately protect against undesirable consequences of uncertain, unexpected and often dramatic events from day 1.

Having the Energy Hub and connected to it OWFs resilient is even much more important because they will represent a very large contribution to the European energy supply. As known, wind farms are sensitive to transients in electrical quality arising from events in the wind farms themselves, from environmental effects and from transients in the transmission networks. Wind turbines have proved to be more sensitive to transients than earlier power generation sources, and decoupling of wind farms to protect the wind turbines has caused or exacerbated several failure cascades, and has contributed to most blackout events in recent years.

Developments have been made in recent years to improve wind farm resilience and survivability, and this is a subject of active research. Further work is nevertheless needed to ensure resilience of both the wind farms and Energy Hub, and the resilience of transmission networks needed to transport energy to users.

# 3 Using an adaptive risk governance framework to the best advantage of the Energy Island program – Starting now

**Info box**

***Risk governance*** *provides guidance to cope with risks in situations of high complexity, uncertainty or ambiguity. It is not just about* ***risk management****. It starts at the earlier stage of* ***risk pre-assessment****, in which the essential perspectives of the problem are identified early and broadly, particularly regarding how the risk is framed by different stakeholders and whether or not there are any applicable legal or other rules or processes.*

*While* ***risk assessment*** *remains a central (technical) part of risk governance, this approach also urges risk governance institutions to gather not only knowledge about the physical, economic and social impacts of technologies, natural events or human activities but also knowledge about the concerns that people associate with causes and consequences of risks.*

*Introduction to the IGRC [3]*

An Adaptive Risk Governance Framework ensures that the Energy Island Program can deliver the most value to its stakeholders while minimizing the associated risks. It supports top leadership in articulating an actionable vision for a risk-benefit balance, as well as articulate clear qualitative and quantitative boundaries for the risk-taking in the organization. It provides the foundation for executing an ambitious innovation strategy responsibly, and safeguards that compliance requirements are met. It ensures that decision-makers remain in control of the program, and creates trust across the stakeholder landscape.

It is important to note that a Risk Governance Framework not only designs the risk management processes of the Energy Island Program, but addresses how the Energy Island Program manages risk, uncertainty and ambiguity as part of their core activities.

In this section, we highlight the key elements of such an Adaptive Risk Governance Framework. We build on the established IRGC Risk Governance Framework [3, 7], emphasizing those aspects we consider particularly relevant for the Energy Island Program.

The Energy Island Program must create an Adaptive Risk Governance Framework that enables it to consciously and deliberately control and direct its risk management activities to protect the program's overall success. In particular, it must be able to evolve the focus and continuously increase the quality of risk management activities over decades of simultaneous design, construction and operation activities of the island. As outlined above, the specific requirements for this risk governance framework are shaped by the three distinct needs of the program to maintain control and continuously build trust:

- Manage a varied scope of risk impact categories, including safety, cost, schedule, performance, assets, and reputational risks.
- Manage risks at very different levels of knowledge, from probabilistically quantified risks to non-quantified uncertainties, to ambiguities based on diverse value priorities of the involved stakeholders.
- Continuously support program management excellence by identifying, adapting, and implementing management best practices addressing risks across organizational, process and disciplinary boundaries

## 3.1 Designing and evolving organizational embeddedness, roles & responsibilities, cross-organizational governance

**Defining risk communication and decision making platform.** We have to designate the core authority that owns the risk governance process across the lifecycle of the Energy Islands Program. It is their authority to make risk governance decisions. This includes the responsibility to establish an effective communication and consultation process across all relevant stakeholders.

**Creating a professional risk management community of practice.** The Energy Island Program will require risk management expertise from a large range of professional background, as well as span professionals across the public, regulatory, owner and contractor landscape. A professional risk management community of practice facilitates the development, exchange and adoption of best practices, and helps to surface unmet competence needs early.

**Integrating the public and public authorities in risk governance.** While many risk management activities will be highly technical, it is crucial to embed the general public, NGOs and public authorities not directly involved in the core program in the risk governance framework. A proper integration will surface concerns early, define (two-way) communication and outreach needs, and enables a responsible engagement of specialized risk management activities with the public discourse.

**Development of a robust stakeholder engagement framework.** Different stakeholders will have different concerns and perceive risks differently at different stages of the Energy Islands program lifecycle. A robust stakeholder engagement framework recognizes and respects a diversity of stakeholder values, as well as different characteristics of risks – from simple to complex risks, but also uncertainty and ambiguity. This requires a broad range of engagement techniques that fit for the specific purpose – from simple newsletters to technical expert working groups to an active engagement of civil society.

## 3.2 Governing pre-assessment activities: Problem framing, early warning, screening, determination of scientific conventions

**Framing and scoping of risk governance activities – the scope, scale and time horizon of the risk and stakeholder landscape.** All critical objectives of the Energy Island program will be affected by uncertainties. The scope of a fully developed risk governance framework is therefore very broad – as broad as the activities and impacts of the Energy Island program. It is critical to clearly frame and focus the initial risk governance activities, including a roadmap of when, how and by whom currently unaddressed uncertainties (and unaddressed impacted objectives) are addressed. As discussed above, objectives impacted by uncertainties range from safety, to cost, to schedule, to resilience of the project execution as well as resilience of the operational activities. Similarly, the stakeholder groups involved in and addressed by risk governance activities will start with a relatively small initial group. That must include a preliminary roadmap to involve and address all relevant stakeholders – from technical experts to the business community, to public authorities and the general public. Additionally, the Energy Island program spans a lifecycle of at least decades, if not centuries. The time horizon of different risk governance activities must reflect the time horizon of activities and impacts of the program. This includes creating responsibility and accountability for advancing the risk management agenda to prevent indecision and inaction regarding risks.

**Acknowledging and accommodating stakeholder priorities and power relationships.** Risk governance cannot afford to be ignorant or naïve regarding the fact that different stakeholders and stakeholder groupings (legitimately) pursue different objectives. This leads to differing priorities, and sometimes incoherent and contradicting goals (for example in client – contractor relationships). Neither unaligned interests or real-world power relationships across stakeholders are per se problematic. But they must be made transparent, so that their impact on risk governance activities can be integrated into the overall risk governance framework. As mentioned, this includes objectives and power relationships, but also differing world views and problem framings, legal and organizational constraints, and degrees of criticality of various risks to different stakeholders.

**Taking stock of existing risk governance and risk management practices, and understanding their integration and dependencies.** All stakeholder groups involved in the planning, design, delivery and operation of the Energy Island program will have formal and informal, explicit and implicit practices to address and manage risk, uncertainty, ignorance and ambiguity in their organization and with their immediate partners. These capabilities (and their associated needs) must be understood in the Energy Island stakeholder network, so that risk governance activities can be targeted to leverage existing capabilities, close capability gap, and integrate management practices on both technical and organizational levels. This will not only significantly improve risk and project management performance, but it will also lay the foundation for a learning program organization.

**Collecting already identified concerns and risks, as well as urgent problems.** Initial risk governance activities must survey the status quo of the concern and risk landscape, even if no formal identification process has been carried out yet. The objective is to identify potential needs for immediate action, as well as beginning activities to define critical protocols for characterizing risks on the critical path of decision makers immediately. This includes leveraging existing foresight and horizon scanning activities in the stakeholder organizations to boost initial risk governance activities.

## 3.3 Governing risk assessments: Hazard identification, exposure & vulnerability assessment, and risk characterization

**Characterizing possible program-level damages and adverse effects.** The program risk governance must explicitly define the categories of risk impact (i.e. health & safety, cost, schedule, reputation, assets, and operational capabilities). Each impact category requires measurement scales that are both meaningful at the operational level and for organization-wide aggregation and prioritization. Risk governance must also define the quality of damages and adverse effects on the program: how wide-spread are impacts? How quickly do they occur and how persistent are they? And are impacts fundamentally reversible or not?

**Identification of sources of uncertainty in the Energy Island program.** To enable a consistent hazard and risk identification across the organization, risk governance activities must structure the sources of uncertainty that face the Energy Island program. This enables participating organizations to coordinate their risk identification and assessment activities, as well as share knowledge and best practices.

**Creating a toolbox for differentiated risk assessment and quantification.** The identified risks will vary greatly in their severity, dynamic and kinetics, as well as in the amount of information available for their characterization. Risk governance ensures that risks and risk scenarios are assessed and quantified to comparable standards across the programs, and that the techniques to do so reflect the risks' severity and available information.

**Describing the core processes that create and control risks in the Energy Island program.** From a risk and uncertainty perspective, not all aspects of the Energy Island program are equal. We must understand what the critical core processes are from a risk management perspective – meaning processes that are both exposed to significant uncertainty, but also processes that are critical for reducing uncertainty and / or accommodating residual uncertainty throughout the lifecycle of the program. These will change as the program evolves.

**Understanding the impact of risks on our ability to control them.** Risks are particularly critical if their impact degrades the Energy Island program's capability to mitigate them. This is a surprisingly common (and surprisingly commonly overlooked) factor in risk management. Cost overruns, for example, lead to organizational restructuring that hampers our ability to better control cost. Or incurred legal liabilities can easily impact an organizations ability to better safeguard compliance. Risk governance must ensure that as part of risk assessment, we understand how risk impacts can systemically affect the organization.

**Documenting and communicating the quality and confidence of risk assessments.** All risk assessments are incomplete, but some are useful. For decision makers to appropriately use risk management products, and specifically risk assessments, risk governance must establish clear guidelines on how to characterize and communicate the quality of risk assessments. This addresses questions of robustness, reliability and accuracy, and includes for example the amount and quality of available data, the type of the used methods in the context of the available data, time and resources to execute it, and the experience of the assessors.

## 3.4 Governing concern assessments: Risk perceptions, social concerns, socio-economic impacts

**Describing the social dimension of the risks we are facing in the Energy Island program.** Risk governance must establish robust processes that reconcile and contrast the technical assessment of risks with an assessment of social and other non-technical concerns, including the social and societal perception of risk impacts. This includes a deep understanding of stakeholders opinions, values and concerns regarding risks. Risk governance also contributes to shaping stakeholders involvement, accountability and responsibility for risks and concerns.

**Sociological factors and constraints of stakeholder actions.** As part of the risk governance activities, we must actively investigate how sociological, organizational and anthropological factors shape stakeholders risk perception, impact engagement options. This includes understanding the impact of cognitive biases and decision making heuristics on risk perception and mitigation. This includes individuals and organizations involved in delivering the Energy Island program, but also the broader public that will be affected in many different ways by the program throughout its life cycle.

**Shaping engagement processes with public concerns.** A critical aspect of risk governance is to enable the Energy Island program to proactively, constructively, respectfully and responsibly participate in the public dialogues that are critical to its mission. This includes a thorough understanding of the political and social mobilization potentials around the risks that the program faces, how existing stakeholder capabilities can contribute to engaging with media and public concerns, and how risk management and other professionals in the program can be best prepared to constructively engage in emerging or evolving public controversies.

## 3.5 Governing knowledge characterization: Risk profile, judgement of seriousness of risks, conclusion and risk reduction options

**Characterizing our knowledge of risks.** The type and amount of available knowledge differs significantly for different types of risks and at different points in the Energy Islands lifecycle. Effective risk governance must ensure that the tools used in risk management are appropriate, reflecting both the availability of knowledge, as well as preventing mischaracterization of risks or misunderstandings at stakeholders. As discussed earlier, risk governance must enable the organization to appropriately address complexity-related risks (characterized by the difficulty involved in developing models and collecting data because of the diversity of factors and their relationships), uncertainty-related risks (characterized by a fundamental absence of or low confidence in models and/or data), or ambiguity-related risks (characterized by divergent perspectives on the risk and impacts by different stakeholders).

**Categorization of risks regarding the underlying causal mechanisms.** Risks can be outcomes of natural phenomena or human action, and complex combinations of the two. Understanding fundamental underlying causal mechanisms of risks and grouping risks accordingly during identification and assessment can enable a more effective control of the risk. This grouping can increase in fidelity, following the principle that risk owners should be those stakeholders that have the most control over a certain risk.

**Extended risk cause and impact characterization.** In addition to the factors discussed above, risks can be characterized according to their impact categories, the degree of novelty, their geographic scope, the time horizon regarding analysis, latency between event and impact, and duration of impact.

**Capturing expected complexity of risk management.** Risk governance must enable specific risk management activities reflecting the organizational complexity of managing different types of risks. Specifically, important aspects that have to be addressed are the possible need for international cooperation, potential impact on established social norms (e.g. values, business prospects, equity concerns, security needs), expected levels of public concern, presence or absence of relevant private or public regulation and technical standards.

## 3.6 Governing risk evaluation: Tolerability, acceptability and need for further risk reduction

**Create a framework for the consideration of ethical issues in risk evaluation.** Risk evaluation focusses on easy-to-measure impacts, such as cost, schedule or performance degradation. While it is critical to have robust frameworks for such risks, it is equally important to develop and organization-wide alignment on the evaluation practices of risks that have strong ethical components. These include well-studied risks such as health & safety, but also risks impacting factors such as *perceived fairness or legitimacy*.

**Articulate the rules and norms underlying the judgements of risk tolerance and risk acceptance.** The risk governance process must be a venue to openly discuss how acceptance or at least tolerance criteria for risks are defined. This includes both the articulation of unacceptable risks (e.g. health impacts on large parts of the population, irreversible environmental damage, maximum acceptable delays and cost overruns before the program is shut down). The conversation must also address trends of evolving norms. Second, the governance activities must establish guidelines for discussing risk-benefit tradeoffs for risks that are not in principle unacceptable, to enable a balance between level of innovation and security of delivery of the program.

## 3.7 Governing decision making: Option identification, option assessment, option evaluation and selection

**Establishing routine-based risk management for simple risks.** For simple risks, i.e. risks that are well characterized from both a model quality and data availability point of view, regulation- and routine-based management and mitigation actions must be set up. Some of the most significant cost and safety risks are 'simple risks': Basic procedures to ensure professional cost and safety risk management, for example, may not be the most exciting set of activities, but are critical to build a strong foundation for the Energy Island program.

**Establishing robustness-focused and risk-informed management strategies for complex risks.** Managing complex risks requires significant input from technical and other subject matter experts from both within and outside the organization. This may include scientific advice and research activities. Robust risk management strategies counter identified and reasonably well characterized risks by including sufficient safety margins in designs and decisions to accommodate residual uncertainty. Risk-informed decision making strategies apply thoughtful risk management best practices to a continuous evaluation of "typical" risk management actions, i.e. avoidance, reduction, transfer or acceptance.

**Establishing resilience-focused and precaution-based risk responses for uncertain risks.** Managing uncertain risks requires to accommodate significant residual uncertainty pertaining to the causal structures and/or impacts of the risks, including long-term impacts and possible irreversibilities. Resilience-focused strategies allow to absorb, resist to and recover from a wide range of potential impacts. This requires that risks are understood well enough to exclude catastrophic or otherwise unacceptable worst-case scenarios. Precaution-based strategies emphasize prudence and reserving the option to reverse decisions that have been made, if new information suggests to do so.

**Establishing discourse-based decision making strategies for ambiguous risks.** Managing ambiguous risks focusses on integrating all relevant stakeholders in a sense-making and risk management process. The objective is to uncover conflicting value commitments, enable conflict resolution, but also to build tolerance, confidence and trust among the stakeholders.

## 3.8 Governing implementation: Option realization, monitoring & control, feedback from risk management practice

**Risk governance contributes to building a learning organization around three themes:** methods and knowledge regarding risk exposure, methods and knowledge regarding risk response, and methods and knowledge regarding risk management and risk governance. It is important to build robust continuous improvement capabilities into the Energy Island program organization that contributes to all three areas. This will have network effects on the overall organizational and process maturity of the program.

# 4 Conclusion

Adequate organizational set-ups, procedural documents, statutory codes, and risk assessment methods should precede the design of technical and operational solutions. This means that the review and, if needed, augmentation and development of risk management methods, procedures and practices should start now. This work can be started without any delay, and existing uncertainties and lack of knowledge about the solutions, interconnections, consequences and likelihoods of those can be accounted by appropriately developed risk governance approach/framework and guidelines for designing for health and safety, for conducting simultaneous potentially hazardous operations (SIMOPS) and for resilience.

It is important to recognize that conformance with statutory codes of practice and standards typically provides a minimum acceptable level of safety. Further, to determine if the suggested design minimizes risks to assets and energy supply and if adequate controls are in place, there must be agreement on risk appetite and risk acceptance criteria; there must be a clear understanding of what type of risk-based or risk-informed decision making to employ. Here there are options: risk-risk trade-offs, a risk-benefit or cost-benefit analysis, As Low As Reasonably Practicable (ALARP) approach, and some other.

The designed system will certainly have features that allow classifying it into a class of cyber-physical systems, which imposes certain constraints on security and safety risk analyses. While existing standards stipulate how to manage those risks separately of each other, there are multiple calls - and already methods exist - for integrated security and safety analyses (security for safety). Adopting such a method for the analysis of propagation of security issues into safety issues can help to determine adequate barriers to prevent the propagation of incidence from security to safety and in the opposite direction from the physical layer to cyber-layer.

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