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Developing stress tests to improve the resilience of critical infrastructures: a feasibility analysis

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Abstract

In this report we aim to provide a feasibility study and describe the main elements for developing stress tests in the domain of critical infrastructures. Stress tests can be a very useful element for the assessment of the resilience of critical infrastructures against a number of hazards. Currently stress tests are developed in the domain of Nuclear and Financial sector in order to assess the safety, security and resilience of these systems. Taking stock of the activities in these sectors we aim to provide a feasibility analysis and sketch the main lines for the development of stress tests for other infrastructures, systems and sectors.

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Chapter 1

Scope and objectives for developing Stress Tests for Critical Infrastructures in Europe

1.1 Introduction

In this report we discuss the outcome of a feasibility study and describe the fundamentals for developing stress tests within the domain of critical infrastructures resiliency. Stress tests can be a very useful tool for the assessment of the resilience of critical infrastructures against a number of hazards. Contrary to what occurs for exercises, which may be broadly classified as a tool that has been so far used mainly in the ICT sector stress tests have been developed and deployed for the nuclear and financial sectors. The staff working document of the European Commission on the revised EPCIP focuses on three pillars, namely prevention, preparedness and response. Stress tests are clearly mentioned as one of the tools to be developed in order to contribute to the improvement of prevention and preparedness in the context of critical infrastructures. Further, they are also mentioned in the roadmap of the improvement measures to be developed in the near future. This report

responds to this policy recommendation and aims to provide the necessary methodological elements taking stock of what already exists in the nuclear and financial sectors.

1.2 The European Programme for Critical Infrastructure Protection

The European Programme for Critical Infrastructure Protection established in 2006, was recently revised. The result of this process is a staff working document with the objective of ensuring a high degree of protection of EU infrastructures and increasing their resilience thus minimising the consequences of loss of services to society as a whole. At political level, these efforts are also supported by the Stockholm Programme [1] and the EU Internal Security Strategy [2].

This new approach of EPCIP aims to drive the attention, among other things, to the issue of interdependencies between critical infrastructures. Events that may disrupt the functioning of a single critical infrastructure, in reality can impact several infrastructures and sectors due to interdependencies between modern infrastructures and systems. This phenomenon is not always thoroughly studied mainly because the full extent of interactions between systems is not always known in depth. Modern critical systems are extremely complicated and interconnected and mapping their dependencies and interdependencies is not a trivial task.

As well as the functional dimension, interdependencies also have an important spatial dimension. Hence several critical infrastructures are not bounded within single countries, thus the cross border dimension needs to be considered. In such cases cross-sectoral interdependencies, and also intra-sector equivalents span over a number of European countries. One such example is the European high-voltage electricity grid, composed of interconnected national high-voltage electricity grids.

Furthermore in the staff working document of the revised EPCIP there are two ad-

ditional key elements pertinent to critical infrastructure protection: 1) protection against all-hazards and 2) resilience. The first is purely risk management based approach. The second sets out to identify the landscape of the relevant measures that need to assure the continuity of services and where the traditional risk management approach is insufficient i.e. low probability but high impact events as in catastrophes. Further, the small number of such events cannot provide a reliable prediction of similar future events. This is where stress tests can support the work of operators, stakeholders, policy makers by providing insight of the impact of such events. Such tests also help to understand the limitations of existing measures, assess the resilience margins of systems and lastly, improve the awareness for the consequences of such events. Highlighting the application of stress tests for critical infrastructures and realising the expectancies for future work in this field is also captured in STREST (FP7), a research project in which JRC is a participant. The aim of this project is to define a framework for stress tests in the domain of critical infrastructures by taking a holistic view on this topic (http://www.strest-eu.org/opencms/opencms/).

1.3 Stress tests vs Exercises in the context of Critical Infrastructures

A common misconception is to consider stress tests to be a synonym of exercises. In this section we will set the scene, by distinguishing stress tests from exercises and emphasising the importance of stress tests in the prevention and preparedness, as far as critical infrastructures are concerned.

The staff working document of the revised EPCIP praises exercises as one of the measures to improve the level of preparedness of critical infrastructures in the EU. However, the scope and objectives of stress tests are substantially different and diverse from exercises. Exercises mainly focus on the assessment of the response mechanisms in the aftermath of a crisis and the communication between the various actors in order to resolve a crisis. The

event provoking an emergency/crisis is part of the scenario and does not need to be the direct outcome of a risk assessment process. Quoting from the ENISA website [3], "Cyber exercises are an important element of a coherent strategy for cyber incident contingency planning and recovery both at the national and European level. [...] Such a plan should provide the baseline mechanisms and procedures for communications between Member States and, last but not least, support the scoping and organization of future pan-European exercises." It is thus clear that exercises are clearly focused on the preparedness and response pillars of critical infrastructure protection and aim to smooth the procedures in the communication between the various stakeholders during a cyber crisis.

Stress tests on the other hand serve the purpose of associating the severity of a hazard or a disruptive event with the potential impact on a system or on the society as a whole. To achieve this implies identifying the operation limits as well as the vulnerabilities of critical infrastructures. Henceforth the importance of stress tests to achieve these targets is paramount.

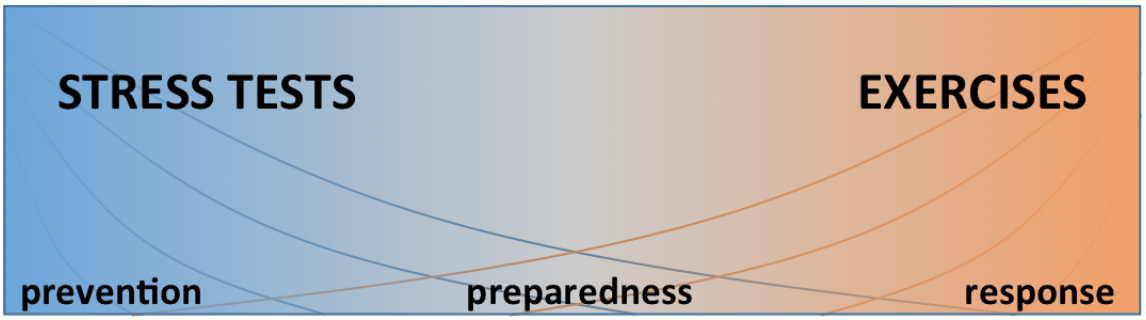

Figure 1.1: *Exercises and stress tests in the EPCIP space*

There is an additional differentiating factor between exercises and stress tests, namely the involvement of actors. Thus exercises require the involvement of public authorities since response to crisis situations requires the support of the public sector e.g. police, fire brigade, civil protection. On the other hand stress tests involve the operators of critical infrastructures and/or the sectoral associations at a higher level. Both perform the core part of the prevention and preparedness work by assessing the limits of their infrastructures

and systems in such crises.

Chapter 2

Stress tests in the nuclear and banking sectors: a state of the art

2.1 Introduction

In this chapter we provide the state of the art of stress tests in the nuclear and the banking sectors. The choice of these sectors is based on maturity and diversity. Indeed the nuclear and the banking sectors represent the only two domains where stress tests are well developed and are considered as an important tool to assess the safety, security and resilience of the relevant systems. This is in spite of the fact that the hazards and the scope vary significantly between these two sectors. Secondly the same sectors represent two different views of stress tests, yet they are complementary. So in the nuclear sector stress tests are applied at asset level (nuclear power stations), while in the banking sector they focus on revealing the systemic vulnerabilities of the sector as a whole taking into consideration the weaknesses of each system component (i.e. individual banks) of this sector/network. As a consequence valuable lessons can be learnt by covering the whole spectrum, from assets to systems.

2.2 Stress tests in the nuclear sector

2.2.1 General specifications and political context of stress tests in Europe

In the conclusions of the European Council on the 24-25th of March 2011 [4] it was decided that the safety of the nuclear power plants in Europe should be reviewed on the basis of a comprehensive and transparent risk and safety assessment ("stress-tests"). To this end the European Council invited ENSREG to develop the scope and modalities of such tests involving Member States authorities taking into consideration the lessons learned from the Fukushima incident. It was also stated that the tests should be conducted by independent national authorities and their outcome should be made public.

Responding to this invitation the Commission, in close collaboration with ENSREG, has developed the relevant scope and the modalities. More specifically the development of the specifications for the comprehensive risk and safety assessments of nuclear infrastructures in Europe. The relevant stress tests were mainly focused on covering extraordinary triggering events such as earthquakes, flooding and also events that may lead to multiple loss of safety actions and require severe accident management. In addition, and this is particularly important for this report, there has been a clear statement from the ENSREG that security threats are not part of its mandate and thus a separate working group should be established with the participation of the MSs and Commission to deal with this issue. To this end the Council has set up an Ad-Hoc Group on Nuclear Security (AHGNS).

Accordingly safety and security require a different approach and which is to be compliant with current international practices. Consequently here we identify three layers of infrastructure assessment for the safety track of stress tests. The first layer refers to the initiating event related to a large scale natural disaster that puts several of the safety systems in stressed conditions i.e. the case of Fukushima. The second layer refers to any

other event that may render safety systems inoperable. In fact events such as power loss would inhibit safety systems to function properly. That said for the purposes of stress tests in the nuclear sector we always refer to assets of infrastructures (nuclear installations) and not to systems of infrastructures. Indeed, from a systems perspective, nuclear power plants are in their turn systems-of-systems. As a consequence we may infer that stress tests even at asset level consider the element of interdependencies, which responds to the priorities set by the revised EPCIP. The third layer of refers to the incident response within the limits of the installation. In practise this means assessing the last resort done by the operator to contain a crisis situation within the limits of its installation.

The security track of stress tests follows a different approach. In this case the assessment is done mostly on the basis of specific threat scenarios and is purely based on a risk management approach. This involves the identification of threats, the identification of potential impact, the assessment of applied security measures applied, the assessment of whether the residual risk is at an acceptable level or not and finally documenting the whole process. We can summarise by claiming that with respect to the discussion for the safety track of stress tests the resulting security track approach is more qualitative than quantitative.

2.2.2 Stress tests for safety assessment in the nuclear sector

2.2.2.1 Organizational aspects

In the Annex I of the ENSREG document [5] concerning the specifications of the nuclear stress tests, there is a clear description for the organisational aspects, dissemination of information and review of the stress tests' output in European nuclear power plants. The responsibility for conducting the stress tests relies on the licensees of the nuclear power plants but the review is the responsibility of the regulatory bodies. The operator of the infrastructure is in possession of all the data, procedures and know-how to run the infrastructure and thus, by default, the appropriate actor to conduct the stress tests.

The review of the output of the stress tests is the responsibility of the regulatory bodies and through the implementation of a two step process.

In the first step the planning for conducting stress tests is provided and the licensees are obliged to provide the national regulator with a report of the resulting stress tests. The national regulator then reviews and drafts a national report. At this point the second phase starts, which is the independent review of the national reports. The team responsible for reviewing the national reports is agreed between the Commission and ENSREG: more details on the composition of the team can be found in [6]. In terms of the methodology used for the review process, it is clearly stated that the MS regulator has to provide access to all information (taking into consideration issues such as team composition, security clearance, etc.).

Transparency is a focal point in the review process. The results of the peer reviewed process should be publicly available, but subject of course to legislative aspects concerning the non-disclosure of sensitive information that could jeopardise the security of such installations. The importance of transparency is related to the element of trust of European citizens on the outcome of these stress tests. From the above we may conclude that the organisational process of stress tests in the nuclear sector is of paramount importance both in terms of end result and credibility. It is interesting to note that the review process of the stress tests is a multi-layered process and involves national authorities and independent international organisations. This is a clear indication that maybe that the majority of effort in stress tests is not restricted only to the execution phase but ensuring that the results are credible and represent the real status of the installations against the hazards for which these stress tests have been conducted. Furthermore, peer reviewing is crucial especially if we consider the ownership status of most nuclear and in general critical infrastructures. The unbundling of the energy sector in terms of production, transmission and distribution and with the private sector involved in all three, stipulates the need for a strong multi-layered review process.

2.2.2.2 Technical Aspects

General considerations The technical details of nuclear stress tests in Europe were obviously influenced by the tragic events in Fukushima. As a consequence the safety stress tests were built around three axes [6] that somehow represent the issues that the authorities had to cope with in Fukushima.

- Initiating events:
  - earthquake;
  - flooding.
- Consequence of loss of safety functions from any initiating event conceivable at the plant site
  - loss of electrical power, including station black-out (SBO);
  - loss of ultimate heat sink (UHS);
  - a combination of both.
- Severe accident management issues:
  - means to protect from and to manage loss of core cooling function;
  - means to protect from and to manage loss of cooling function in the fuel storage pool;
  - means to protect from and to manage loss of containment integrity.

The above list of issues is a clear depiction of a comprehensive assessment, meant to cover:

- the response of the nuclear infrastructure with respect to certain extreme natural disasters;

- the response and the safety margins of the nuclear power plant due to loss of safety functions that may be triggered by various events. Here the triggering event may even be a security breach, although this was not considered during the stress tests;
- the accident management side.

This last topic should not be misconceived as an activity that falls within the domain of exercises. In fact it refers mainly to the actions that have to be undertaken once safety measures have failed. Such actions serve to avoid the evolution of the incident to a non-recoverable nuclear incident (as in the case of Fukushima) that would require intervention from the authorities (evacuation, crisis management, etc.). Thus this severe accident management process refers to the internal measures, procedures, and the technical means that need to be assessed to understand the capacity to contain the consequences of loss of safety functions.

An important technical parameter of stress tests, at least for the safety domain, is that a deterministic approach is assumed. According to what is explained in the technical specifications document, our interpretation is that the safety measures are defeated in a sequential fashion, thus performing a worst case scenario analysis.

For the purposes of the present report the first two aspects of stress tests (initiating events and loss of safety functions) are of particular interest. The response of an infrastructure to a set of predefined initiating events is beyond any doubt an element that is relevant to all types of stress tests independent of the sector under scrutiny. Nevertheless, and in any case, the initiating event has to be selected on the basis of the particular hazards for a specific site.

The stress tests report issued by the licensees and reviewed by the national authorities should include the following information:

- level of conformity of the nuclear power plant to its design requirements;

- robustness of the plant beyond its design basis and also identification of cliff-edge effects, in other words identify the point after which a cascade effect occurs;
- possible measures for improving the current status of safety.

Additional information that the licensee may provide in the stress test report may include measures to avoid the worst case scenarios for which stress tests have been conceived.

Assessment of the initiating event Looking at the technical details of the stress tests we see that the response of the infrastructure against each initiating event (in this case the earthquake and subsequent flooding) is assessed by implementing a multi-layered approach as is depicted in the scheme shown in Figure 2.1.

The applied methodology assesses the efficiency of risk barriers as well as the resilience margins of an infrastructure when the latter is stressed beyond its design footing. This methodology is applicable to each initiating event, in this case flooding and earthquake.

Assessment of the loss of safety functions Following the assessment of the initiating event the next step is to assess the infrastructure performance after the alternative electrical power supply and ultimate cooling sink are not functional any more. This can be considered as a type of resilience analysis, since the performance of the infrastructure is assessed independently of the event that provoked the failure of safety systems and without linking this failure to a specific initiating event. In the framework of this assessment, we observe that the loss of off-site power is also considered, thus underlining that interdependencies are (implicitly) taken into account.

The last part the stress tests for the nuclear sector refers to severe accident management. This part of the stress tests assesses the mitigation measures of the organisation

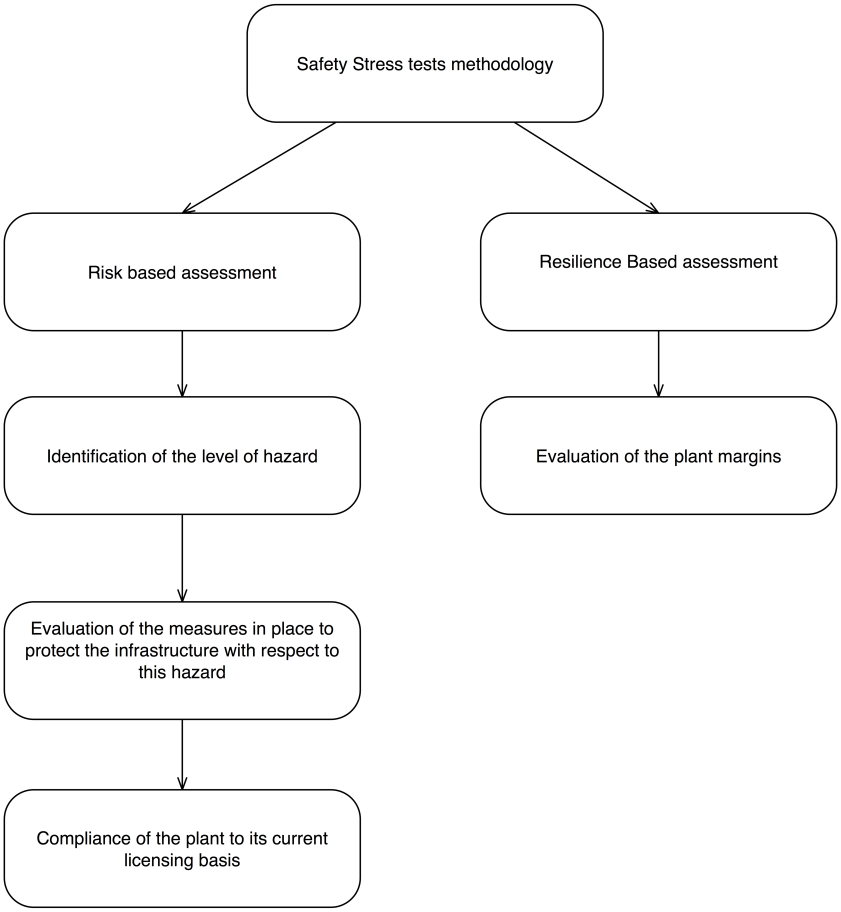

Figure 2.1: *Stress testing approach for the nuclear sector.*

in order to contain a severe situation when all other protection and resilience measures have failed. As in the previous steps of stress tests this too is also infrastructure specific. Therefore the test measure specifications cannot be freely replicated as such to other infrastructures.

The technical issues discussed so far were necessary both to extract the main elements that one should address when performing stress tests in infrastructures and identify those elements that can be generalised and implemented also to other sectors.

2.2.2.3 Review process of safety stress tests

As mentioned above, the technical characteristics of stress tests for nuclear infrastructures are infrastructure specific. In addition, stress tests are executed at a technical

level by the licensees, who in principle, are the infrastructure owners. The peer review process of stress tests is of particular importance for the success and credibility of the whole process. It is evident that it is in the interest of the licensees to overestimate the safety margins of the measures in place, Further they must demonstrate their capacity to withstand a shock without the need for additional investments or with small modifications of the existing safety measures, especially for events that are described as low probability (although with high impact). As a consequence the review process is a cornerstone of the whole process. The fact that the peer review is a multi-step process, with well established milestones is a clear confirmation of this claim.

The first step of the review process is the review, by the national regulator, of the stress test reports issued by the licensees. In the next step the reports of the national regulators are reviewed by the peer reviewers. This peer review process was organised in three phases [6]:

- a desktop review phase of the national reports taking into account 200 questions posed by the public to the reviewers;
- a peer review on the horizontal topics explained above, namely extreme natural hazards, loss of safety functions and severe accident management. Three topical reports and 17 countries reports were produced;
- an individual review of the country reports. These reports together with the topical reports are the basis for the overall peer review board report to ENSREG.

In addition to the peer review process, the country reports as well as the final reports are publically available. This practice enhances the credibility and the acceptance of the stress tests output by the general public.

Some very useful conclusions can be drawn from the final review report of the stress tests. In principle with respect to the initiating event, almost all countries (with a few ex-

ceptions) are using similar exceedance probabilities for earthquakes and flooding. However, this is not the case for the beyond design footing margins. A few countries have demonstrated the robustness of their installations for events exceeding the design basis up to cliff-edge effects (i.e. the onset of domino effects), whereas others have provided some general information and the claim that sufficient margins exist without entering into details. In this report we translate this into a clear indication of the difficulty to assess the resilience capacity of an infrastructure whereas the effectiveness of risk barriers (design basis assessment) seems to be much more straightforward and quantifiable. As a consequence we conclude that additional guidance and research work may be needed to push the assessment of margins beyond design basis.

With respect to the loss of safety functions all countries appraised that cliff-edge effects correlated to various combinations of loss of power and cooling water, irrespective of the event that led to the loss of these safety functions in the facility being assessed. The electricity black out is of course one of the most crucial cases for most reactors. Although we will not go into the technical details why this is so it is worth mentioning that most operators have both the means and mitigation measures (e.g. mobile equipment) in place to make sure that the necessary safety functions will be up and running in case of a major emergency.

This discernment is the result of a technically detailed review process and clearly is not restricted to compliance issues with the agreed methodology for the stress tests. So we conclude that the review process needs such technical details in order to reassure the objectivity and the reliability of the process results. This implies that the review authority/organization should be technically competent in order to perform this task. Consequently we foresee that for the development of stress tests in other sectors the involvement of sectoral associations empowered with technical competencies is paramount.

2.2.3 Stress tests for security assessment in the nuclear sector

2.2.3.1 Scope and mandate of AHGNS

As mentioned stress tests in the nuclear sector were initially foreseen to cover both safety and security issues. ENSREG and the Commission agreed that a two-track process should take place and thus the Ad-hoc Group on Nuclear Security (AHGNS) was established. With respect to the safety stress tests, the approach has been somewhat different. The aim of AHGNS was to focus on evaluation methods. More specifically, this implies taking preventive measures and protecting NPPS [7] and to identify and share good practices based on the recommendations of IAEA.

Focusing on safety track issues has already made a major difference. The security track employs a more qualitative rather than quantitative approach, in the sense that it sets the general framework of the threats, vulnerabilities and potential impact. It does not quantify the threat/hazard, which is not possible for security threats. Further, there is no information on the effectiveness of the threat, while the impact can be assessed if it is assumed that the security threat is successful in taking advantage of a system's vulnerabilities. As a consequence it is not surprising that only recommendations and best practices can be extracted from this process. We may even conclude that this process is not really a stress test, at least in the strictest sense. Rather it is a review of the methodologies and practices commonly applied in nuclear power plants in order to protect critical infrastructures from external threats. In the next section we provide an overview of the issues that were assessed through the security track of the stress tests.

2.2.3.2 Technical Aspects

The security track of stress tests focused on 5 topics: 1) cyber-security; 2) physical security; 3) intentional aircraft crash; 4) nuclear emergency planning and 5) exercises and training. It is evident that the security track of stress tests addressed issues related

to specific initiating events of concern . But there are also more horizontal issues such as emergency planning. In terms of initiating event(s) a pure risk management approach is followed. This implies assessing the existing measures and proposing best practices in order to improve the protection of installations against these hazards. It is mostly a table-top review of the applied approaches rather than a pure stress test approach.

The assessment of emergency planning is particularly interesting since it liaises the safety issues with security matters. The rationale is that a security breach may lead to a safety incident. As a consequence synergies between the safety and security domains are recommended in order to reduce the consequences of a nuclear incident. According to [7] the emergency and contingency plans should be especially consistent in terms of:

- understanding of the different operational responses needed for each type of event;
- coordination between the safety and security elements of the response;
- cooperation between response organisations;
- understanding and harmonizing of technical terms for both emergency and contingency plans.

Concerning contingency planning, it is recommended that a three layered approach is applied namely, 1) on-site, 2) off-site at local level and 3) at national level. These plans should be closely connected.

The report by AHGNS concludes with six main recommendations in order to improve the security of nuclear power plants in the MS. For more details see [7].

The security track of stress tests for the nuclear sector is actually a review of the risk management procedures applied by the operators and MSs with NPPs. The usefulness of the security track for developing stress tests for critical infrastructures concerns the

alignment of stress tests with risk management. This allows the stress tests output to be exploited for the improvement of the overall risk management of critical infrastructures.

2.3 Stress tests in the banking sector

2.3.1 Introduction

The use of stress testing methods in economics is generally led by the idea of assessing the stability of some components of an economy (either financial instruments or institutions), intended as the capability of withstanding sudden perturbations. The interest in these methods is gauged by some evidence suggesting that, "while markets, asset types, players involved and the triggering events differ from one episode to another, risk accumulation cycles tend to be similar" [8].

According to [9], originally in finance stress tests there were tools used "to simulate the performance of individual portfolios and to gauge the stability of individual institutions" (*micro stress testing*). Banks generally started to use microeconomic stress tests as a micro-prudential complement to their internal models, in order to enhance their risk management capabilities. More recently, the idea of stress testing has been extended to assess also the stability of sets of financial institutions having an impact on the economy as a whole (*macro stress testing*). Macroeconomic stress testing is emerging as a key tool in the general framework of macro-prudential analyses. The objective is the assessment and monitoring of financial systems based on both quantitative information on the financial system and on qualitative information about the institutional and regulatory framework [10]. As discussed later in this chapter, the main initiatives conducted up to now for macro stress testing at the institutional level are referred principally to the banking sector. This is due to the high impact on the financial stability and for which we can find a more developed set of methodologies and studies. The idea is to promote the ability of the banks to absorb the losses while continuing to lend and retaining sufficient regula-

tory capital. Stress testing initiatives were strongly motivated by recent prudential bank regulation acts, e.g. the Basel Accords.

A very interesting perspective towards the appreciation of the role of stress tests in finance today is provided in [8]. Therein, the two components concurring to the definition of a crisis are identified in the shock and the contagion channels (representing the propagation mechanisms for financial instability), see also [11]. This distinction brings into the stress testing problem two domains: 1) the risk analysis and 2) the fragility analysis of financial institutions. In particular, stress tests are identified as a tool for the authorities to be aware of the potential channels through which a systemic crisis may appear and, consequently, to identify leading indicators of distress.

From the risk analysis viewpoint, we can draw a basic distinction between risks arising within the financial system or on the outside of it. In the first case, a typical institutional perspective could be to search for both preventive policies and crisis management tools; in the second case, the analysis could lead to the definition of mitigating policy responses. In [8], macroeconomic stress tests are qualified as "quantitative tools used by banking supervisors and central banks for assessing the soundness of financial systems in response to extreme, but still plausible, shocks". This definition emphasizes the importance of a suitable choice of type and extent of the shock to the overall quality of the analysis, enforcing the role of risk analysis inside the stress testing procedure.

Furthermore, the concept of fragility seems central in the most recent approaches to stress testing. An interesting discussion is provided in [9], where the authors discuss how "the essence of financial instability is that normal-size shocks cause the system to break down". They also state that "An unstable financial system is a fragile financial system; it is not one that would break down only if hit by severe macroeconomic shocks". This observation is supported by historical data, suggesting that "financial crises generally do not begin after output has collapsed, but before it contracts significantly". In the fragility

analysis perspective, a comprehensive categorization of the system's vulnerabilities is a fundamental support toward the definition of policy responses. The structural fragility analysis of a financial system can offer interesting perspective. One of them consists in the identification of multiple contagion channels such as [8] the exposure channel and the information channel e.g. deposit withdrawals and asset sales by depositors/investors who are not properly informed about the shock hitting the financial system.

The usage of stress testing outcomes, either as an early warning device or as a support to crisis management and resolution, is a subject of debate today [9]. In particular, in the latter reference their effectiveness as early warning devices is criticized based both on technical considerations (quality of the models, scarce awareness of the context, inability to qualify the system's fragilities) and on behavioral observations (scarce trust in the test outcomes in growth periods, possible over-enhancement of the sense of security in policymakers). On the other side, the utility of stress tests in the crisis management and resolution perspective appears clear.

In the rest of this chapter, we will first review some aspects about the structure of stress tests in finance today, especially macro stress tests. After that we will discuss some of the institutional practices found recently.

2.3.2 Stress testing architecture and categories

The recent literature identifies some common architectural elements common to both micro and macro tests. According to [9], in particular, we have the four components discussed next.

- **The set of risk exposures.** These define the stress extent and the focus of the analysis. Usually, in the case of banks, they basically refer to the credit risk exposures; in advanced stress tests, they can also incorporate further risk components (e.g. market risk, liquidity risk, interbank contagion risk).

- **The scenario**. This component specifies the (exogenous) shocks affecting the exposures specified for the analysis. We can distinguish between the analysis of the impact of a single risk factor (*sensitivity analysis*) or of a multivariate scenario involving simultaneous changes in several risk factors (*scenario analysis*)[1] [8]. The single-factor options usually allows faster computation while its utility may be narrow. On the other side, multi-factor tests can introduce both computational burdens and issues related to their compatibility with the stakeholders' assessment methods. In the definition of the stress test scenario, a common issue is related to the choice of the severity of the stress level, which usually highly impacts the results of the analysis in view of the inherent nonlinearity of the system. As mentioned above, a common ground for the stress test specification is that stress scenario should be severe yet plausible [8]. In [10], in particular, a distinction is drawn between the level of shocks and scenarios calibration that is between

  1. worst case approach: based on searching for the most severe scenario while having a certain minimum degree of plausibility;
  2. threshold approach: the objective in this case is to search for the largest shocks that let the system perform above a given threshold.

  The definition of the plausibility degree is in itself a degree of discussion. In practice, choices can vary according to the standing macroeconomic conditions when the analysis is performed and to the stress definition criteria (e.g. historical-data-based scenarios, hypothetical plausible and worst case scenarios). Typically, institutions consider a set of possible scenarios with different degrees of severity in their analyses. While the second approach can provide advantages by eliminating the need for scenario calibration, it can be more computationally intensive when multiple risk factors are involved. The latter distinction has also implications on the way the stress tests analysis results can be presented. As discussed in [12], typically

[1] http://www.mas.gov.sg/~/media/resource/publications/staff_papers/StaffPaper%20Lily%2012Aug_rv1pwp.pdf

in macro testing the stress test's scenario effects on macroeconomic conditions are measured using a structural econometric model, vector autoregressive methods or pure statistical approaches.

- **The model.** This element maps the scenario (and the macroeconomic conditions induced by it) to the outcome, and its choice usually represents a highly complex task, especially at the level of macroeconomic analysis. We can summarize some of the main difficulties in constructing suitable macro stress testing models, see for instance [9]:

  1. taking into account for the nonlinearities affecting the system, especially during crisis periods which can strongly affect its dynamic behaviour;
  2. incorporating a non-trivial description of feedback effects, e.g. from the financial sector to the real economy;
  3. detecting and modelling endogenous risk factors, which can produce crisis events with moderate shocks even under otherwise favourable circumstances;
  4. taking into account how the endogenous vulnerabilities build up.

- **The outcome**: it describes the impact of the considered scenario. The outcome is typically evaluated in terms of the impact of the scenarios on the balance sheets and income statements of the stakeholders. The representation of the outcome of stress tests usually require to put together the outcome of analyses based on different scenarios and should be interpreted as a "first order approximation with respect to the true potential loss exposure" [10]. In this perspective, it should be integrated in a broader set of evaluations about the system's vulnerability. An issue arises concerning the strength of the assumptions made in performing the stress tests. In particular, this kind of analysis typically does not extensively consider the ability of the financial institutions to adapt swiftly to stress situations.

A common risk about the use of macro stress tests is represented by their possible inability to describe common paths of financial instability, i.e. the fragility of the system with respect to shocks of moderate severity. Furthermore, issues are related to the quality of the models being used and often require a comprehensive involvement of all the institutions involved in the analysis.

2.3.3 Special features of macro stress tests

Generally, the search for plausible financial soundness measures [13] in the macroeconomic context requires a non-trivial combination of macro- and micro-prudential dimensions [14, 15]. This observation leads, in many cases today, to an interpretation of stress tests as a collaborative effort involving a central authority and the financial stakeholders. The above observations suggest that stress tests for the financial sector are a multi-step process [10].

In this sense, we can distinguish between two fundamental approaches to stress testing:

- **top-down approach**: the analysis is performed entirely by the governing institution, relying on its own internal models, and simulated on the basis of data received from the stakeholders involved in the study;
- **bottom-up approach**: the authority provides a set of scenarios to the individual stakeholders, these actors perform their analyses based on internal, institution-specific models and the authority finally aggregates the results.

According to [8], both top-down and bottom-up approaches can be applied to different analysis classes, namely sensitivity analysis and scenario analysis.

The prevailing perspective today seems to merge the top-down and bottom-up philosophies [9]. This idea also fits both benchmarking and surveillance purposes. For instance

public institutions can exploit top-down generated test outcomes to check for the quality of the results generated in a bottom-up approach in collaboration, say, with banks and investment firms. To illustrate this and as discussed in [16], currently the ECB solvency analysis framework for top-down macro stress testing, applied in conjunction with bottom-up tests, comprises four pillars, see Figure 2.2. These consist in: the macro-financial scenario scheme to be imposed on the banking sector; a set of top-down satellite models used to translate the scenario into its effects on the balance sheets of banks; a balance sheet module determining the impact of the projected profit and losses into the banks' solvency position; a set of feedback modules used to compute higher-order impacts of bank capitalization within the banking sector as well as on the real economy.

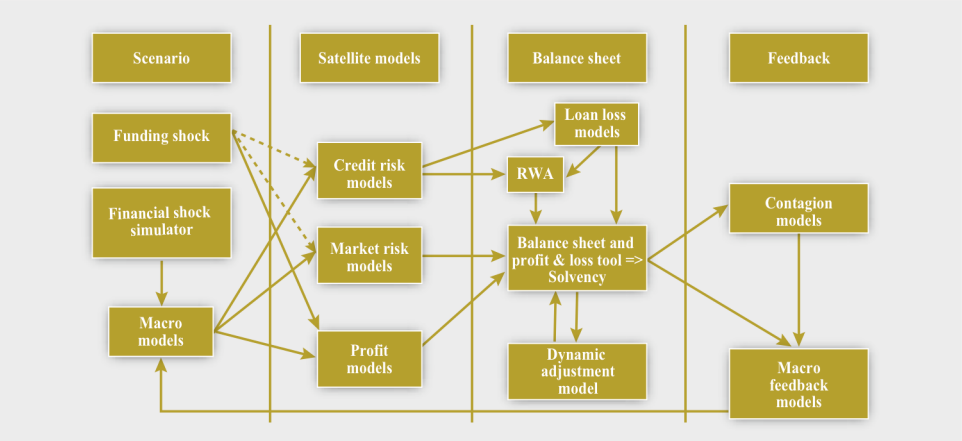

Figure 2.2: *Structure of ECB's solvency analysis framework. Source: [16].*

For an extended survey of authorities' approaches to stress testing credit risks and related references, see [12]. As a concluding remark, a relevant political factor about performing stress tests in finance is related to the strategic choice about the public disclosure of the results. As discussed further on in this chapter, a common trend in these years seems to be in the direction of a higher degree of transparency. For an extended discussion of these issues, see [17, 18] and related references.

2.3.4 Recent institutional initiatives on stress testing

Today, large-scale stress testing initiatives for the financial sector are being promoted by governmental, inter-governmental and non-governmental bodies within the context of the rise of the macro-prudential regulation. The interest in institutionally-managed banking stress tests, in particular, is synchronised with the evolution of the banking regulation. A notable instance in this sense is the amendment to the Basel Capital Accord in operation since 1996. Here banks and investment companies are required to perform stress tests. This event boosted the internal stress testing initiatives started by some large international banks at the beginning of the 1990's, involving a larger number of companies in the process. However, such initiatives have been somehow circumscribed to internal self-assessment, while some approaches to the problem by financial authorities generally lacked the ability to identify significant vulnerabilities [19]. The 2007 crisis, on the contrary, emphasized the role of such initiatives in view of the severity and scarce predictability of such a crisis. As a consequence, stress tests are becoming a routine for financial regulators.

In this section we review some relevant aspects of the banking regulation and subsequently we focus on stress testing initiatives run in recent times by EU and US authorities, as well as the International Monetary Fund (IMF) and the World Bank (WB). We observe that similar or related initiatives have been/are also led by other authorities around the world (e.g. China Banking Regulatory Commission, Bank of England, Reserve Bank of India, Monetary Authority of Singapore).

2.3.4.1 Basel Accords

Basel Capital Accord (Basel I) In 1988, the Basel Committee of Banking Supervision (BCBS) introduced a global level risk and capital framework through a document titled "International Convergence of Capital Measurement and Capital Standards" (also referred to as Basel Capital Accord or Basel I). Basel I set down an agreement among the G-10

central banks to apply commonly agreed minimum standards for capital in their banking institutions, to be achieved by 1992. These standards were mainly related to credit risk, which represents the main risk component for banks. In particular, banks were required to ensure 8% of capital adequacy against Risk Weighted Assets (RWA). In 1996, an important amendment was made to the original accord. In particular, the usage of stress testing methodologies was introduced as a prerequisite for using the advanced methods introduced for the quantification of the banks' minimum capital requirements.

Basel II and Basel III In 2004, a new framework (Basel II) was introduced by the BCBS, which provided specifications about minimum capital requirements, supervisory review process, and market discipline. The capital requirement of 8% was extended to cover the three major risk components for banks, namely credit, market and operational risks. Stress testing for credit risk is a fundamental component of the Basel II framework. In particular, Pillar II of Basel II (Internal Capital Adequacy Assessment Process, ICAAP) establishes micro-prudential stress tests to be conducted at a bank level. Some requirements in this sense make explicit reference to the economic cycle.

The 2007-2009 financial crisis revealed some weaknesses and insufficiency in the Basel II measures of capital adequacy to deal with credit risk. Therefore, BCBS issued some documents which consolidated into the document "Basel III: A Global Regulatory Framework for more Resilient Banks and Banking Systems" in 2010 (rev. 2011). Basel III reflects the development of the macro-prudential approach to financial regulation [20]. In particular: the systemic role of financial institutions is acknowledged in the text; the larger banks are required to hold more and higher quality capital and the banks' capital requirements are strengthened, also introducing new liquidity requirements, together with a leverage cap and a countercyclical capital buffer.

2.3.4.2 EU

In the last decade, the EU undertook several initiatives towards the improvement of resilience in the financial sector, particularly in banks. The Capital Requirement Directives (CRD) were introduced by the EU in its financial supervisory framework reflecting the Basel II and Basel III statements. Member states implemented the directives and financial firms started to apply the regulations from January 2007 and were requested to comply with Basel II starting from January 2008. The CRD were updated in time and in July 2013 the CRD IV entered into force, implying the compliance of the European banking sector with the Basel III standards. Furthermore, we assisted to a progressive institutional reorganization. In 2004, the Committee of European Banking Supervisors (CEBS) was established as an independent advisory group. More recently, the EU legislation set up the European Systemic Risk Board (ESRB) and three European Supervisory Authorities (ESAs), namely the European Banking Authority (EBA), the European Insurance and Occupational Pensions Authority (EIOPA) and the European Security and Markets Authority (ESMA). In particular, starting from 2011 the EBA replaced the CEBS in its ongoing activities and responsibilities, including that of coordinating stress tests on the European banking sector solvency. Aside EBA, also other authorities (e.g. EIOPA) run stress tests in their respective field of competence and in the general framework of the enhancement of the EU capabilities in terms of the management of financial risk. Also, complementary initiatives such as capital exercises and assessment are run. In this perspective, a new evolution of the control mechanisms is going to be established in late 2014 through the introduction of the Single Supervisory Mechanism (SSM), which will perform micro- and macro-level risk assessment tasks and support the Member States in managing stress situations. Observe that the EU tests today represents the only multi-country tests [9].

In the rest of this subsection, we refer particularly to the bank solvency stress tests run by the EBA. Currently, these tests are bottom-up in nature, requiring banks to submit

their stress test results to the national supervisory authorities for review and finally to the EBA itself. While based on micro-prudential projections run by banks, these stress tests are the outcome of a global macroeconomic scenario defined by the ECB and have as an objective the overall assessment of systemic risk in the EU financial system. A particular feature of the EU situation is related to the necessity to take into account the presence of the single nations' jurisdiction which has to harmonize with the EU public authorities on one side and with the national banks on the other. In the rest of this section we review some driving concepts related to the recent years' banks solvency stress tests rung in the EU under the guidance of the EBA.

- **The 2009 bank solvency stress test**. In 2009, the European Economic and Financial Affairs Council (ECOFIN) mandated CEBS to coordinate, in conjunction with the ECB, a EU-wide forward-looking stress test devoted to the baking system. The initiative involved 22 major European cross-border banking groups, representing 60% of the total assets of the EU banking sector on a consolidated basis. The test was performed under the responsibility of different national supervisory authorities and the outputs were aggregated by CEBS. The tests involved the following two major components:

  - an assessment of credit risks, based on two commonly agreed macro-economic scenarios (respectively, a baseline scenario based on current macroeconomic projections and an adverse scenario affected by a severe, yet plausible shock) over a testing horizon of 2 years;
  - a sensitivity analysis on the trading book/market risk positions, based on commonly agreed parameters.

  The official documents emphasized the role of this stress test as a tool "to enhance the level of aggregate information among policy makers in assessing the resilience of the European banking system", in contrast to the assessment of recapitalization

needs of individual firms. The outcome of the tests reflected dependence of the resilience of the banking system on both the increase in the earning forecasts and the support provided by the public sector to the banking system, contributing to the enhancement of the capital buffers of the institutions.

- **The 2010 bank solvency stress test**. In 2010, a second stress test exercise was run. In addition to objectives of the previous tests here the focus was on "the dependence of EU banks on public support and on the amount of capital available for further lending in the context of exit strategies" (European Council - PRES/09/352, 02/12/2009). As in 2009, the exercise was bottom-up, based on commonly agreed scenarios and assumptions informing the calculations to be carried out by the single institutions. The coverage of the test was extended also by increasing the number of involved institutions. The sample in this case was considerably extended with respect to 2009 involving also key domestic credit institutions as well as cross-border stakeholders. Thus totaling 91 banks for a coverage of 65% of the European banking sector. In this framework, banking groups were tested on a consolidated level, including their subsidiaries and branches. In the official documents, it was specified that "a stress testing exercise does not provide forecasts of expected outcomes, but rather a what-if analysis aimed at supporting the supervisory assessment of the adequacy of capital of European banks" (European Commission - MEMO/10/355, 23/07/2010). The main focus of the tests was on credit and market risks, including the exposures to European sovereign debt. Capital adequacy was the main focus of the test, while liquidity risks were not directly stress tested. In particular, a passing criterion based on a threshold value of 6% on the Tier 1 capital ratio was fixed, in order to determine the potential need of banks to recapitalization. This percentage compared to the minimum fixed by the Capital Requirement Directive (CRD) at 4% and was in line with the US SCAP value. In the 2010 tests, 7 banks did not pass the tests under the adverse scenario including the sovereign risk shock. The banks

closer to the threshold or underperforming were put under closer supervision by the national supervisors. The possibility of stricter scrutiny was envisaged, involving the possible request to banks to develop plans to increase their capital buffers. In delivering the test results, the accompanying documents proposed a brief comparison with the corresponding tests performed in the US. The following differences were emphasized:

- objective: while the EU tests was devoted to provide policy information and to assess the resilience of the EU banking sector as a whole, the US test was more directly related to evaluating the capital needs of the individual banks;
- complexity: the EU test involved more banks (91 versus 19) and more supervisory authorities (27 versus 3), while also the number of risk factors included in the analysis was different;
- timing: the US tests were performed in the context of government interventions, while the EU tests took place after some major government actions.

Despite these difference, the two approaches displayed a number of similarities, including the time horizon, the use of two sets of macro-economic scenarios, a similar coverage, in terms of total assets, of the banking system. Both administrations put emphasis on the public disclosure of the test results.

- **The 2011 bank solvency stress test**. In the framework of the institutional reorganization taking place in the EU, this test was performed as a part of the resilience assessment for the financial sector being set up by the European System of Financial Supervision (ESFS). Particularly, it was realized in parallel with other stress tests involving EIOPA.

  The 2011 EU bank stress test involved 90 banks in 21 countries. Banks had an incentive to enhance their capital position prior to the tests. In fact, capital raising implemented in the first 4 months of 2011 were included in the calculations. While

in the 2009 and 2010 stress tests the adverse scenario included a -0.6% macro-economic growth in the Euro area, the 2011 adverse scenario had a considerably higher parameter of -4.0%.

Three main quality control mechanisms were included in the process: 1) the banks' internal controls; 2) the supervisory control by the competent national authorities; 3) the quality assurance process by EBA, led by a Quality Assurance Task Force involving secondees from NSAs, the ECB and the ESRB. The bottom-up results produced by the banks were benchmarked against top-down stress test results performed by the ECB and the ESRB.

The results led the EBA to issue formal recommendations to the national supervisory authorities. The intent was to counteract capital shortfalls of the banks and to strengthen the position of banks with considerable exposure to sovereign debts. EBA was also entrusted to monitor the implementation of their recommendations. Emphasis was given to the transparency of the stress test results, in order to enhance the understanding by the public of the resilience levels of the EU banking sector.

- **The 2014 bank solvency stress test**. The 2014 banking sector stress tests will involve a sample of 124 EU banks, covering at least 50% of each national banking sector. The analysis will be performed over an assessment period of three years (2014-2016) and under the assumption of a static balance sheet (no new growth and constant business mix and model over the considered period). The set of risks to be considered will include credit risk, market risk, sovereign risk, securisation and the cost of funding. National authorities may include additional risks and sensitivities specific to the countries, while ensuring the comparability of the results on the ground of the common risk set. The capital thresholds have been updated. This exercise has been designed by the EBA in coordination with the ECP, which is conducting a comprehensive assessment comprising risk assessment, asset quality review and a stress test in preparation to the SSM. The release of the banks'

individual results is expected for release in late October 2014.

The outcome of the test were disclosed by publicly providing a detailed report.

2.3.4.3 US

In the US, the Board of Governors of the Federal Reserve is responsible for conducting macro stress testing initiatives. In recent times, the first large test launched in response to the 2008 financial crisis was the 2009 Supervisory Capital Assessment Program (SCAP).

In 2010, the Dodd-Franck Act introduced the requirement to run annual stress tests over the US financial system. Consequently, the Federal Reserve's 2011 capital plans rule required all US bank holding companies with consolidated assets of at least 50 M$ to submit their capital plans on an annual basis. Thanks to this initiative, the Federal Reserve performed stress tests in 2011, 2012 and 2013 within the framework of the Comprehensive Capital Analysis and Review (CCAR). The CCAR, therefore, qualifies as an annual exercise by the Federal Reserve to ensure that the largest bank holding companies have sufficient capital. The objective here is to ensure continuity of operations throughout times of economic and financial stress and guarantee robust, forward-looking capital planning processes that account for risks unique to this specific sector. The scope of this exercise is closer to a micro stress test, leading to possible requests to the single institutions to revise their plans when their capital or internal capital adequacy assessment processes are deemed as unfavourable under the CCAR. The evaluation includes institutions' capital adequacy, internal capital adequacy assessment processes, and their plans to make capital distributions, such as dividend payments or stock repurchases. Therefore, these stress tests substantially differ in nature from the bottom-up approach followed in the EU.

Furthermore, the Dodd-Frank Wall Street Reform and Consumer Protection Act (Dodd-Frank Act, DFA) introduced by the Congress as a consequence of the recent financial crisis imposes the Federal Reserve to conduct an annual stress test of large bank

holding companies as well as other designated financial companies chosen by the Financial Stability Oversight Council (FSOC).

"DFA stress tests are forward-looking exercises conducted by the Federal Reserve and financial companies regulated by the Federal Reserve to help ensure institutions have sufficient capital to absorb losses and support operations during adverse economic conditions." [2] In October 2012, the Federal Reserve publicized rules to run these tests, and in the 2013 Dodd-Frank Act supervisory stress tests 18 bank holding companies were included. Currently, the stress tests required under the DFA implementation rules primarily focus on credit risk and market risk and not on other types of risk, such as liquidity risk or operational risk unrelated to the macroeconomic environment. Tests are performed both by the companies and by the Federal Reserve itself (based on input data provided by the stakeholders and on models developed internally and/or provided from external organizations). The Federal Reserve Board provides different sets of scenarios to be considered in both supervisory and company-run stress tests. These include a baseline, an adverse and severely adverse scenario. The first of them is drawn by taking into consideration the average projections from surveys of economic forecasters. The other two consider different degrees of weakening in economic activity across the considered economies, generally leading to more severe impacts on the capital of the companies. Further specific scenarios can be determined by the Board in specific circumstances supporting the need of a specific risk analysis.

As part of the DFA analysis, the directives put in place macro scenarios and market shock components for the stress test scenarios. The macro scenarios describe the hypothetical evolution of some economic and financial variables which may change over time. The market shock component, applying to companies with significant trading activity and their subsidiaries, consists of large moves in market prices and rates that would be expected to generate losses. The two tools differ in terms of dynamics, affecting risk factors

[2] http://www.federalreserve.gov/bankinforeg/stress-tests-capital-planning.htm

etc.

Indeed CCAR and DFA are intended as complementary tools while, in the case of DFA, the analysis is extended to a larger number of companies than the CCAR. The use of complementary tests is proposed since it appears that no single tool is adequate to assess the ability of the financial institution to withstand any kind of risk source.

Starting in 2014, also mid-sized firms (10-50 B$ of assets) are being required to conduct Dodd-Franck Act Stress Testing.

2.3.4.4 IMF and WB

In 1999, the International Monetary Fund (IMF) and the World Bank (WB) established the Financial Sector Assessment Program (FSAP), striving to analyze strengths and weaknesses of the financial sector within each of the member countries. The objective is to promote financial stability and to gauge the potential of the different countries. For advanced economies, the FASP studies are conducted by the IMF alone and lead to a financial stability assessment. In the case of developing and emerging market economies, the IMF assessment is completed by a financial development assessment performed by the WB. The objective of FASPs is not to classify the fragility of single financial institutions or to predict crises, but to identify the systemic vulnerabilities. In this perspective, stress testing was intended as a main component of the financial stability assessment.

To assess the stability of the financial sector, FSAP teams examine the soundness of the banking and other financial sectors; conduct stress tests; rate the quality of bank, insurance, and financial market supervision against accepted international standards; and evaluate the ability of supervisors, policymakers, and financial safety nets to respond effectively in case of systemic stress. While FSAPs do not evaluate the health of individual financial institutions and cannot predict or prevent financial crises, they identify the main vulnerabilities that could trigger one. To assess the development aspects of the financial sector, FSAPs examine the quality of the legal framework and of financial infrastructure,

such as the payments and settlements system; identify obstacles to the competitiveness and efficiency of the sector; and examine its contribution to economic growth and development. Issues related to access to banking services and the development of domestic capital markets are particularly important in low-income countries.

The financial crisis emphasized both qualities and limits of the FSAP procedures. Despite the general success they obtained in identifying risk sources, some studies pointed out the under appreciation of some risk sources, including liquidity risks, sovereign risks, and cross-border or cross-market linkages. Consequently, in 2009 the IMF and WB introduced new features in the FSAP procedures. These included: the introduction of the risk assessment matrix, supporting a systematic and transparent approach to the stability assessment; and improved analytical toolkit, to deepen the identification and description of linkages between the financial sector and the economy in general; modularity in the assessment, allowing financial stability analysis and development assessment to be conceived separately for higher flexibility; an improved assessment of the standards applied in the supervision and regulation of financial entities.

Most of the member countries have undergone FASP assessments today. In 2010, every five years periodic FASP assessments were imposed by the IMF to 25 jurisdictions with systemically important financial sectors. These were selected based on their size and the interconnectedness of their financial sectors. The procedure used for identifying the interested jurisdictions was revised in 2013 and greater emphasis was put on interconnections, number and type of covered exposures, contagion risks. The list of jurisdictions was expanded to 29, while the procedures are being periodically revised. For the other member countries, the FASP assessments are performed on a voluntary basis.

2.3.5 Concluding remarks

Stress testing in finance was strongly promoted in recent decades and in the perspective of prudential regulation. The need for testing initiatives and tools was emphasized by

the 2007 economic crisis, which also demonstrated the need for higher analytical skills which favoured the recognition of these tests as a joint effort between public authorities and financial firms towards stability.

This interpretation of stress tests builds on former experiences (micro stress testing) that were first performed by larger banks and gauged by the bank regulation, especially the Basel Accords. Consequently, and also taking into account transparency issues related to the involved bank stakeholders, today we can qualify two main approaches to performing these tests, namely a top-down and a bottom-up approach. In the top-down case, the procedural difficulties of a large-scale stress testing are mitigated by the fact that all projections are run by the authority itself, based on models internally available plus data provided by the financial firms involved in the analysis. The bottom-up approach, instead, implies an active involvement of the firms in performing the computations. Despite the organizational issues, this approach allows the exploitation of the internal models of different participants, which often have a good degree of refinement at a firm or micro level. In this case, the bottom-up test results can be compared to the results of a complementary, top-down analysis in order to check the (black-/grey-box) output provided by the individual stakeholders. Depending on the jurisdictional framework the stress test refers to the active involvement of competent authorities to coordinate the task at the intermediate level, which is typical.

Chapter 3

Guidelines and recommendations for developing stress tests for Critical Infrastructures in Europe

3.1 Introduction

In this chapter we aim to provide recommendations and high level guidelines for the development of stress tests for critical infrastructures. We will base our approach on the review work on the stress tests for the nuclear and financial sectors. This chapter is organised as follows: The first part is dedicated to the organisational aspects of such stress tests, we will then present the architecture and the technical procedures to be developed and finally we will provide some elements on the dissemination of the results of these stress tests.

3.2 Organizational aspects

The cornerstone for the development of stress tests is beyond any doubt the mobilisation and involvement of the right actors. We stress the importance of this point as we have seen in the previous sectors that there is a multilayered approach that requires the involvement of several actors from private and public sectors. By reviewing the stress tests in the nuclear and banking sectors it has been possible to identify four distinct phases in stress tests, namely preparation, execution, review and dissemination of results. It is a mixture of a bottom-up and top-down approach as will be shown shortly.

We strongly believe that the stress tests for critical infrastructures need to have both a national and an international dimension since several critical infrastructures expand well beyond the limits of one state. In addition these infrastructures are also interconnected with other infrastructures and thus the element of interdependencies cannot be excluded. As a result in the preparation phase of stress tests of critical infrastructures (actually the definition of the stress test scenario) it is necessary to involve the private sector as well as national and international authorities.

During the preparation phase the technical details of the scenario have to be defined in close agreement among the actors. Clearly this is necessary in order to match the high level objectives of the authorities with the feasibility assessment done by the owner of the infrastructure. In this way the owner is in a position to evaluate the limitations and can provide feedback on the requests from the authorities or the regulator.

The execution phase is purely a task that has to be entrusted to the owner/operator of the infrastructure. We have seen this model being applied in both the nuclear and banking sectors. As mentioned above, the owners/operators of critical infrastructures are the only actors that are actually in a position (in terms of means, procedures and know how) to execute the scenario of stress tests. The next step in the process is the evaluation of the re-

sults by the regulator or national authority responsible for this particular sector. One may already identify that this process is strictly sectoral. This reflects the sectoral knowledge of the critical infrastructure owner/operator who is not in a position to assess interdependencies clearly due to lack of knowledge of the modus operandi of the other sectors. This is the role of the regulator/authority to identify elements of interdependencies and inject the second round of analysis in order to reveal the level of interdependencies among sectors. The report at this stage of the stress tests is derived by the national authorities that will be able to depict the interdependencies at national level.

Reflecting on the best practises from the nuclear sector, the last step is to submit these national reports to an international body or authority in order to identify the cross border interdependencies and also render the whole process homogeneous and comparable among the various MSs (here we are referring to the EU28).

The final stage of stress tests process is the dissemination of results to the general public. As in the case of nuclear stress tests, this would enhance the confidence in the resilience of relevant critical infrastructures.

3.3 Architectural and procedural considerations

In this section, we propose some thoughts about the design and execution of stress tests on critical infrastructures. We will draw some elements from the discussion provided in the previous chapter, taking as reference both the nuclear and the financial sectors.

Modern CIs are often characterized by a high degree of interconnection and display complex performance capability. Complexity derives from various factors: size of the infrastructure; interaction with other infrastructures belonging to the same or different classes; different ownership and competitive aspects; in many cases, with a high degree of specialisation in the service delivered.

These aspects seem to suggest that the interpretation of the task of CI stress testing

should be a collaborative effort involving public (national and international) authorities, sectoral associations and firms. Moreover, experience reveals that individual firms often have some capability to deliver a detailed analysis of the risk factors specific to the infrastructure they manage, as well as its fragility. This is witnessed, for instance, in the nuclear sector, as discussed above. Furthermore, in high-specialisation sectors, exploiting the specific competencies (special knowledge) is both a need and an advantage for the different parties (security, insurances, certification of CIs) involved.

Conversely evaluating interdependencies, their qualities and implications is typically a non-trivial task for the individual stakeholders. For instance in the EU the assessment of interdependencies has two dimensions. First, and in a jurisdictional/national sense, we have to take into account how the different critical sectors of a country interact with the corresponding partners of other countries (*cross-national interdependencies*). Second, and generally speaking, interdependencies involve different sectors (*cross-sectoral interdependencies*). Together they take CI stress testing initiatives into the domain of System of Systems testing. Within this framework the exchange of data and the interfacing among different infrastructure operators becomes awkward. Further it considerably complicates the analysis because during critical events a trigger starting in one sector will affect others causing occasional cascading effects which equally represent a criticality. This eventuality is even more pressing because of today's market liberalization initiatives that involve an increasing number of European CIs and introduce further competitive dynamics. All these features (network structure, interdependence, competitive framework) emphasize some similarities with stress testing in the financial sector.

In view of the remarks proposed above, here we propose some architectural and procedural considerations to be taken into account for stress testing in CIs.

- **Hierarchical involvement of the jurisdictions and sectoral associations**. Public authorities should play multiple roles. Indeed they should interface with the man-

agement of the CIs involved in a given stress test initiative so as to provide scenarios and reap the benefits of the resulting analysis. They should act as an interface among CI operators from different sectors/countries for the stress testing. They should define the level of disclosure of the results of the tests. Sectoral associations could mediate between the national authorities and the CI administrators, see Figure 3.1.

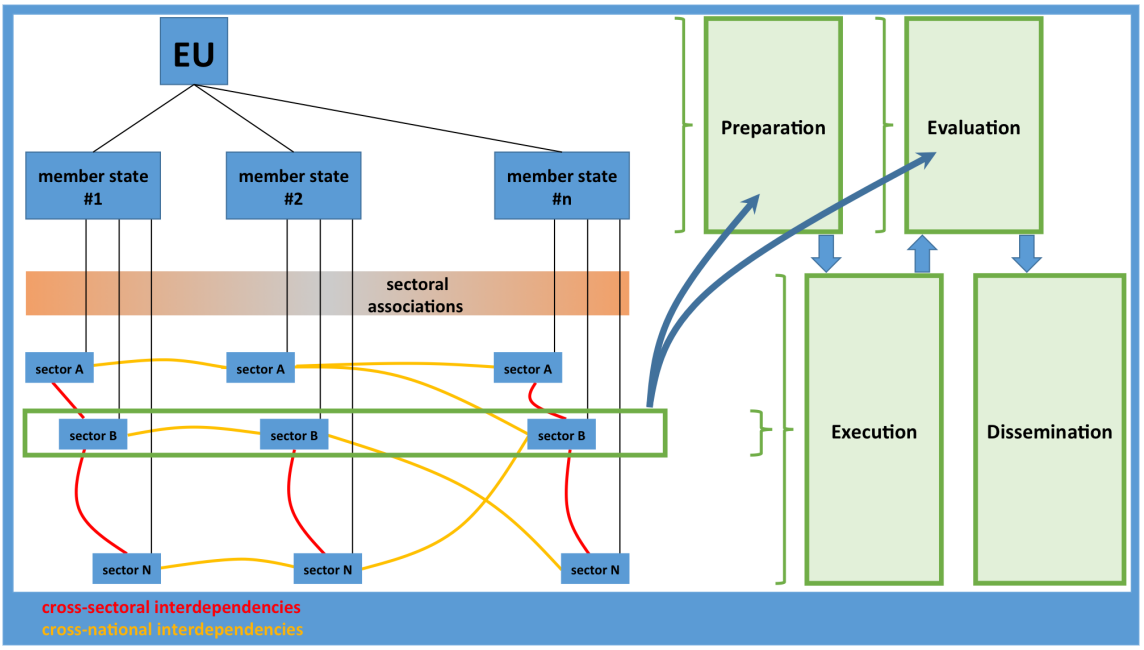

Figure 3.1: *Top-down and bottom-up approaches promote inclusiveness for CIP (from authorities to operators).*

- **Interdependency identification and description**. When different countries/sectors are involved, the public authority could hold the onus to identify and qualify the interdependence relationships. To this end, a top-down approach to interdependence qualification could be applied. This would require that the operators provide data (especially when critical events take place), targeting performance correlation indicators, and qualifying the importance of the coupling factors. In time, the public authorities should be able to construct a larger and larger database describing interdependencies. By doing so they would end up with the improvement of the quantification of these factors. The definition of interdependencies requires access to restricted information and data which often are owned by operators. Blending

this approach with the actual performance of stress tests in a bottom-up fashion (as described below) could favour cooperation with the operators.

- **Choice of scenarios and CI sample**. The selection of the scenarios for stress tests could be driven by both historical considerations and by observing the importance of the sector and its centrality to the proper operation of other sectors. The sample of CIs to be involved in the analysis should be representative and involving firms having the technical capabilities to perform sound stress test analysis. Support from external specialists could be necessary to tackle the most critical sectors.

- **Running first-order bottom-up stress tests**. Consider a specific stress test scenario affecting, say, a specific CI. A first step in the testing procedure could consist in evaluating the resilience of the CI itself and the coupled response of other homogeneous CIs, neglecting cross-national and cross-sectoral interdependencies. The outcomes of these tests should be provided to the public authorities.

- **Running higher-order bottom-up stress tests**. Based on the outcomes of the latter procedure and the knowledge of the coupling factors, the public authority should coordinate a further stage of testing based on transferring the outcome of the previous procedures to the most critically interdependent sectors indirectly affected by the critical event. Results should be aggregated again after this stage thus gaining a broader view of the effects of the assessed stress condition.

- **Comparing the results with top-down stress tests**. In particular when referring to competitive sectors where the disclosure of sensitive information could be critical from a strategic market perspective a public authority should be able to run independent tests. These would be based on the information available and would allow the evaluation of the soundness of the outputs provided by the individual CI administrators.

- **Review**. The quality of the stress test results should be checked by independent ex-

perts, with special emphasis on the cross-sectoral and cross-national relationships.

- **Disclosure of the stress test results**. The public disclosure of results concerning the outcome of stress tests is subject to safety and security considerations. These should be defined in such a way so as to enforce cooperation between stakeholders and avoiding to spoil the quality of their competitive activities.

3.4 Dissemination of results

We consider that the peer review and dissemination of results of stress tests are fundamental procedures in the nuclear and banking sectors. This helps to build trust and confidence in the security, safety and resilience of critical infrastructures among the general public. We suggest a similar procedure also for critical infrastructures. With the exception of test data that may jeopardise the security of critical infrastructures, the dissemination of results should be done through official and acknowledged organisations and methods. For example, dissemination could be done through dedicated portals managed by the public sector or international organisations. This is a practice that we consider fundamental in order to properly complete the process of CI stress testing.

3.5 Concluding remarks

To our knowledge it is the first time that there is an effort to provide some methodological elements for establishing stress tests for critical infrastructures. We consider that there is a lot of room for development for this tool to assess the level of security and resilience of critical infrastructures. The revised EPCIP puts stress tests in the discussion for prevention and preparedness of critical infrastructures and with the present report we aim to investigate the feasibility of this and propose an approach for CI stress testing. Here we have assessed stress tests in the nuclear and banking sectors where stress tests play an important role in order to assess their safety, security and resilience. The approaches implemented in each sector vary significantly but at the same time can be considered as

complementary. This provides a holistic view of the necessary parameters in order to develop stress tests for other sectors and systems. As an output of the assessment on nuclear and banking sector we propose in this report the guidelines and general framework for developing stress tests in the domains of energy and transport CIs. Also we consider stress tests to be mainly a tool for assessing the resilience of a system but without excluding the assessment of safety and security of an infrastructure. In terms of future work in this field we expect that operators and sectoral associations may build on the elements that we present in this report in order to build stress tests tailored to the needs of the corresponding sector.

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