Design and Investigation of a Decision Support System for Public Policy Formulation

Osama Ibrahim

Abstract

The ultimate aim of support for public policy decision making is to develop ways of facilitating policymaking that can create policies that are consistent with the preferences of policymakers and stakeholders (such as an increase in economic growth, the reduction of social inequalities, and improvements to the environment), and that are at the same time based on the available knowledge and evidential information.

Using the design science research methodology, an iterative design process was followed to build and evaluate a research artefact in the form of an analytical method that is also operationalised as a decision support system (DSS) – in order to facilitate the problem analysis, the impact assessment and the decision evaluation activities carried out at the policy formulation stage of the policymaking process. The DSS provides a web-based, user-friendly interface for two main software modules: (i) a tool for modelling and simulation of policy scenarios; and (ii) a tool for multi-criteria evaluation of policy decisions. The target end-users of the DSS tools are policymakers, the support staff of politicians, policy analysts and researchers within governmental departments and parliaments at the various institutional levels of the European Union.

The proposed model-based decision support approach integrates systems thinking, problem structuring methods and multi-criteria decision analysis, in what can be described as a ‘sense-making’ approach. A new policy-oriented quantitative problem structuring method is introduced in this research, the ‘labelled causal mapping’ method, which aims to reduce the cognitive overload involved in representing complex mental models using system dynamics simulation modelling in order to facilitate knowledge representation and system analysis. One contribution of this work is an object-oriented implementation of a prototype tool for systems modelling and simulation of policy decision situations based on the labelled causal mapping method. The method provides a basis for further computational decision analysis. We proposed criteria models and data formats for common (generic) policy appraisal, and a preference elicitation method for in-depth decision evaluation based on the results of scenario simulation and the preferences of decision makers and stakeholder groups.

The artefact evaluation clarifies how well the proposed approach and the DSS tool prototype support a solution to the problem and the extent to which the outcomes in two policy analysis use cases are useful in terms of output analysis and knowledge synthesis.

The contributions of this research to theory and practice were articulated based on the design knowledge obtained through an iterative design process, notably the emergence of the concepts of transparency and intelligibility in policymodelling, (i.e., the need for explicit and interpretable models that can provide justification of a specific decision).

Keywords: Systems Thinking, Prescriptive Policy Analysis, Policy modelling and Simulation, ICT for governance, Sense4us, Policy Impact Assessment, Scenario Planning, Knowledge synthesis.

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DESIGN AND INVESTIGATION OF A DECISION SUPPORT SYSTEM FOR PUBLIC POLICY FORMULATION

Osama Ibrahim
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This work is dedicated to my parents for their love and endless support.
Abstract

The ultimate aim of support for public policy decision making is to develop ways of facilitating policymaking that can create policies that are consistent with the preferences of policymakers and stakeholders (such as an increase in economic growth, the reduction of social inequalities, and improvements to the environment), and that are at the same time based on the available knowledge and evidential information.

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Sammanfattning

Det yttersta målet för beslutsstöd i skapandet av policyer i offentlig verksamhet är att utveckla sätt att underlätta skapandet av policyer som överensstämmer med politiska beslutsfattares och intressenters preferenser (till exempel enökning av ekonomisk tillväxt, minskning av sociala ojämlikheter och förbättringar av miljön), och som samtidigt baseras på tillgänglig kunskap och tillförlitlig information.

Med hjälp av designforskningsmetodiken följdes en iterativ designprocess för att bygga och utvärdera en forskningsarbetefakt i form av en analysetechnik som också är operativiserad som ett beslutsstödssystem för att underlätta problemanalys, konsekvensbedömning och beslututvärdering som genomförs i formuleringssjöet i den policyskapande processen. Beslutstödssystemet tillhandahåller ett webbaserat, användarvänligt gränssnitt med två huvudmoduler: (i) ett verktyg för modellering och simulering av policyscenarier och (ii) ett verktyg för utvärdering av policybeslut med flera kriterier. De tänkta slutanvändarna av beslutstödsverktygen är policyskapare, politiska tjänstemän, politiska analytiker och forskare inom statliga myndigheter och parlament på de olika institutionella nivåerna i Europeiska unionen.

Det föreslagna modellbaserade beslutsstödsättet integrerar systemtänkande, problemstruktureringsmetoder och multikriteriesbeslutssyntes, i vad som kan beskrivas som en meningsskapande strategi. En ny policyorienterad kvantitativ problemstruktureringsmetod introduceras i denna forskning, "labelled causal mapping"-metoden, som syftar till att minska den kognitiva överbelastningen som följer av att representera komplexa mentala modeller genom att använda systemdynamisk simulering och modellering för att underlätta kunskapsrepresentation och systemanalyser. Ett bidrag från detta arbete är en objektorienterad implementering av ett prototypverktyg för systemmodellering och simulering av beslutssituationer på policynivån utifrån "labelled causal mapping"-metoden. Metoden utgör grunden för vidare datorstöd beslutssyntes. Vi har föreslagit kriteriemodeller och dataformat för gemensam (generisk) policybedömning och en preferenseliciteringsmetod för djupgående beslutsvärdering baserat på resultaten av scenariosimulering och beslutsfattares och intressentgruppers preferenser.
Artefaktutvärderingen klargör hur väl det föreslagna tillvägagångssättet och beslutsstödsverktygsprototypen stöder en lösning på givna problem och i vilken utsträckning resultaten i två policyanalyssfällstudier är användbara med avseende på resultatanalys och kunskapssyntes.

Bidragen till teori och praktik från denna forskning formulerades på grundval av den designkunskap som erhölls genom en iterativ designprocess, särskilt framväxten av begreppen insyn och förståelse i policymodellering (dvs. behovet av tydliga och tolkbara modeller som kan tillhandahålla motiveringen av ett visst beslut).
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List of Publications

The thesis is a compilation of the following research papers.

**Paper I: An integrated decision support system framework for strategic planning in higher education**

_Osama Ibrahim_, David Sundgren and Aron Larsson


**Paper II: A causal mapping simulation for scenario planning and impact assessment in public policy problems: The case of EU 2030 Climate and Energy Framework**

_Osama Ibrahim_, Aron Larsson and David Sundgren


**Paper III: Text analysis to support structuring and modelling a public policy problem: Outline of an algorithm to extract inferences from textual data**

Claudia Ehrentraut, _Osama Ibrahim_ and Hercules Dalianis


**Paper IV: Modelling for policy formulation: Causal mapping, scenario generation, and decision evaluation**

Aron Larsson and _Osama Ibrahim_

Paper V: A systems tool for structuring public policy problems and design of policy options

Osama Ibrahim and Aron Larsson

Paper VI: Multi-stakeholder preference analysis in ex-ante evaluation of policy options - Use case: ultra low emission vehicles in UK

Anton Talantsev, Osama Ibrahim and Aron Larsson

Paper VII: Fossil-free public transport: Prescriptive policy analysis for the Swedish bus fleets

Maria Xylia, Osama Ibrahim and Semida Silveira


Osama Ibrahim, Aron Larsson and Leena Ilmola
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<tr>
<td>API</td>
<td>Application program interface</td>
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<tr>
<td>ABM</td>
<td>Agent-based modelling</td>
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<td>DSR</td>
<td>Design science research</td>
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<td>DSS</td>
<td>Decision support system</td>
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<td>DGMS</td>
<td>Dialog generation and management system</td>
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<td>DBMS</td>
<td>Database management system</td>
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<td>MBMS</td>
<td>Model base management system</td>
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<td>KBMS</td>
<td>Knowledge base management system</td>
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<td>EU</td>
<td>European Union</td>
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<td>EC</td>
<td>European Commission</td>
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<td>EP</td>
<td>European Parliament</td>
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<td>GUI</td>
<td>Graphical user interface</td>
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<td>IS</td>
<td>Information systems</td>
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<tr>
<td>ICT</td>
<td>Information and communication technology</td>
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<td>IA</td>
<td>Impact assessment</td>
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<td>MADM</td>
<td>Multi-attribute decision-making</td>
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<td>MCDA</td>
<td>Multi-criteria decision analysis</td>
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<td>PSM</td>
<td>Problem structuring method</td>
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<td>Robust decision making</td>
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<td>RQ</td>
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1 Introduction

1.1 Background and Motivation

Contemporary policy domains are very complex, have a high number of dimensions and involve a high degree of uncertainty. Governance is also becoming increasingly complex, as it is influenced by the complexity of the policymaking process itself. Complaints related to failures and capacity in governance have been voiced to a wide variety of governments, and particularly those in developed democracies (see Painter and Pierre, 2008), and have forced these governments to engage in large-scale modifications of their traditional forms of governing. Some of the issues with these forms of governing have been related to the quality of the decisions being made; others involve the efficiency of the processes used to govern, and still others the democratic nature of governing. Policymaking involves the management of a multiplicity of goals that are all operational simultaneously, although at different levels of generality, such as:

- Governments’ core values, which affect all aspects of the public sector, such as democracy and efficiency;
- Cross-cutting goals, which governments attempt to achieve in all their programs, such as environmental goals;
- Broad policy goals, which are directed at a strategic level towards social and economic services that affect most or all members of society; and
- Individual organisations and programs that have their own goals, which may be mutually contradictory (Peters, 2011).

The need to find solutions that are acceptable in terms of all goal dimensions may make reaching any decision, and especially one that is better than the lowest common denominator, more difficult (Scharpf, 1988).

Scientific evidence\(^1\) have a place in policy decision-making. Waddell, et al. (2005) found that although research evidence was valued and used by politicians and senior civil servants, it was just one source of ideas and

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\(^1\) Evidence that has been obtained through human intellectual activity aimed to understand the structure and functions of the world in which they live, through the rigor of quantitative or qualitative research. This evidence can be produced through observation, identification, description, experimental investigation, and theoretical explanation of natural phenomena.
information among many sources of information considered by the policy-maker. Policy decision-making often requires eliciting scientific/technical evidence information and expert judgements, and consultations with stakeholders and the public.

Achinstein (2001) proposed two orientations to evidence and its relationship to the context of decision-making:

(i) Philosophical-normative, where evidence is unconstrained by context, suggesting evidence has inherent value with the potential to provide veridical justification for decisions; and

(ii) Practical-operational, where evidence is defined with respect to a specific decision-making context.

The literature on public policy analysis tends to see policies in terms of options. Policy options invariably include more than one class of ‘tools of policy’ (or ‘policy instruments’, which is the term used in this thesis).

Hood’s (1983) NATO model provides a useful categorisation of policy instruments into four groups:

- **Nodality** – control over information flows as a means of attempting to implement change, e.g. public information programmes;
- **Authority** – control over formal (legal) authority in a regulatory form;
- **Treasure** – control over money (both gathering and distributing);
- **Organisation** – direct or indirect organisation of actions must be authorised, financed and justified.

The structures and means of governing are undergoing changes, as new instruments such as networks, voluntary agreements, partnerships, ‘soft law’ and the other instruments of New Governance (Freeman, 1999; Salamon, 2001) are replacing, or at least are used to complement, more conventional instruments. Most policy analysis (pre-implementation) focuses on only a limited subset of policy instruments; these are typically issues involving the use of **authority** (laws, rules, regulations) and **treasure** (taxes and exemptions, benefits, subsidies) (Talbot, 2005). There have been many developments in terms of analytical methodologies for **authority** (e.g. regulatory impact assessment) and **treasure** (e.g. cost-benefit analysis, the precautionary principle, cost effectiveness analysis or multi-criteria decision analysis).

The design of policy options is a complex decision-making and planning process, in which the effects of policy alternatives are often delayed in time and the ultimate impact is affected by a multitude of factors within rapidly changing environments. Policy interventions are carried out within a system of interest with the intention of improving the overall outcomes of that system. A multidisciplinary and systemic approach is needed due to the dynamic and complex contexts of public policy problems. A systemic perspective effectively represents the needs of a public policymaker facing the expected impacts of a policy; this is mainly due to the fact that a policy always affects several sub-systems of a society (humans, critical infrastructure, financial
systems, communities, cultures, etc.) (Stefano et al., 2014). Problems in central policy areas, such as finance, energy and transportation systems and policy for innovation and growth, are typically systemic; that is, they deal with complex systems. A suitable policy for dealing with these problems needs to be based on a view of the system as a whole. This may be an unfamiliar concept for many policymakers, and may lead to simplified and ineffective policies. An understanding of complex systems requires the use of formal models and simulations to test our mental models and develop our intuition about complex systems. This requires a mastery of concepts such as feedback, stocks and flows, time delays and nonlinearity (Sterman, 2002).

The use of computational methods can support decision making in these situations. Decision analysis represents a systematic approach to incorporating evidence into policy and management decision-making processes, (Gray, 1997), since it does not only describe the evidence that must be taken into account but also estimates the impact of taking any of the various options. Simulation modelling is frequently employed to improve and demonstrate an understanding of the system of interest. Unfortunately, the results of these models usually form an insufficient basis for decision making by policymakers, since the interpretation of the results often requires a scientific and technical background and an understanding of the choices that were made when developing a particular model; however, if the model does not require substantial interpretation for decision making, it can be presented as an analytical methodology for the purposes of decision making, or as a complement to one of the existing analytical methodologies for interpreting the results of the model.

The development of a model can give rise to discussions about which aspects to include and which factors are influential, thus contributing to a better understanding of the situation at hand. Furthermore, experimentation using models allows one to investigate different settings and the influence of different scenarios over time on the outcomes of a policy.

The use of a visual problem tree or causal map is an effective way to map all the relevant major drivers and to explain their complexity, interrelationships and feedback. It has the potential to clearly structure and communicate the policymakers’ thoughts, and to bring together the different policy actors (European Commission EC, 2014).

The amount of data available for use in making sense of the socioeconomic environment is increasing exponentially. Open data and social media movements have made large quantities of new data available such as sensor data, text, social media and expert repositories of knowledge, and policy makers are now grappling with the issue of how to separate noise from signal.
The insights and methods of complexity science can be applied to assist policy makers in areas such as environmental protection, economics, energy, security or public health and safety (Janssen and Wimmer, 2015).

New information and communications technologies (ICT) and sophisticated modern techniques of data gathering, visualisation and analysis have expanded our ability to understand, display and disseminate complex, temporal and spatial information to diverse audiences. At the same time, enhancements in terms of computational power have expanded the repertoire of the instruments and tools that are available for studying dynamic systems and their interdependencies. There has been an infusion of technology that is changing policy processes at both the individual and group level. Some of these developments that are opening new avenues for innovative policymaking are social media as a means to interact with the public (Bertot et al., 2012), blogs (Coleman and Wright, 2008), open data (Janssen et al., 2012; Zuiderwijk and Janssen, 2013), freedom of information (Burt, 2011), the wisdom of crowds (Mennis, 2006), open collaboration and transparency in policy simulation (Wimmer et al., 2012) and hybrid modelling techniques (Parrott, 2011).

ICT for governance and policy modelling has emerged as a new research field that aims to achieve better and more participative, evidence-based and timely governance, and to make the policymaking cycle more effective and more intelligent. See (Stefano et al., 2014; Mureddu et al., 2012; Charalabidis et al., 2012).

This new field has been shaped by various disciplines including e-policymaking, digital policy science, computational intelligence and data sciences for policy and policy informatics. The essence of this field is that it: (i) is practice-driven, i.e. the policy problem is the foundation of policy analysis; (ii) employs modelling techniques; (iii) needs knowledge from various disciplines; and (iv) is focused on governance and policy-making (Janssen and Wimmer, 2015).

Model-based collaborative governance represents a grand research challenge in this field. This focuses on the development of advanced tools and methodologies that can support an efficient and effective decision-making process that is able to anticipate future events, promptly detecting emergencies, evaluating the impact of different policy choices and reflecting real-life complexity while making it simpler and more addressable. In this context, the primary challenges for policy makers that should be addressed include the ability to:

- Deal with a distributed governance model;
- Understand the ultimate impact of policies;
- Ensure long-term thinking;
- Generate more participation in policymaking;
- Detect and understand problems before they become insoluble;
- Encourage behavioural change and uptake;
- Manage crisis and “unknown unknowns”.
Model-based collaborative governance implies the need to improve the state-of-the-art ICT tools and methodologies in terms of usability and consequently time and cost consumption, as well as in terms of reliability and knowledge of both models and policies. The key challenges for research on policy modelling are: (Stefano et al., 2014)
- Systems of atomised models (integrated, composable and reusable): These involve the definition of suitable policy modelling standards, procedures and analytical methodologies to ensure model interoperability;
- Collaborative modelling: This can be achieved by the implementation of web-based, user-friendly tools for different levels of domain-specific knowledge and technical skills, in order to ensure the participation of key actors and stakeholders in the policymaking process;
- Easy access to information and knowledge creation, with a focus on the elicitation of relevant evidence information, in order to learn how a certain system works and ultimately to gain insight into how to successfully implement a policy;
- Model validation, in order to guarantee the reliability of models and, consequently, of policies;
- Immersive simulation using animation and visualisation techniques within the simulation environment;
- Output analysis and knowledge synthesis: This refers to output analysis of a policy model and, at the same time, to feedback analysis.

1.2 Contextual Background

Government action is increasingly put under pressure. European governments and the European Union (EU) as an institution are currently confronting major challenges such as financial, economic and spending crises, impending resource shortages, migratory pressures and climate change. At the same time, policymakers are required to be more inclusive and to co-create policy with stakeholders.

The current research was conducted at Stockholm University in the context of an EU research project entitled ‘Data Insights for Policymakers and Citizens: SENSE4US’, funded by the EU’s Seventh Framework Programme (FP7) for research, technological development and demonstration, running from October 2013 to January 2017. This research also received financial support from the Swedish Research Council, ‘Formas’, for participation in the
Young Scientists Summer Program at the International Institute for Applied Systems Analysis (IIASA), Austria, from June 1st to September 30th, 2016.

The European Commission’s (EC) ‘Better Regulation Guidelines’ set out the principles that the EC follows when preparing new initiatives and proposals and when managing and evaluating existing legislation. These guidelines apply to each phase of the law-making cycle, including planning, preparing proposals, implementation and transposition, monitoring, evaluation and fitness checks. The Better Regulation toolbox contains detailed advice on how to apply methods, models, costs and benefits (EC, 2015). Impact assessment (IA) is one of the smart regulation tools employed by the EC. Ex ante IA represents an attempt to provide, in advance of legislation, a coherent analysis of the reasoning that lies behind, and the foreseeable effects of, any proposed measure or policy initiative. The following questions need to be dealt with in a transparent manner and from an early stage in the process:
- What is the main purpose(s) of the policy?
- What is the context of the policy (influencing factors)?
- What are the relevant tools of intervention (policy instruments)?
- What are the relevant impacts that require further analysis?
- Who are the relevant stakeholders and the target groups that should be consulted?
- What are the appropriate methods for assessing the impacts and comparing the policy options?

According to the EC’s current internal rules, IAs should be prepared for a broad range of initiatives, including all legislative proposals appearing in the institution’s annual work programme, and other legislative and non-legislative initiatives, together with delegated acts or implemented measures that are likely to have significant impacts. The EC’s IA follows a standard format that starts by defining the problem in need of possible action, backing this up with evidence. The policy objective is then set, and different strategic options for achieving this elaborated, and an analysis is carried out of whether EU action is justified (subsidiarity) and whether it goes beyond what is necessary (proportionality). The IA should then analyse and weigh up, in a balanced and neutral way, the likely economic, social and environmental impacts of each option. Both quantitative and qualitative methodologies may be used for this purpose. In the light of the findings, a preferred course of action is usually identified, although this is not, strictly speaking, a requirement. Finally, the IA should consider future monitoring arrangements and the use of indicators to assess whether the action taken corresponds to what was intended (EPRS, 2015).

An international research roadmap entitled ‘ICT for Governance and Policy Modelling’ has been developed through two consecutive ‘support actions’ or
projects funded by the EC between 2010 and 2013: the CROSSROAD\textsuperscript{2} and CROSSOVER\textsuperscript{3} projects. Both projects adopted a demand-driven approach, rather than focusing on technology; the roadmap starts from the needs and activities of policymaking and then links the research challenges to these. The methodological approach involved: (i) identifying the state of the art in terms of policy modelling case studies, applications and projects; (ii) eliciting policy makers’ needs; (iii) identifying the research and technological gaps; and (iv) identifying the most promising approaches to address research issues. The results from these two projects revealed the relevance of the SD methodology to the policymaking and IA processes as it allows decision makers and stakeholders to share a common view (or mental model) of the problem under analysis (Stefano et al., 2014). An analysis of the deployed cases showed that there is a wide space for the uptake of modelling and simulation as key research methods and practices. Success in almost all cases related to policy assessment has been mainly due to the application of modelling techniques (Sonntagbauer et al., 2014; Boughzala et al., 2015).

SENSE4US offers a package of utilities involving techniques and software tools to support information gathering, analysis and policy modelling in real time. Integrating the benefits of both quantitative and qualitative data, these tools enable policymakers to find and select relevant information; link and homogenise data; discover and incorporate views from NGOs and the public; model policy in terms of drivers, constraints, actions and goals; simulate the societal impacts of a policy; evaluate policy options; and provide understandable visualisations. This endeavour concerns both sense-making and the building of trust, within the constraints of a participatory exercise. As part of this project, a web portal was developed that integrates three sets of tools developed in different research work packages, as follows:

(i) The ‘semantic search and consolidation of linked open data’ work package, which designs and develops models and services for capturing, analysing and integrating related but heterogeneous large datasets, using search queries based on the results of text analysis of policy-related documents (research partner: the University of Koblenz-Landau, Germany);

(ii) The ‘analysis models and tools’ work package, which develops analysis and prediction models to extract evidence and understand the dynamics and spread of polarised sentiments in policy discussions on social media, (e.g. those for and against a policy proposal). Therefore, we can gain insights into both the level of disagreement between different stakeholder groups and how

\textsuperscript{2} http://is.jrc.ec.europa.eu/pages/EAP/CROSSROAD.html
\textsuperscript{3} http://www.crossover-project.eu/
a policy could be refined for the mutual benefit of two or more stakeholder groups, (research partner: The Open University, United Kingdom) and (iii) The ‘decision support’ work package (research partner: Stockholm University, Sweden). The overall objective of this work package is to create ICT tools for policy specialists that can assist public decision processes through the structuring of policy decision situations and the simulation of policy consequences and possible future scenarios for risk assessment and policy decision evaluation. The results from other research work packages provide necessary information to understand the criteria on which a policy proposal should be evaluated, and to gain insights into public opinion regarding the policy impacts related to these criteria.

The ‘decision support’ work package involves two main areas of research and development:

- Research into systems science methods, soft systems methodology, simulation and gaming, to define an integrated approach in line with policy IA frameworks;
- Multi-criteria decision analysis (MCDA), stakeholder analysis and negotiation analysis, taking into account the typical features of a policy decision process, including many potential stakeholder groups and multiple policy actors (decision makers) with differing preferences and a portfolio representation of policy options. In a comparison of competing policy options, the appraisal of a policy is based upon the results of a simulation and a criteria model that encompasses different viewpoints and perspectives, multiple objectives, and multiple stakeholders.

An ‘integration of proof of concept’ work package is used to develop a demonstration system infrastructure that integrates the components developed by the research partners in the project as a publicly available prototype toolbox for use by the target audience (research partner: IT Innovation Centre, University of Southampton, UK.).

A ‘requirements, feedback and evaluation’ work package is used to engage with policymakers and the target audience, in order to understand their requirements in relation to the data and sources used to inform policy. In addition, the ways in which policy modelling, simulation and decision analysis might fit into the current policymaking process are examined while incorporating feedback into future iterations of the prototype, and defining scenarios and policy issues that can be used to drive and evaluate the accuracy and usefulness of the final prototype for the target end-user group. This work package involves three end-user partners who work with policy makers at the different institutional levels of the EU (local level, national level and EU level):

- GESIS, (the Leibniz Institute for Social Sciences, https://www.gesis.org/home/) has a focus that includes both national and local levels, and has active contact with many political stakeholders. For
example, at the national level, its contacts include members of parliament (MPs) and employees from the German Bundestag; at the state level, contacts include the State Parliament of North Rhine-Westphalia; and at the local parliamentary decision-making level, contacts include representatives of the cities of Cologne and Kempten;
- HanSoc (Hansard Society, https://www.hansardso ciety.org.uk/) has a UK-based national focus and engages with MPs, civil servants, committee clerks and parliamentary officials;
- Gov2U (legislative ICT and community activism, http://www.gov2u.org/) has an EU level focus and engages with members of the European Parliament (EP) and their staff (assistants), EP officials from selected committees and EC officials (policy officers).

The ultimate objective of the SENSE4US project is to advance data analytics, policy modelling and simulation, providing economic and social benefits at all governmental levels across Europe. Through close interaction with policy makers around Europe, the project will validate results in complex policymaking settings, and direct research towards support for policy creation that is more timely, more effective and better understood. The strategy of the project involves the implementation of technical components that are frequently used to discuss ICT-related challenges, benefits and risks with stakeholders within the EU political sphere.

1.3 Research Problem and Research Questions

The decision-making process was defined by Simon (1965) as comprising three steps: intelligence, design, and choice. At the intelligence stage, group members exchange relevant information. The design stage involves the development of potential options or decision alternatives, while choice involves the process of selecting the option that is identified as being the best (Simon, 1965). Simon (1988) distinguishes between two types of rationality in decision making: substantive rationality (what to choose) and procedural rationality (how to choose). Any type of policy planning will, in theory, lead to a satisfactory solution in the best case (March, 1988); this is a solution path that is acceptable to rather than optimal for almost all of the parties concerned. From an application perspective, support for policy planning lies in the area of procedural rather than substantive rationality. The practical application of prescriptive decision theory (how people ought to make decisions) aims to find methodologies, tools and software to help people make better decisions. The most systematic and comprehensive software tools developed in this way are called decision support systems (DSS).
Policy specialists lack the resources and the methodology to elicit, integrate and process relevant information and the most current data from various sources in order to support informed policy decisions. In view of the complexity and uncertainty of policy outcomes, policy researchers, analysts and decision makers need to develop policy models, collect data to validate these models and simulate scenarios to explore the implications of the various possible assumptions and alternative actions. There is a lack of decision support tools that can provide operational approaches and/or formal methods of facilitating the cognitive activity of structuring public policy decision situations, designing policy options or alternative actions to be taken, and evaluating alternatives leading to a policy decision.

Despite the availability of powerful computer modelling and simulation tools used by domain specialists, operations research and management science researchers, these tools are time-consuming, not user-friendly for decision makers and frequently result in models that fit the modeller’s conception of the problem rather than the decision maker’s (Mason and Mitroff, 1981). There is a need to develop robust, intuitive decision support tools that provide an environment for model-based collaborative governance. These tools should enable multiple policy actors to:
- Build and share a mental model of the problem under analysis;
- Design policy options, each structured as a particular combination of various types of policy instruments, and assess the likely impacts of a policy option in terms of the economic, financial, social, environmental and other impacts;
- Compare competing policy options, taking into account the preferences of policymakers and stakeholder groups.

The main rationale is to support a more rational and structured policymaking process through the development of a DSS that integrates:
1. ICT tools for modelling policy scenarios and simulating alternative policy consequences and possible future scenarios. This requires the definition of standards and a procedure for policy modelling and model analysis. These tools will visualise and demonstrate to policymakers the likely results of their decisions on certain issues in terms of societal impacts;
2. ICT tools for evaluating decisions on policy options, taking into account the existence of multiple objectives and multiple stakeholder groups with differing preferences. The evaluation of policy options requires the design of criteria models and data formats and also of a preference elicitation method. The results of IA (scenario simulation results) serve as a basis for weight elicitation, following a prescriptive decision analysis process.

The overarching research question for this work is as follows:

_How to support EU policy decision-making processes at the different institutional levels, using ICT tools for problem analysis, impact assessment, and evaluation activities related to policy formulation?_
In view of the centrality of this research question, it was iteratively reviewed as the exploratory research unfolded. It was divided into three more specific research questions (RQ1 to RQ3) for granularity and clarity, as follows:

**RQ1: How to support the structuring of public policy problems, design of policy options and impact assessment using ICT tools?**

Since policies are designed to address particular societal problems, the relevant problem must be kept in mind as the foundation of any policy analysis. Problem definition or structuring is therefore a key element of the policy analysis process. From a cognitive point of view, the structuring of public policy problems is complex, and a method for handling the complexity of such ‘macro problems’ must be applied, according to Duke and Geurts (2004). Simulation and visualisation techniques can help policymakers to reduce the uncertainties associated with the possible impacts of policies and to anticipate unexpected policy outcomes.

**RQ2: How to support a multi-criteria evaluation of policy options, based on impact assessment results and taking into account the preferences of policy makers and stakeholders using ICT tools?**

While simulations allow policymakers to identify feasible policy options and estimate their impacts over time, they do not provide an explicit evaluation of these options. An in-depth performance evaluation of policy options is needed in which multiple objectives, multiple stakeholder groups with differing preferences and the views of citizens are taken into account.

**RQ3: How fit for use are these decision support tools in problem analysis, impact assessment, and evaluation activities related to policy formulation?**

This requires an evaluation of the utility of the proposed decision support approach to policy formulation (pre-implementation analysis) in terms of the usability of the underlying tools. The evaluation process should clarify how well the proposed DSS supports a solution to the problem, how well it supports the utilisation of evidence information and the extent to which the outcomes are useful in terms of output analysis and knowledge synthesis. Tests and evaluation cases should involve use cases of real policy problems at the different EU policymaking levels: the EU, national and local levels. The evaluation of design research should be conducted using established theories and guidelines in an artificial setting.

An understanding of the key research challenges is required. One of the primary challenges is the necessary level of knowledge about the policymaking mechanisms, actual processes and context at each of the different institutional levels of the EU. In order to develop an integrated approach to computational policy analysis, an assessment of existing methodologies and case studies is required. Further, it is important to identify
relevant and trusted data sources and consider policymakers and stakeholders’ preferences.

In general, the key challenges involved in the wide-scale adoption of advanced modelling and simulation techniques and modern decision analytics in a policy context involve the challenges and limitations of cumulative learning in digital environments, the interaction of domain expertise with digital processing technologies, and dealing with imperfect/uncertain data.

1.4 Research Justification

Based on an understanding of the research problem, questions and challenges described in the previous section, this section justifies the need for the current research and provides an overview of its expected contributions to both research and practice.

1.4.1 Contributions to Research

The policymaking literature shows that there is a lack of research into public policy that involves the quantitative, empirical testing of models (Klodnicki, 2003). The systems thinking approach addresses the central problem of empirical study in this area. A systems approach to policy analysis allows for the better operationalisation of research evidence, supporting decision making for complex problems and offering a foundation for strengthening the relationships between policymakers, stakeholders, and researchers. The proposed systems methodology for policy analysis aims to enable policy actors across multiple governmental institutions to organise system-wide intelligence regarding a particular policy problem and to reach an understanding of how best to achieve specific policy goals.

This research provides a theoretical point of departure for model-based decision support within policy analysis. The proposed approach supports the analysis of both the qualitative and quantitative data that are available on the policy issue, thus facilitating the modelling process. This research contributes to the existing knowledge of the use of problem structuring methods (PSMs) to model complex strategic decision-making problems, using causal maps for knowledge representation and systems analysis and integrating these maps with modern methods of decision evaluation.

A literature review of OR methods and model-based decision support techniques for policy analysis (as presented in Chapter 2) revealed a number of research gaps in relation to the concepts and applications of modelling and simulation techniques. It highlights a need for the following aspects:

(i) Procedures for collecting and analysing qualitative data to support the modelling process;
(ii) Research and practice involving how to apply PSMs in combination with a systems thinking approach or other formal and/or quantitative methods, e.g., MCDA;

(iii) Formal methods for addressing the cognitive activity of generating and designing decision alternatives; and

(iv) Further research into how scenarios are constructed and how to address issues of robustness in scenario planning.

We believe that analytical methodologies for both public policy development and strategic analysis for organisational strategy play a minor role in the existing research on DSS. There is a lack of decision support tools for public policy analysis and integrated IA that can provide policy-oriented modelling, simulation and decision analysis capabilities.

The research presented here addresses these research gaps and contributes to existing knowledge of policy modelling, simulation and decision analysis through the design and implementation of a systems approach to policy analysis that aims to support:

(i) Evidence-based policymaking, by bringing facts and abstractions from scientific research and expert knowledge into the modelling process; and

(ii) Incorporation of the newest management technologies into public decision-making processes, including participation, cognitive strategic thinking, and scenario planning.

The use of this decision support approach in public policy analysis will improve policy modelling and simulation, create an important body of knowledge (by defining public problems in a structured form) and result in the development of participative, transparent and forward-looking decision support tools for public policymaking.

1.4.2 Contributions to Practice

The proposed DSS is a complex sociological structure that models human cognition and knowledge of public problems by clarifying, testing and reassessing assumptions about the web of cause-effect relationships underlying the problem situation. Once developed, the policy model becomes the explicit foundation upon which the particular problem is defined and through which policy options can be appraised. Causal mapping is an abstraction of problems as deviations from goals or standards, those deviations originate in a change that propagates itself through causal connections, while a policy intervention is seen as a purposeful and goal-oriented action for change that can resolve these deviations in order to achieve policy objectives. In addition, analysis of the transfer of change throughout a policy system, allows to tackle the system analytically and results can be used to assess the effectiveness and efficiency of alternative scenarios of change in achieving
objectives. A policy model can be integrated with numerous simplified decision models, for example optimisation models and decision trees, thus improving scenario generation and the design of policy options by taking into account the costs, benefits, resource constraints and risks associated with natural, socio-economic and technological systems.

The primary end-user target group includes policy specialists dealing with policy planning, implementation and evaluation (e.g. mayors, executive officers, heads of administration, elected representatives, civil servants, and policy advisors, policy analysts and researchers). In addition to policymakers operating within governmental departments and parliaments, the involvement of the research community can offer multiplication effects on policymaking at all institutional levels.

Systems modelling and simulation tools can allow a group of users to build and share mental models, make and test assumptions, and try out different scenarios. These tools therefore have the potential to provide a formal channel for ongoing communication or information translation between researchers and policymakers, through policy models. The translation of the mental models of policy actors into explicit models can provide useful input for specialised scientific models, and can be iteratively updated to incorporate additional or changing evidence over time.

A secondary, broader target group includes all stakeholders who can benefit from improved decision making, facilitated dialogue and interaction with policymakers, and ultimately, the enhanced relevance of policymaking to their needs.

1.5 Methodology

Design science research (DSR) (Hevner et al., 2004; Carlsson, 2006; Vahidov, 2006) is chosen here as an overall methodological framework for the thesis. Design research complements the positivist and interpretative perspectives in analysing the use and performance of designed artefacts. Design research permeates several research disciplines; it has origins in engineering, computer science and management, and employs a variety of methods and techniques.

In the book *The Sciences of the Artificial*, first published in 1969, Simon (1996) describes the knowledge underlying the construction of artefacts with the status of theory. According to Simon (1996), design theory is concerned with how things ought to be in order to attain certain goals; although the final goals of a design activity may not be explicitly realised, the designer can usefully proceed with a search guided by ‘interestingness’. The design process is generally concerned with finding a satisfactory design, rather than an optimum design (Simon, 1996).
Research in the field of information systems (IS) investigates the phenomena that emerge when a technological system and a social system interact (Gregor and Jones, 2007). DSR has been an important paradigm of IS research since the inception of the field, and its general acceptance as a legitimate approach to IS research is increasing. IS artefacts have a certain degree of abstraction, but can be readily converted to a material existence; for example, a method can be implemented as operational software. Within IS, DSR involves the construction of a wide range of socio-technical artefacts, such as decision support systems, modelling tools, governance strategies, methods for IS evaluation, and IS interventions for change (Hevner and Chatterjee, 2010; Vaishnavi and Kuechler, 2015).

DSR is a problem-solving paradigm that addresses what are called ‘wicked problems’. These problems are characterised as follows: (i) a definitive formulation of the problem does not exist, and there are unstable requirements and constraints; (ii) complex interactions take place between the problem and solution domains; (iii) there is an inherent flexibility allowing change in design processes and artefacts; and (iv) the solution is critically dependent upon human cognitive ability and human social abilities (Hevner et al., 2004). Public policy decision making is an example of a wicked problem. Policy decision situations are characterised by disputed knowledge, values, motivations, norms and world views. Formulation of the problem requires identification and representation of the drivers, barriers, instruments and consequences of change, the public concerns, needs and sentiments. It is dependent on the level of information provision and access to data and involves many interdependent stakeholder groups who have differing ideas, interests and preferences. Complex interactions, therefore, arise between the problem and solution domains. Various policy analysis and IA procedures exist within the different levels of EU policymaking and policy areas. Several methods can be used to solve the problem, and each of these choices lends itself to a different design process and artefact. Therefore, there is an inherent flexibility allowing change to the design processes and artefacts. Furthermore, policy actions involve biases in terms of choices (bounded rationality) and aim to influence behaviours and win political support, preventing decision makers from performing adequately in such dynamic decision-making environments. The solution is critically dependent on the prioritisation of interventions, promoting behaviours and stimulation of realistic change.

Constructive research approaches emphasise the central role of an artefact, which is seen as a vital part of the process and possibly the sole, or chief, output of the research. The construction of an artefact that is sufficiently novel is seen as a significant contribution in its own right. This view stands in contrast to the IS design theory approach of Walls et al. (1992), where an
artefact is constructed as a “test” of the design theory (Van Aken, 2004, p. 226). Even within the DSR paradigm, several differences of opinion have emerged regarding the research contribution. One example of this is its bifurcation into a design theory camp (Gregor and Jones, 2007; Markus et al., 2002; Walls et al., 1992) and a pragmatic design camp (Hevner et al., 2004; March and Smith, 1995; Nunamaker et al., 1990), with the two camps placing more emphasis on design theory or artefacts, respectively, as research contributions. Gregor and Hevner (2013) have claimed that the apparent inconsistencies between the two camps can be reconciled by recognising the importance of contributions made both in the form of viable artefacts and at more abstract levels. These authors demonstrate that the construction of an artefact and its description in terms of design principles and technological rules are steps in the process of developing more comprehensive bodies of knowledge or design theories (Gregor and Hevner, 2013).

1.6 Scope, Delimitations and Key Assumptions

The current research is limited in terms of geographical location, time and the assessment models used. The proposed decision support approach considered specific activities of the policy formulation stage of the policymaking process.

We acknowledge critiques of the position that policy formulation is a totally rational process that objectively evaluates alternatives and chooses on the basis of a set of criteria. These critiques include:

‘Bounded rationality’: the idea that there is never sufficient information about all the available options, and even if there were, the information processing capacity of humans is so limited (in a rational sense) that the best that can be hoped for is approximate judgements founded on limited information;

‘Incrementalism’: the idea that policy legacies, ‘path-dependence’ and pluralistic politics mean that policy choices are in practice restricted to a few variations on existing themes; and

‘Public choice’: the idea that individuals such as voters, politicians and bureaucrats act as ‘rational utility maximisers’, so that actual policies emerge from a complex system of bargains and negotiations rather than from rational analysis.

The acknowledgement of certain assumptions and their influence on the choice of methods is a form of conceptual awareness (Yanchar and Williams, 2006). The selection of research strategies and methods for this study was based on several assumptions about the policymaking process; one such assumption is that this is a planning process demonstrating compliance with EU policies and international obligations. As a political phenomenon, it reveals examples of power, coalition building, negotiations, and trade-offs,
while as a social experience, it is important to understand the communication, collaboration and understanding that are constructed during the process.

Due to the temporal constraints of the research study, only two evaluation cases were performed in collaboration with policy researchers and systems analysts. The policy use cases considered here were limited to EU policy problems at the different institutional levels. The inclusion of more cases from real environments would require more time to engage more process stakeholders in evaluating the artefact.

1.7 Thesis Outline

This thesis is structured based on the DSR publication schema proposed by Gregor and Hevner (2013) and contains seven chapters. Chapter 1 has introduced the thesis by presenting the research background, the state of the art, motivations, contexts and objectives, and has provided a justification for the research, a statement of the research problem and research questions, an overview of the research methodology and the delimitations of the scope of the research. Chapter 2 presents a literature review of the policymaking process, model-based decision support, OR methods for policy analysis, systems science methods and MCDA. Chapter 3 describes the DSR methodology used in this research. The research philosophy, research design and research methods are described in detail, along with the ethical issues considered in this research. Chapter 4 presents the artefact design, development and demonstration, through discussing requirements, the proposed decision support framework, adopted policy modelling approach and implementation into DSS tools. Chapter 5 provides the evaluation of the artefact. Chapter 6 presents a discussion of the research findings and the ways in which this research addressed the research problem and lists the author’s contributions. Finally, in Chapter 7, the research contributions and directions for future research are presented.

Appendix I provides the current technical specifications of the Sense4us policy modelling and simulation tool web-based prototype.
2 Literature Review

The objective of a literature review is to build a theoretical foundation by reviewing the current literature to justify the research problem. It also ensures that the design process is not only motivated by the need for a solution to the problem but is grounded on the theoretical shortcomings and research gaps in this class of problems.

In order to develop a comprehensive decision support framework for public policymaking, we need to gain a better understanding of the “how” of the process and the key influencing factors. The current research is guided by a literature review of the public policymaking process, strategic theory, OR methods, model-based decision support techniques and systems science methods, which reveals a number of research gaps or research problems in relation to the concepts and applications of modelling, simulation and multi-criteria evaluation techniques for public policy analysis. In addition, presentations and group discussions by Sense4us end-user partners in meetings and facilitated workshops allowed the research team to gain an understanding of the policymaking mechanisms, actual processes and context at the different institutional levels of the EU.

We executed a review of the primary studies surrounding policymaking, policy analysis and IA processes, strategic theory, electronic governance, electronic participation, policy modelling, systems analysis, OR methods, PSMs, complexity, simulation, visualisation, decision analysis and game theoretic analysis, using a general search of online databases and search engines. We also executed specific searches of other policy-related government, research and industry websites and blogs within the scope of the EU policymaking process and IA use cases.

The aim of this preliminary investigation was to determine the primary functional requirements for a DSS for policy formulation that integrates both human and software systems for decision modelling and analysis.

Section 2.1 reviews the major frameworks for the study of public policymaking and introduces the conceptual process model for policymaking adopted in this research. Section 2.2 provides an overview of DSS technologies and presents the proposed DSS structure. Section 2.3 discusses model-based decision support for policy and reflects on the limitations of models for policy analysis and how to use these models. Sections 2.4 and 2.5 present a review of OR methods, PSMs and systems science methods for
strategic decision-making situations and identifies research gaps and opportunities. Section 2.6 discusses the multi-criteria evaluation of policy options, the application of MCDA and its integration with problem structuring approaches.

2.1 The Policymaking Process

The first framework for the study of public policymaking, the ‘rational-comprehensive behaviouralist’ framework, sought the most logical, rational, and optimal choice for solving a problem from an unlimited set of solutions. The rational-comprehensive framework defines the actors as those involved in the decision-making process. This includes the policymakers, the stakeholders, the policy scientist/analyst, and the general public. However, the primary actor is the decision maker. The framework defines the primary variables as the problems facing the decision maker, the entire realm of solutions (which were left unbounded) and their environment. The unit of analysis is defined as the arena in which decision making occurs and the level of analysis as the outcome of the decision maker, who it was assumed used a rational decision-making process and was therefore predictable (Dye, 1972; Easton, 1965; Lasswell, 1951). The scope was also unbounded, which led to later developments that specifically addressed the scope.

Another framework, the case study, sought to add a more realistic and human component to the decision-making process, which some early policy scientists thought the rational-comprehensive behaviouralist framework lacked. It sought to explain the public policymaking process in broader and more general terms, since the process itself was not actually rational; the process of public policymaking did not always select the optimal solution, nor did it consider the full range of options for solutions. The case study maintained the same definitions of actors, variables, units and levels of analysis as the rational-comprehensive behaviouralist framework, but had a different definition of scope, which was limited to the actors immediately involved in the research, or the variables of interest (Gall et al., 1996; Majchrzak, 1984).

Another early and persistent heuristic for the study of public policymaking was Lindblom’s counter to the rational-comprehensive behaviouralist framework known as ‘bounded rationality’ or incrementalism. Lindblom offered incrementalism as a decision-making model in which policy change occurs through incremental decisions rather than through a rational system. The treatment of the model derived from Lindblom’s framework is then described as an adherent to the systems approach of policy analysis. The two
core tenets are: (i) that policymakers and decision makers disagree on values and policy objectives; and (ii) the difficulty of gathering and processing sufficient information to make “limited comparisons” (Lindblom, 1968).

Kingdon (1995) examined two major pre-decision processes: agenda setting and alternative selection. Kingdon relied on the earlier work of Cohen, March, and Olsen and their development of the ‘garbage can’ model to establish his idea of ‘multiple streams’. The garbage can model describes the decision-making process in organised anarchies, with three elements or streams: problems, solutions, and participants (Cohen et al., 1972, p. 16). Kingdon simplifies the public policymaking process to include (i) the setting of the agenda; (ii) the specification of alternatives; (iii) an authoritative choice from these specified alternatives; and (iv) an implementation of the decision. Kingdon’s concept of multiple streams, like the garbage can model, describes three separate streams (problems, politics, and policy) as flowing separately; when coupled in a policy window, these form policy agendas and alternatives for selection. The first two streams (problems and politics) involve agenda setting, while the last stream (policy) involves alternative selections (Kingdon, 1995).

Easton (1965) presented the public policymaking process as continuous, fully integrated, bounded, open, and with an organic life cycle, when addressing the variety of activities within that life cycle. Easton’s systems approach provided a method for examining the complex public policymaking life cycle in the fullness of its complexity (the role of the framework) and within the confines of its unique components (the role of the model). The systems approach argues that public policy is the product of a system, and that the system is a compilation of both intra-societal and extra-societal components and actors within an environment. This compilation of components and actors, together with the interjected demands, forms an input to the political system (decision-making processes), which in turn generates outputs (public policy). The effectiveness of the outputs, as measured by feedback, forms new inputs that are acted upon by the system (Easton, 1965). In order to assess the impacts on the system of a policy or an environmental change, we need to reduce the enormous range of influences to relatively few, and a manageable number of indicators, using a model. Several vital considerations are implicit in this interpretation, and it is essential that we become aware of them: (i) such a framework assumes that political interactions in a society constitute a system; (ii) the system must be seen as being surrounded by physical, biological, social, and psychological

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4 An organized anarchy is an organisation which does not meet the conditions for more classical models of decision making.

5 The policy window is an opportunity for advocates of proposals to promote their preferred solutions, or to call attention to ‘special problems’ (i.e. opportunities for action) (Kingdon, 1995, p. 165).
environments; (iii) what makes the identification of the environments useful and necessary is the further presupposition that political life forms an open system; and (iv) systems must have the capacity to respond to disturbances and thereby to adapt to the conditions under which they find themselves (Easton, 1965, 17-18).

Anderson (1975) conceptualised policy-making as a series of events occurring in distinct stages, and labelled these stages ‘categories’. This sequential approach helps to capture the flow of action in the policy process and defines a dynamic rather than a static system, which is highly flexible and open to change. Anderson does not ignore the dynamics of human interaction in the policymaking process; these stages allow the analyst to narrow the focus of study to a particular step in the process. Anderson’s framework is not culture-bounded, and can be utilised for policy analysis in different policymaking systems. The five categories are: (i) problem identification and agenda formation; (ii) policy formulation; (iii) policy implementation; (iv) policy adoption; and (v) policy evaluation. Anderson’s stages provide a grounding for a scientific and relevant approach to the study of the public policymaking process (Anderson, 1975, p. 9).

We can highlight two main types of policy analysis that are carried out within the policymaking life cycle:

1- Prospective and prescriptive analysis: This involves ex ante IAs and evaluations, carried out at early stages of policy development in order to answer forward-looking questions related to policy consequences, and to provide prescriptions for policy proposals under consideration. Within this activity, scientific knowledge is a central variable influencing the shaping of ideas, and this is particularly applicable in complex policy problems that involve a high level of (scientific) uncertainty.

2- Retrospective analysis: This involves ex post evaluations used in the assessment and performance measurement of policies and programmes that are already in place.

In order to position our decision support approach within the policy life cycle, we introduce a process model for policymaking that is based on Anderson’s heuristic of policymaking stages. The process model defines the following stages and underlying activities:

1- The problem identification stage:

(i) Recognition and diagnosis: Recognition is the process through which decision makers become aware of the fact that there is a problem, and a diagnosis is required to order and combine the information related to that problem.
Agenda setting: This involves focusing attention, involving interest groups, setting targets, defining and documenting the long view and/or the short view of the policy.

2- The policy formulation stage: (Focus of the DSS)
Policy formulation is the process of standardising or rating the proposed policy as a viable, practical, relevant solution to the identified problem. The drafting of legislation is usually considered the second activity of policy formulation but is outside the scope of this research. Policy formulation for complex problems can be factored into a set of related design sub-problems, each with a ‘champion’ or ‘most interested party’. The policy formulation stage includes the following activities:

(i) Problem analysis: This involves creation of a policy coordination structure, identifying the elements of a policy problem (e.g., actors, variables, goals, stakeholders), risks, technologies and associated limitations, decision dynamics of interrupts, feedback loops, delays, and speedups, and the problem environment characterised by conflicting goals, inter- and intra-group negotiations.

(ii) Design of policy options: This involves formulating policy proposals through political channels by policy-planning organisations, interest groups and government bureaucracies; and identifying the feasible options that will or may lead to desired policy consequences through IAs.

(iii) Multi-criteria evaluation of policy options: This involves comparing policy options in order to gain insights into which options should be preferred. This can be achieved by defining evaluation criteria, eliciting preferences, since conflicting goals and differing acceptance levels are likely to exist for different stakeholders, and framing the elicited preferences to allow the use of MCDA methods.

(iv) Policy decision: Decide upon policy after evaluation of the options, encompassing different viewpoints and perspectives, multiple objectives, and multiple stakeholders using integrated assessments.

3- The policy implementation stage:
This combines policy adoption with the implementation and evaluation of Anderson’s model.

(i) Legitimising and implementing a public policy: The policy is legitimised as a result of public statements or actions of government officials, including executive orders, rules, regulations, laws, budgets, appropriations, decisions and interpretations that have the effect of establishing the policy direction. Policy is implemented through the activities of public bureaucracies and the expenditure of public funds.

(ii) Monitoring and evaluation: Recording and control of the implementation; analysis, evaluation and feedback of the results of implementation.
2.2 DSS Technologies

DSSs symbolise a specific class of information systems, designed to help users who rely on knowledge across a range of decision-making positions to solve the encountered problems. An important point in the definition of most common DSSs is that they are applications that are designed to support rather than replace decision makers. Recent analysis of decision support and expert systems has shifted from considering them as solely analytical tools for assessing the best decision options to seeing them as a more comprehensive environment for supporting efficient information processing, based on a superior understanding of the problem context (Gupta et al., 2007).

DSSs (i) cover a wide spectrum of combinations of methodological tools or ideas; (ii) allow a decision maker to translate a subjective world view into explicit models; and (iii) support the values of rationalism, intuition and participation. State-of-the-art research into decision support for socio-economic areas includes (van Leeuwen and Timmermans, 2004):

- E-management models that incorporate reliable participatory practices and quality indicators;
- The implementation of digital media to allow well-informed collaborative decision making;
- Platforms that support the integration of various data sources; and
- Online planning support systems.

Group decision support systems (GDSS) are meant to support several participants with similar power-positions who have to interact and collaborate at certain time moments to make co-decisions. End users may pursue a common goal (group decision making), or may be in a competition and even in conflict (negotiation that leads to collaborative decisions that are acceptable for all parties) (Klingour and Eden, 2010; Gray et al., 2011; Zaraté, 2013). The specifics of GDSS are highlighted in special literature in terms of support for both the decision process and the content of the problem (Wibowo and Deng, 2013; e Costa et al., 2014).

DSSs described in the literature as ‘intelligent’ systems aim to provide recommendations, problem solving, and analysis rather than data (Turban et al., 2007). Categories of these systems include recommender systems (Wang and Wu, 2009; Chen et al., 2011), advisory systems (Lee et al., 2008) and expert systems (Kidd, 2012; Zagonari and Rossi, 2013). Expert systems are used to solve problems in well defined, narrowly focused problem domains, whereas advisory systems are designed to support decision making in more unstructured situations which have no single correct answer (Beemer and Gregg 2008).
There have been various scientific examinations and DSS developments on text analytics and mining based DSS (Khare and Chougule, 2012; Gerber, 2014); use of knowledge discovery and data mining to create data backbones for DSS (Renu et al., 2013); Artificial Neural Networks based DSS (Tsadiras et al., 2013); intelligent agent-assisted DSS (Dong and Srinivasan, 2013); adaptive biometrics based DSS (Pagano et al., 2014); ambient intelligence and the Internet-of-things based DSS (Dunkel et al., 2011; Fricoteaux et al., 2014); sensory DSS and robotic DSS (Heikkilä et al., 2014).

According to Turban et al. (2007), a conventional DSS with the purpose of delivering intelligence information consists of three subsystems: data management, model management, and a user interface. The DSS is configured with four subsystems:

(i) Dialog generation and management system (DGMS);
(ii) Database management system (DBMS);
(iii) Model base management system (MBMS); and
(iv) Knowledge base management system (KBMS).

A significant component of the DSS is the user (and his/her tasks), who is usually understood as a decision-maker or an analyst who analyses the situation and draws certain conclusions (Turban et al., 2007). Figure 1 illustrates the structure of the proposed DSS. The above components (DGMS, DBMS, MBMS, and KBMS) constitute the software aspect of the DSS. The DGMS supports dialogue between the user and the other components of the DSS, while the DBMS allows the linking of data from different sources to a database. The primary functions of the MBMS are the creation, storage and update of models that enable the problem solving inside the DSS. The KBMS provides the necessary execution and integration of the other subsystems.

The model base of the DSS integrates various quantitative models, which enables the DSS to support decision making for public policy formulation (design). The DSS database contains both qualitative and quantitative data (e.g. problem formulations, model descriptions, data formats for parameters and variables, scenario simulation results and multi-criteria models). The DSS knowledge base contains formal ontologies of the different policy domains, definitions of the roles, relationships and interactions among participants (analysts, experts, decision makers and representatives of stakeholder groups), questionnaires, future scenarios and meta-knowledge (justification and explanation). This structure allows users to interact with the databases, quantitative decision models, qualitative knowledge and other users within the DSS.
2.3 Model-Based Decision Support for Policy

“Mathematical models are a more deliberate act of representing the problem we are concerned with in a scientific form” (Winz et al., 2009).

Dye (1972) discussed the role of the model in describing, simplifying, clarifying, identifying, communicating, directly inquiring, and providing possible explanations for policy as an outcome of the policymaking process. A policy model should be operational; that is, it should refer to real-world phenomena that can be observed, measured, and verified. It should identify the most significant aspects of policy, focus upon the real causes and significant consequences, and direct attention away from irrelevant variables or circumstances. A model approach should be based on a sense of shared meaning (transparency and understanding), and finally, should suggest an explanation of policy. “It should suggest hypotheses about the causes and consequences of policy—hypotheses which can be tested against real world data” (Dye, 1972).

All models are simplifications, but good models provide insights and understanding if used correctly. This requires transparency in terms of understanding the strengths and limitations of a chosen modelling approach.
and how a model works. Communicating and understanding uncertainty in model outputs is also vital. Model validation processes and, where relevant, sensitivity analysis can ensure that decision makers receive this key information. Prediction requires a theoretical understanding of the phenomena to be predicted, as a basis for the prediction model, and reliable data about the initial conditions the starting point from which the extrapolation is to be made. Designing an acceptable future for the needs of a society requires the selection of a planning horizon, short-term (perhaps five years), middle-term (a generation) or long-term plans (a decade or two), and an examination of alternative target states for the system. Having chosen a desirable (or acceptable) target state, and having satisfied ourselves that its realisability is not unduly sensitive to unpredictable effects, we can then turn our attention to constructing paths that lead from the present to that desired future (Simon, 1990).

Various models are used in the EC, covering a wide range of different policy areas, including economic models, micro-simulation models, input-output models and systems modelling approaches. Integrated modelling approaches combine relevant models or modules, and the resultant model can be applied to assess impacts within several policy areas simultaneously. Population projections (EUROPOP), GDP projections and projections of energy, transport and GHG emissions are performed by several EC departments and executive agencies, and are published on the EU’s open data portal. Sustainable development indicators are used to monitor the EU’s Sustainable Development Strategy and are published by EuroStat.

In fact, it has been shown that classical IA methodologies are ineffective in terms of their inability to grasp the inherent nonlinear, dynamic and complex nature of public problems, as well as the difficulty in sharing the modelling assumptions with a wider audience of involved stakeholders (Stefano et al., 2014).

The use of cognitive or causal maps was among the early approaches to enabling problem understanding, and was originally intended for the representation of social science knowledge (see Axelrod, 1976). In general, such representations refer to “mechanisms whereby humans are able to generate descriptions of system purpose and form explanations of system functioning, observed system states, and predictions of future system states” (Rouse and Morris, 1986).

The use of cause and effect diagrams is highly valuable in capturing and explicitly representing the decision makers’ understanding and subjective view of a public policy problem; consequently, evaluation criteria for the decision options can be identified or derived from concepts of the causal

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7 http://ec.europa.eu/eurostat/web/sdi/indicators
The contribution of causal maps is a visual, mental imagery-based simulation of the system's behaviour, for use in system analysis and social communication. It is obvious that such maps can be useful in analysing, developing and sharing views and understanding among key actors, and in creating certain preconditions for intervention (Laukkanen and Wang, 2015).

There exist several software packages for processing causal data, and graphing and analysing cognitive maps; none of these, however, are dedicated to policy analysis and decision support for policymaking. For instance, CMAP3 provides a qualitative method for acquiring data from multiple actors or other sources (e.g. documents) in order to identify similarities and differences in notions and causal beliefs (Laukkanen and Wang, 2015). Decision-Explorer facilitates the management of large sets of interrelated qualitative data and the analysis of both the structure and the content of cognitive maps. It helps to clarify thinking and provides a focus for debate and reflection by building a visual representation of the ideas and perspectives surrounding an issue (Brightman, 2002).

Simulation of the complexities involved may allow the evaluation and observation of global behaviour and system dynamics that cannot be analytically predicted. Particularly in those situations where it is important to understand the interactions among the variables over time, the value added by causal maps can be significantly increased if they are complemented by simulation modelling (Senge, 1990; Sterman, 2000).

Arguments have been made that without support for the generation and design of policy options, interesting and sometimes important alternatives are omitted from the analysis (Arbel and Tong, 1982; Einhorn and Hogarth, 1981). The reasons for this include a narrowed view of the solutions in the early phase through the use of a solution-oriented rather than a problem-oriented approach in the decision-making process (Arbel and Tong, 1982). The choice of decision alternatives may be biased due to the cognitive ability of the decision maker (Einhorn and Hogarth, 1981). The alternatives considered may also be limited by complex trade-offs, contradictory objectives or by the influence of numerous stakeholders and the social interaction between them (Gregory and Keeney, 1994). Even though these aspects have been known in the decision support community for quite some time, Kelly et al. (2009) still argue that the option generation phase of the decision-making process has not received the level of attention it deserves; according to Comes et al. (2011), there exists no approach that systematically integrates support for problem modelling, policy option design and decision evaluation.

Most decision problems discussed in the literature consider the set of alternatives to which they apply as a given (Franco and Montibeller, 2011).
There is a lack of formal methods for facilitating the cognitive activity of designing policy options or alternative actions to be taken. In fact, most policymaking involves the design or construction of policy alternatives in a process that aims to support forward-looking thinking and the design of innovative policies.

An exploratory approach can contribute to an improved analysis of complex and uncertain policy problems by revealing the implications of our knowledge and assumptions, which may include unexpected impacts. The building and using of models of what is known and what is uncertain about a policy or governance system can reveal unanticipated implications of our knowledge and assumptions (Bankes, 1993). Here, the model serves as an inference engine showing where assumptions can lead. Unexpected outcomes expand the range of possible behaviours of the system considered in the analysis. The possible exploratory research strategies can provide a basis for decision making and a guide for information search, through: (i) searching for special/extremal cases; (ii) suggesting plausible explanations for puzzling facts (hypotheses generation); and (iii) developing worst case scenarios for risk aversion situations.

2.4 The Systems Thinking Approach

Policies must address the complexity of a situation in a holistic way, rather than propose solutions to single problems. Formulating and understanding the situation and its complex dynamics is therefore key in finding holistic solutions. This indicates a systems approach to policy analysis that is integrative, holistic, and inter-subjective.

Systems thinking advocates the treatment of a system as a whole, and as composed of related elements, while events can be viewed as a system and/or part of larger systems (Checkland, 1998). According to Hwang (2001), the idea behind considering the wholes and related elements as a single system is based on the perception of causality.

Stewart and Ayres (2001) have argued for the use of a systems approach in policymaking based on the following points: (i) the systems approach offers policymakers a fresh set of perspectives on the fundamentals of policy analysis; (ii) policy design is as much a matter of choosing structures and relationships as choosing instruments; and (iii) understanding causation means acknowledging two-way influences and the role of feedback. They introduced the terms ‘systems analysis of policy’ (understanding what is happening when policy is made) and ‘systems analysis for policy’ (generating concepts, ideas, and modes of action to make recommendations about policy problems) (Stewart and Ayres, 2001).
Saritas and Öner (2004) have discussed different dimensions of systemic thinking in foresight studies, using examples of British, Irish, and Turkish national foresight exercises. In one study (Öner and Saritas, 2005), they proposed an integrated development management model for the systems analysis of policy and systems analysis for policy.

Atkinson et al. (2015) have discussed the role of the systems approach in identifying where best to target public health action and resources for optimal impact, and have demonstrated the potential of systems tools to support evidence synthesis and knowledge translation for policy analysis. The potential utility of systems science methods lies in their ability to systematically and quantitatively analyse a range of interventions and policy options and to identify leverage points (places to intervene) in the system where small inputs might result in large impacts (Meadows, 1999).

System dynamics (SD) is a research method with strengths in terms of depicting the internal structure of complex closed-loop systems as stocks, flows and feedback loops (Richardson, 1981; Sterman, 2000). Causal relationships codify the main assumptions about the nature of such relationships through mathematical formulations, allowing researchers to better understand the likely effects of their assumptions. Experimentation with small conceptual models has been recognised as a valuable tool in the process of developing public management theories and policies; that is to say, simulation experiments can generate insights about effective policies and certain consequences that may not have been considered in the first place. In general, SD enables us to “experience the long-term side effects of decisions, speed learning, develop our understanding of complex systems, and design strategies for greater success” (Sterman, 2000).

SD simulation modelling has made significant contributions to policymaking (e.g. Forrester, 1992; Zagonel and Rohrbaugh, 2008). Moreover, SD has been successfully used to understand digital government phenomena (Black et al., 2003; Luna-Reyes and Gil-García, 2011), including the dynamics of open government (Scholl and Luna-Reyes, 2011). Several software packages exist for quantitative SD simulations, for system performance analysis and prediction in a strict sense. For instance, STELLA is a quantitative SD simulation tool that offers strong visualisation capabilities. It uses stock and flow diagrams, and is highly dependent on data and the definition of equations for the relationships between model variables (Richmond, 2004).

Consideration should also be given to agent-based modelling (ABM) (cf. Macal and North, 2010) as a methodology, due to its increasing importance in providing behavioural insights and understanding the dynamics and impacts.
of policy interventions on complex systems. Existing applications of ABM simulation policy analysis are single-purposed and fragmented.

Multiscale modelling combines SD modelling (which captures population level, ecological influences, and whole-system dynamics) and ABM (which is capable of capturing heterogeneous attributes, behaviours, and the interactions between individuals). It provides policymakers with a powerful analysis tool that is also capable of exploring the equity effects of policy scenarios (Atkinson et al., 2015).

These methods require a high level of technical competence and substantial programming expertise, and can result in models that are expensive to develop and maintain. The resulting simulation models are too often perceived as black boxes that are unintelligible to users. This is a particular challenge in public policy, where decisions need to be taken on the basis of transparent information; ABM is therefore not the only innovative approach adopted in the context of model-based decision support for policy (Stefano et al., 2014).

The combined use of qualitative and quantitative modelling enriches the policy analysis and can provide useful insight. However, there is an absence of an integrated set of procedures for collecting and analysing qualitative data to support the modelling process. This creates a gap between the problem and the resulting model. If an integrated set of procedures for qualitative analysis were to exist, the application of these procedures in one or more case studies could lead to specific recommendations for enriching the practice of system analysis through the development and testing of reliable formal protocols that can be replicated and generalised (Luna-Reyes and Andersen, 2003).

Sterman (2002) discussed the role of soft (unmeasured) variables in systems modelling. He argued that the omission of structures or variables that are known to be important because numerical data are unavailable is actually a less scientific and less accurate method than using one’s best judgment to estimate their values. Omission of such variables is a certain route to a narrowing of the model boundaries, biased results and policy resistance. Of course, we must evaluate the sensitivity of our results to uncertainty in terms of our assumptions, regardless of whether we estimated the parameters using a judgment or by statistical means. It is important to use proper statistical methods to estimate model parameters and to assess the ability of the model to replicate historical data when measurable indicators and numerical data are available (Sterman, 2002).

The long-term implications of policymaking imply a need to consider the range of possible futures, which is sometimes characterised by large uncertainties. Scenarios are a primary method of projection, and attempt to

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8 Qualitative data here refer to text-based information on the policy issue, which is either simply a recording of information from the mental database of policy decision-makers, stakeholders and domain experts, or concepts and abstractions that interpret scientific evidence and facts from other information sources.
show more than one version of the future. Scenario analysis is designed to improve decision making by allowing the consideration of future conditions or outcomes and their implications. “The analysis of scenarios of change allows the design of strategies to take place in spite of the messiness of the situation” (Schoemaker, 2002).

Scenario-driven planning is a widely employed methodology that helps decision makers devise strategic alternatives and think about possible futures. It closes the gap between problem framing, which depends on qualitative analysis, and problem solving, which depends on quantitative analysis, by blending qualitative and quantitative analytics into a unified methodology (Georgantzas and Acar, 1995). Further research is needed into how scenarios are constructed in policy planning and ways in which to address issues of robustness in scenario planning.

Games can be used to allow users to interact and experience what will happen in the future based on their interventions. A gaming simulation mimics the behaviour of a real-world system using (computerised) simulation models in which the role of a human decision maker is enacted by a real human participant (Duke and Geurts, 2004). Gaming simulations have three main uses: as a research tool for hypothesis testing; as a policymaking tool; and as an educational or training tool (Peters et al., 1998; Meijer, 2012).

Duke and Geurts (2004) have emphasised that gaming simulation techniques show considerable promise in improving the quality of decisions and provide an appropriate process for dealing with the increasing complexity of policy environments and the problems of communication within these environments. They can create policy exercises in which many different sources and types of data, insights and tacit knowledge can be integrated in a problem-specific knowledge household. Furthermore, these policy exercises provide an environment that allows the exploration of possible strategies for entering uncharted territory. These games offer a safe environment in which to test strategies in advance.

2.5 OR Methods

OR modelling aims to compute optimal or sufficiently good solutions based upon a mathematical representation of the problem, for which the user needs to define the objective (cost) functions to be minimised or maximised, a feasible region and the constraints on variables (see Winston and Goldberg (2004) for a comprehensive treatment). The limitations of traditional OR methods such as linear programming and goal programming include an
overreliance on quantitative data collection and the use of an expert mode of analysis (Franco and Montibeller, 2010).

Basic game theory, as stated by Von Neumann and Morgenstern (1944), involves the zero-sum game. Nash (1951), the Nobel Prize winning economist, theorised about this, proving that these games reach equilibrium; each player utilises a dominant strategy to reach their own ‘MaxiMin’ that is maximizing the minimum gain. He introduced the idea of the “Nash equilibrium”, a situation in a multiplayer game in which each player’s position is optimised with respect to those of the others. Most issues involve multiple players, and the payoffs are usually determined to some extent by the actions taken by the players. Non-zero-sum games assume that value is created. Von Neumann and Morgenstern (1944, p. 241) developed a characteristic function to simplify the representation in n+ person games and to handle coalition building. The characteristic function extracts the essence of the game (the core), that is, the factors or conditions germane to coalition forming.

Game theory is a method of decision making that ranks the relative utilities of the available courses of actions by quantifying the possible outcomes, enabling participants to choose an optimum course of action. Furthermore, game theory allows for a relative ranking of all the players involved, and the utility preferences for the possible outcomes can be defined for each player. An analysis of these utilities helps to predict which course of action each competitor is likely to choose, assuming that each player is rational and hence likely to choose the course of action providing the greatest utility.

Game theory has traditionally been developed as a theory of strategic interaction among players who are perfectly rational, and who (consequently) exhibit equilibrium behaviour (Roth and Erev, 1998, p. 1). Brandenburger and Nalebuff (1995) developed a useful tool for identifying the various courses of action available to leaders, using the acronym PARTS (players, added values, rules, tactics, and scope). Players, in a policy context, are the involved parties with strategic goals and interests. “Added values are what each player brings to the game” (Brandenburger and Nalebuff, 1995, p. 57). Value can be added through actions that lead to increased effectiveness, complementarities and the need to continue an action. Rules give structure to the game and define how it is played. These may arise from laws, customs, practicalities or contracts. Tactics are players’ moves or courses of action, logically paired with what other players might do. Sometimes, tactics are designed to reduce misperceptions; at other times, they aim to create or maintain uncertainty. Scope describes the boundaries of the game. It is possible for players to expand or shrink these boundaries.

Common tools for the assessment of the costs and benefits of potential public policies include net present value and cost-benefit analysis (CBA) (Munger, 2000). CBA remains the best-known method among practitioners for evaluating public policies, despite some recent criticisms (Ackerman and
Heinzerling, 2004; Adler and Posner, 2006; Dunn, 2012). This criticism focuses on how to properly monetise all costs and benefits and on the claims to objectivity that CBA approaches tend to make.

Problem situations involving public policy, organisational strategy and organisational change are often ill-structured, multi-actor decision problems with multiple, unclear and/or conflicting objectives. Since traditional OR methods generally ignore the typical complexities of multi-actor problem situations, they have serious limitations when dealing with these problems. In response, a variety of PSMs have been developed in recent decades. PSMs belong to the group of so-called ‘soft OR techniques’, and aim to help an actor or a group of actors confronted with an unstructured decision problem to come to a shared understanding of the problem situation or to decide on a joint course of action. Rosenhead and Mingers, (2001) give an overview of the characteristics of a wide range of PSMs, including strategic options development and analysis (SODA), soft systems methodology (SSM), strategic choice approach (SCA), robustness analysis, drama theory, the viable systems model (VSM) and decision conferencing. PSMs are widely acknowledged as part of the range of decision analytical tools, and there is a growing (although still small) body of research and practice on how to integrate such methods with other formal and/or quantitative methods (Tsoukias et al., 2013).

Van der Lei and Thissen (2009) described what constitutes a quantitative or qualitative PSM as a sliding scale in which game theory can be placed at the quantitative extreme. Softer methods such as SSM (Checkland, 1989) and SODA (e.g. Eden, 1995) can be placed on the qualitative side of the scale, with anthropological and ethnographic methods at its most extreme end. The authors analysed the different applications for a subset of PSMs that belong to the more quantitative group of PSMs for multi-actor situations, including metagames (conflict analysis), hypergames, drama theory, Q methodology and transactional analysis. Using a modelling perspective, this analysis addressed (Van der Lei and Thissen, 2009):

– The nature of the problem situation, categorised into three different types of problem: conflict, negotiation, and deadlock;
– The approach and way of working in the modelling process, which can be either intervention (where the analyst facilitates the decision makers in the form of a workshop, and thus the primary information comes directly from the actors) or desk research (where the analyst primarily learns about the decision environment and then communicates the results of the study, i.e. the information typically comes from publicly available reports, sometimes supplemented with interviews);
The results of the PSM application, categorised into two types of purpose: a descriptive purpose (framing a decision problem and explaining the situation) and a normative purpose (finding prescriptive solutions to a decision problem). This boundary may be vague, since all models used to design solutions have a descriptive aspect;

- Justification for choosing a particular method. Hypergames, for example, are described as providing more conceptual complexity because of the different perspectives they can deal with (Bennett et al., 1980). The most common reason for applying the PSM is that it allows for a method of modelling that has not been done previously or which deviates from current practice. Metagames are, for example, frequently contrasted with game theory as offering a more tractable approach. The application of a PSM in a new way or testing of a PSM are reasons that are often mentioned for applying the PSM;

- Validation of results. This refers to what has been done to judge the relevance of the model and its results for the real-world situation. Researchers mostly refer to real-life events or input data when validating desk research. An intervention is validated by looking at the sense of ownership/responses of participants in the intervention.

Döll et al. (2013) introduced ‘semi-quantitative actor-based modelling’ as a tool for integrated assessments that aim to support sustainable natural resources management. This approach aims to support the identification of sustainable development options in problem fields with high levels of uncertainty. It simulates the behaviour of societal actors who also participate in model development within a participatory process. Actor-based modelling is carried out using an enhanced version of Dynamic Actor Network Analysis (DANA)$^9$ software. In addition to actor modelling, DANA also supports the modelling of actions and factors.

- Actor modelling refers to the representation of the subjective perspectives of actors with regard to a problem, using semi-quantitative causal networks, also known as perception graphs.
- The modelling of actions involves inferring the actions these actors will take in certain scenarios and based on certain assumptions, taking into account the diverse perceptions of the problem held by the individual actors in the problem field, the actions of the other actors and exogenous changes.
- The modelling of factors refers to a semi-quantitative calculation of the resultant changes of relevant factors.

The authors recommend the actor-based modelling approach in the case of sustainable management problems requiring the cooperation of various societal actors with different problem perceptions, especially when there is a

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$^9$ DANA software is available at: http://dana.actoranalysis.com
lack of quantitative knowledge in the problem field under consideration (Döll et al., 2013).

Researchers in SD modelling (Andersen et al., 2007; Bryson et al., 2004) and causal mapping (Ackermann and Eden, 2005) have been working together to find the right mix between methodological power and richness, using a systems thinking approach. Richmond (1994) identifies three impediments to the representation of complex mental models as the series of stocks and flows in system dynamics modelling:

- The gap between the explicit graphical representation and the mental model;
- The complexity of the explicit model, which results in cognitive overload;
- The ambiguity of the semantics of SD diagramming.

A problem structuring methodology provides an alternative path. Recent reviews of these alternative procedures by Ackermann (2012), Rosenhead (2006), Franco (2006) and White (2006) show them to be numerous and divergent; they also often overcompensate for the formalism of OR/MS by incorporating more qualitative approaches. Ackermann (2012) highlighted a number of significant benefits of PSMs (also known as ‘soft’ OR) as evidenced from practice, including:

1. The management of complexity, and thus being able to see the whole picture, enables groups to achieve a number of additional advantages, including: (i) ensuring the situation is explored from a range of perspectives, and thereby enabling a representative appreciation to be developed; (ii) widening the number of alternatives generated; and (iii) enabling new options to emerge;

2. Taking into account multiple perspectives by ensuring all views are represented (and listened to) means that miscommunications and thus conflict can be reduced, and a greater overall understanding can be gained.

3. The management of process and content involves support for negotiation within a group towards an agreed outcome. From an overview of the situation, a number of benefits emerge: (i) all participants can see how their ideas interrelate with those of others, and often realise that there is less difference than initially thought; (ii) support for negotiation and PSMs through graphical representations enables each idea to be separated from its proponent, thus enabling contributions to be examined on their own merit.

PSM was selected in the design of the proposed policy-oriented modelling and simulation tool; this facilitates the development of a ‘mental model’ for progress and consensus on policy decisions through a mapping of the system components, their interrelationships and their interactions. Two main
drawbacks of this methodology were addressed in the current research when
defining the new policy-oriented modelling and simulation approach:
1. These methods rely heavily on participative engagement with decision
makers and the use of a facilitated mode of consultancy engagement. It
was therefore important to design a clear procedure for policy modelling
using this approach that is in line with policy IA frameworks. The
resulting models allow the user to simulate and analyse policy
options/changes within a policy-friendly framework. It was also important
to create standards for modelling the components of a policy system, to
allow the creation of reusable and customisable models and sub-models.
These were developed within the Sense4us project.
2. PSMs often result in solely qualitative models, although there is a
requirement to be able to use the model for simulation. It was therefore
important to identify a PSM providing computational semantics that
supported simulation.

In his PhD dissertation, Acar (1983) introduced the ‘causal mapping and
situation formulation’ method as an analytical method for
the formulation and
analysis of unstructured strategic problems. This method enhances causal
mapping by including indications not only of the directions and signs of the
presumed causal influences, but also of their intensities, minimum threshold
values and the possible time lags (see Acar and Druckenmiller, 2006). Acar’s
method, also referred to as comprehensive situational mapping (CSM), is an
adequate vehicle for capturing and representing the main elements of a social
system and handling it analytically. Its computational capabilities provide
support for systems thinking approaches in a system that is easy to learn and
use (Druckenmiller and Acar, 2009). Table 1 summarises the procedure used
to graph a problem situation manually, and shows the primitive elements used

Table 1. Acar’s (1983) causal mapping: Graphing a problem situation manually

<table>
<thead>
<tr>
<th>Level 0 – Surveying – Checklist model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stage 1: Elements</strong></td>
</tr>
<tr>
<td>1- The social system under consideration and its boundaries.</td>
</tr>
<tr>
<td>2- Actors: persons, groups, or schools of thought involved in the system as single entities.</td>
</tr>
<tr>
<td>3- Variables: Components or factors characterising the situation are idealised as quantitative variables, or quantified using value scales, so that it is meaningful to talk about change in the form of increases or decreases in their levels.</td>
</tr>
<tr>
<td><strong>Stage 2: Distinction</strong></td>
</tr>
<tr>
<td>1- Independent variables: Sources or drivers of change (graph origins). Dependent variables: consequences, outcomes, or extrinsic goals (middle and end nodes).</td>
</tr>
<tr>
<td>2- Controlled variables: Decision variables (planned changes). Uncontrolled variables: State variables (unforeseen changes).</td>
</tr>
</tbody>
</table>
Level 1 – Structuring – Qualitative model

**Stage 1: Protocol**
(Operational definitions)

1- Identify origins under your control (main actor decision variables).
2- Identify origins under other actors’ control (decision variables of other actors).
3- Identify the uncontrolled origins.

**Stage 2: Structure**
(Change transmission channels and restrictions)

1- Full channel: A double arrow is used from the upstream variable X to the downstream variable Y, if X is sufficient to induce change in Y. Place a “−” sign next to the arrow if changes in these variables are in opposite directions. If a minimum change in X is required to be transmitted to Y, indicate this using a threshold level L<sub>X</sub>. If the change transmission is not instantaneous, indicate the time lag of change transfer in terms of the number of time periods T.

2- Half channel: A single arrow is used from variables U,V,… to variable Z if a change in any of these variables is necessary but not sufficient to induce change in variable Z. Indicate the sign, minimum threshold and time lag as above.

3- Restrictions: A dotted arrow to a variable indicates a qualitative constraint (binary condition) on the transmission of a change from any link to that variable.

4- Complete the network: All quantified variables or factors are represented by nodes, and all uncontrolled origins appear in bold; if an origin is a decision variable of some actor J, label this as (J).

Level 2 – Graphing – Quantitative model

1- Improve the structure resulting from level 1 by specifying the proportionality ratio of the change transmitted by each channel (change transfer coefficients).

2- Goal vector: List all variables in which you have particular interest, writing the target percentage change(s) in outcome variable(s) relative to the status quo values. The goal vector for each of the actors can be one-dimensional or multi-dimensional.

3- Indicate if internal or external problems need to be overcome to achieve your goals.
Acar’s causal mapping method supports three classes of analyses (see (Acar 1983) for a detailed description), as follows:

1. **Backward analyses:** These clarify, test and reassess assumptions about the web of cause-effect relationships underlying the situation, and can be divided into:
   - (i) **Major assumptional analysis** (validity of the major aspects of the graph elements and relationships); and
   - (ii) **Minor assumptional analysis** (validity of the detailed qualifications and quantifications of the graph);

2. **Structural analyses:** These include the scope of the graph (numbers of nodes and links), connectivity analysis, reachability analysis and qualitative/quantitative goal comparative analysis (among actors).

3. **Forward analyses:** These estimate the implications of changes by generating change scenarios and simulating the transfer of change. They include:
   - (i) **Scenario simulation:** Running change scenarios on the graph and the transfer of change from origins throughout the network;
   - (ii) **Goal negotiation analysis:** Feasibility and compatibility of actors’ goals (the existence of a scenario that realises a goal or multiple goals jointly); and
   - (iii) **The effectiveness and efficiency of a change scenario:** This is an expression of the outcomes in comparison with the objectives and relative to the change needed at the origins.

### 2.6 Multi-Criteria Decision Analysis

In the context of policymaking, a decision maker is confronted with a huge amount of complex information, usually of a conflicting nature and reflecting multiple interests; the use of MCDA can consequently be very valuable in assisting decision makers in organising such information in order to identify a preferred course of action. It allows decision makers to judge the performance of alternative policy options using different measures and from the points of view of the different stakeholders regarding what represents a positive or negative policy impact. The integration of MCDA into the dynamic simulation of policy consequences also reveals key uncertainties related to the evaluation criteria for policy options that will be implemented in the future and their importance to stakeholders. While IA describes the impact on objectives, or the extent to which a goal vector is reached, preference elicitation should then allow decision makers to provide preferential information on these impacts, enabling the building of MCDA models.

Multi-criteria evaluation may be organised with the objective of producing a single synthetic conclusion or to produce conclusions adapted to the
preferences and priorities of several actors and stakeholders. The application of MCDA is thus particularly useful when selecting one of a finite set of feasible alternatives, and can provide the relative global performance of each alternative.

Problem structuring approaches facilitate context-setting activities and the definition of the environment of a decision problem to be modelled and subsequently evaluated (see, for example, Belton and Stewart (2010) for an introduction to how problem structuring relates to the decision analysis process).

Franco and Montibeller (2011) examined the role of problem structuring within MCDA interventions, including defining the problem and the required level of participation and structuring the evaluation model. They introduced a framework for conducting MCDA interventions in which the role of problem structuring is made explicit. The framework involves three phases. In Phase 1, the analyst structures the problem situation and designs a decision process with the right level of participation. Once completed, the analyst starts Phase 2, the structuring of an MCDA evaluation model, which consists of structuring a value tree, developing attributes and identifying decision alternatives. Finally, the analyst can conduct Phase 3, the evaluation of decision alternatives. This process has a recursive nature, since the MCDA model can change the definition of the problem or the scope of the participation by stakeholders; similarly, the assessment of alternatives can change either the structure of the MCDA model or the definition of the problem (Franco and Montibeller, 2011).

Since feasible policy options can be identified from scenario generation and simulation-based IA, according to (Franco and Montibeller 2011), there are two main tasks remaining in the structuring of MCDA evaluation models: i) the representation of objectives in a value tree; and ii) the definition of attributes to measure the achievement of objectives.

Several integrated models have been suggested at a higher abstraction level; these show how causal mapping and decision evaluation methods complement each other in a decision support context, but without detailed specifications (see Montibeller and Belton, 2006). The most recent proposal, the decision maps suggested by Comes et al. (2011), integrates scenario construction and evaluation of alternatives, although it does not propose a method for the scenario-based simulation of decision options.

Given $M$ criteria, we can represent a decision option $A_k$ by a vector of performance levels $(x_{k1}, x_{k2}, \ldots, x_{kM})$. Following multi-attribute value theory (MAVT), the global value of a decision option $A_k$ is given according to the additive value function, $V(A_k) = \sum_{i=1}^{M} w_i v_i(x_{ki})$, where $w_i$ is the weight of criterion $i$ and $v_i(x_{ki})$ is a value function representing the value of alternative
Alternative \(A_k\) is then preferred to alternative \(A_l\) if and only if \(V(A_k) > V(A_l)\). See, for example, Eisenführ et al. (2010) for a comprehensive introduction to this preference model.

Using the so-called additive model, meaning that \(0 \leq w_i \leq 1\) and \(\sum_{i=1}^{M} w_i = 1\), this implies that the model cannot capture dependencies between criteria, such as those that are substitutes or complements of each other; however, since there is a requirement that the elicitation method should be simple to use, we refrain from eliciting such dependencies from decision makers.

Multi-attribute decision making (MADM) techniques can be applied when the decision requires the selection of one of a finite set of feasible alternatives \(\{A_1, \ldots, A_N\}\) (Belton and Stewart, 2002). In MADM techniques, the decision process starts by structuring the problem as an attribute tree, hierarchically ordering the decision makers’ aims at different abstraction levels. It is generally assumed that each criterion can be operationalised by a set of measurable attributes that allow for the assessment of the consequences arising from the implementation of any particular alternative. The performance of each decision option in terms of each attribute is determined, and weights reflecting acceptable trade-offs of performance for the objectives are elicited from the decision makers (Comes et al., 2011).

Reports in the literature show that since decision analysis involves the preferences of the decision maker, these need to be obtained in such a way that they can be formally represented, leading to cognitively demanding methods that are less convenient for decision makers to use. One increasingly popular way of relaxing the cognitive burden on decision makers is to create rankings of criteria and/or alternatives, and to generate surrogate values from these rankings. An early version of this approach is given in Barron and Barrett (1996), who proposed rank-ordered centroid weights as the most robust way of generating surrogate criteria weights. More recent studies of rank-based approaches include Sarabando and Dias (2010), Wang and Zionts (2015) and Danielson and Ekenberg (2015); these show that by allowing the user to provide preference strength information, the equitability of the generated surrogate numbers is improved, and more closely reflects the preferences of the decision maker.

Several tools for stakeholder analysis are available in the literature. The most widely used of these include the power-interest grid, star diagram, stakeholder influence map, stakeholder-issue interrelation diagram and problem-frame stakeholder maps (Bryson 2004). In order to operationalise a policy stakeholder analysis for the visualisation of the impacts of a policy on the different stakeholder groups, this research seeks a format for defining policy stakeholder groups and for eliciting weights, priorities and preferences. The data framed by this format can be used as an input for further decision and risk analysis.
3 Research Methodology

In Section 1.5, a rationale was given for choosing DSR as the overall methodological framework for this thesis. Here, we explain how DSR guided the processes of problem analysis and the elicitation of requirements, and particularly the application of the selected research methods and the use of the knowledge base.

This research was largely exploratory in nature, particularly during the design and development of the artefact. The design methodology followed a general process design cycle, involving a suggestion for a solution (motivated by awareness of a problem), the development of an artefact, and evaluation of the artefact; this cycle is then iterated until the specific requirements are met (Baskerville et al., 2009).

The research philosophy is discussed in Section 3.1, and this is followed by a description of the research design in Section 3.2. The research approach is discussed in detail in Section 3.3, followed by a description of the methods for data collection in Section 3.4. Ethical considerations are discussed in Section 3.5. Finally, the alignment of this research project with DSR guidelines is examined in Section 3.6.

3.1 Research Philosophy

This section discusses the research philosophy; the ontology (researcher’s view of reality) and epistemology (stance regarding valid knowledge) positions of this research are considered in order to direct the research methods used (Lee, 2004). This study takes the philosophical worldview of critical realism (Bhaskar, 1978) as a guide for the research design.

Critical realism focuses on explanations of underlying mechanisms that may be unmeasurable. A hypothesis for the mechanism may therefore be postulated, while acknowledging that the underlying mechanism may never be identified (Collier 1994). In such a scenario, a hypothesis can be tested by looking for alternative mechanisms and their effects (Mingers, 2004). Mingers (2004) stated that a social system is an open system that can only be closed by force, thus making the empirical testing of theory highly complex.
A critical realist epistemology therefore views science as “an ongoing developing process of explanation and enlightenment rather than the derivation of immutable scientific laws” (Dobson 2001, p. 202). This stance supports the choice of an iterative design process as a core research method, as used in this work to develop the research artefact.

There is strong support for critical realism as a suitable governing philosophy in IS, as opposed to positivism or interpretivism (Dobson, 2001; Mingers, 2004), particularly because this philosophy is flexible, allowing a methodology to be chosen that fits the research requirements (Saunders et al., 2009). Moreover, when identifying the structured interactions between complex mechanisms, qualitative methods are strongly supported within critical realism (Zachariadis et al., 2013).

In contrast to a positivist ontology, which attempts to study objective social reality independently of human activities (Khazanchi and Munkvold, 2000), a critical realist stance proposes the existence of the real, the actual and the empirical. The real domain includes underlying structures, events and experiences that exist independently. Events and behaviours in the social world that influence the real domain are categorised as the actual domain. Finally, the domain of the empirical exists where a researcher experiences and measures some aspect of the actual events (Collier, 1994; Mingers et al., 2013).

3.2 Research Design

In this research, a critical realist philosophy is used to guide the DSR methodology, which is the underpinning research design. DSR places emphasis on achieving clarity in terms of the goals and underlying theoretical constructs of a new artefact, and on carefully evaluating how well the new artefact meets these goals (McLaren et al., 2011).

In the DSR paradigm, knowledge and understanding of a problem domain and its solution are achieved through the construction and application of the designed artefact (Johannesson and Perjons, 2012).

Research activities can be divided into two design processes, building and evaluation, where ‘building’ activities concern the construction of the artefact and ‘evaluation’ activities deal with the development of criteria and the assessment of the performance of the artefact against these criteria (March and Smith, 1995).

Since an IS artefact is developed in this research, the design and evaluation are viewed as part of a socio-technical system in which design knowledge is developed through an iterative design process. This project has three overlapping but distinct phases, as described below.


3.2.1 Preliminary investigation

Gregor and Hevner (2013) considered design theory to be prescriptive knowledge (the ‘how’ knowledge of human-built artefacts), as opposed to descriptive knowledge (the ‘what’ knowledge about natural phenomena). They argued that a mature body of design knowledge should include any descriptive theory that informs artefact construction, including informal knowledge from the field and the experience of practitioners. This theory explains, at least in part, why the design works. According to the authors, a literature survey should include both the relevant descriptive knowledge and prior prescriptive knowledge, since together, these comprise a comprehensive knowledge base for a particular DSR domain (Gregor and Hevner, 2013).

3.2.2 Iterative design process

The iterative design process cycle ensures the utility and efficacy of the artefact in terms of achieving its stated purpose and assessing the end-user benefits. During the development of the artefact several formative evaluations were conducted as part of the ‘build-evaluate’ design cycle. These include testing results and feedback from end users, peer-reviewers of research publications and Sense4us project reviewers. RQ1 and RQ2 were addressed through the designed artefact, which is described in detail in Chapter 4.

3.2.3 Summative evaluation

Two evaluation studies of use cases of real public policy problems were conducted in order to provide evidence that establishes the efficacy, validity and generality of the goal of the Sense4us DSS. In addition, a formative evaluation study of the Sense4us prototype user interface was conducted through both face-to-face and remote heuristic evaluation and usability testing. RQ3 is addressed through summative evaluation of the artefact, which is discussed in detail in Chapter 5.

3.3 Research Approach

This work entailed a collaboration between researchers and practitioners, and involved a review of existing methodologies for policy IAs and evaluations. The research approach follows a typical DSR project, with a focus on the development of a DSS for public policy formulation as the research artefact. The methodological approach of this work will be described in more detail in the following sub-sections with respect to the main activities of the DSR methodology, as defined by Johannesson and Perjons (2012).
3.3.1 Explicate the problem

The goal of this activity is a precise formulation of the initial problem, a motivation of its importance, and an investigation of its underlying causes. Paper I deals with the problem of decision support for strategic planning in public higher education (HE) institutions. It adopts a conceptual model for the strategic planning process. Using the strategic planning process model, a decision support framework is proposed that assigns DSS methods and tools to the three activities of policy formulation. The issue of strategic analysis is an area that has been generally neglected within the strategic management literature. The situation has a very strong parallel in the policy analysis literature, which shows a lack of analytical methods and tools for the design of policy options. Another factor reinforcing this problem is the absence of analysis of policy instruments and their combination in specific policies.

Paper II discusses model-based decision support for policy analysis using an evidence-based policymaking approach. It highlights a number of research gaps in relation to the concept and application of modelling and simulation techniques. Firstly, there is a lack of operational and/or formal methods for facilitating the cognitive activity of designing policy options; secondly, there is a lack of procedures for analysing qualitative information for SD modelling, which creates a gap between the problem to be modelled and the model of the problem, especially when the model involves the use of qualitative or “soft” variables; thirdly, there is a need for case studies involving the practical engagement of PSMs with strategic and public policy problems, in order to identify the benefits and challenges of using PSMs in the modelling and analysis of complex problem situations; and finally, there is a need to develop future scenarios to assess the long-term implications of a policy, implying that more research is needed into how scenarios are constructed and how to address issues of robustness in scenario planning.

Paper IV discusses how to enable policy makers to gain a comprehensive understanding of the problem by facilitating the development of a meaningful problem definition that allows the design and integrated assessment of policy options. The paper explores the linkages between the policy formulation stage of the policymaking process and contemporary decision analytic methodologies.

Paper V discusses the systems approach to policy analysis and systems science methods, SD and agent-based simulation modelling, and the lack of policy-oriented systems modelling and simulation tools.

Paper VI discusses how MCDA techniques and preference elicitation methods can support an in-depth performance evaluation of policy options, taking into account the preferences of decision makers and stakeholders, which reflect acceptable trade-offs in performance for the policy goals.
3.3.2 Outline the artefact and define the requirements

The goal is to identify and outline an artefact that can address the explicated problem and to define its requirements. Initially, a quantitative approach was adopted for the assessment of user requirements, and qualitative methods were subsequently used to strengthen the online survey results, including interviews, group discussions and document studies.

*Paper II* presents a decision support framework for policy formulation, and introduces the text synthesis methodology for analysis of the verbal descriptions of a problem, in order to construct a qualitative causal diagram representation. A causal mapping simulation model for scenario planning and IA was developed for a policy use case at the EU level concerning EU climate and energy targets for 2030. The model was developed using the causal mapping and situation formulation method (Acar, 1983) and involves structuring or framing the problem using the derivation of an SD model from verbal descriptions of the problem. The resulting model, a topology of quantified causal dependencies between the problem key variables, can be used to simulate the transfer of change.

*Paper III* outlines an automated algorithm for the analysis of text-based information relating to a policy problem, using natural language processing (NLP) and text analysis techniques. The analysis process aims to identify key variables and cause and effect relationships and to map the structure to a graphical representation. A small prototype is presented which automates the first step of the algorithm, the extraction of causal inferences.

*Paper IV* outlines an integrated modelling framework for computer-assisted policy formulation. This approach combines causal mapping for problem structuring and the simulation of consequences, and identifies potential scenarios for further investigation using MCDA evaluation. This sequence follows a logical work process that conforms to the activities of the policy formulation process.

*Paper V* provides the functional requirements for a policy-oriented modelling and simulation tool, based on the research challenges of model-based collaborative governance and an assessment of the end-user requirements, in a study conducted within the Sense4us project using an online survey, multiple interviews, focus groups and group discussions.

3.3.3 Design and develop the artefact

The goal at this stage is to create an artefact that fulfils the requirements identified in the previous activity. This includes designing the functionality and construction of the artefact using research-based and creative methods.
According to Jennings’s (2000), who quotes Grady Booch (originator of the object-oriented design paradigm), as identifying three tools for tackling complexity in software:

- **Decomposition**: The most basic technique for tackling large problems is to divide them into smaller, more manageable chunks each of which can then be dealt with in relative isolation.

- **Abstraction**: The process of defining a simplified model of the system that emphasizes some of the details or properties, while suppressing others.

- **Organization**: The process of identifying and managing the interrelationships between the various problem solving components. The ability to specify and enact organizational relationships helps designers tackle complexity in two ways. (Jennings, 2000, p. 282).

**Paper I** details the modules and structure of the proposed DSS for strategic planning in higher educational institutions and their integration. The results guided the design of the structure and components of a DSS for public policy formulation with a focus on the strategic analysis module.

In **Paper II**, we developed an initial prototype of the policy modelling and simulation tool, which was used to develop a causal mapping model based on Acar’s (1983) method.

**Paper V** describes the labelled causal mapping method, a policy-oriented PSM designed in this work using several iterations of the build-evaluate cycle, and provides descriptions of the model element categories, the simulation concepts and a step-by-step procedure for the modelling and simulation of public policy problems. It also presents an implementation of a web-based prototype of the Sense4us policy modelling and simulation tool based on the labelled causal mapping method.

**Paper VI** describes the common policy appraisal format, which is designed for the evaluation of policy options, and a rank-based approach for eliciting preferences. The proposed approach seeks to combine systems modelling and the simulation of policy scenarios with MCDA, stakeholder analysis and preference elicitation.

### 3.3.4 Demonstrate the artefact

The goal is to demonstrate the use of the artefact, thereby proving its feasibility and relevance.

**Paper II** provides a demonstration of the text analysis algorithm to support the structuring and modelling of public policy problems using causal mapping for the EU 2030 Climate and Energy Framework, a project at the EU level.

**Paper V** describes a demonstration of problem structuring using the labelled causal mapping method and the proposed procedure for policy modelling and simulation using the Sense4us tool prototype. Two real-world policy analysis cases were used for demonstration, as follows:
- Regulations of the European Parliament and the Council of the EU on personal protective equipment (EU level); and
- The uptake of ultra-low emission vehicles (ULEVs) (national level, United Kingdom).

*Paper VI* provides a demonstration of the proposed approach for policy MCDA and preference elicitation, based on the policy model and simulation results of policy options, for the policy use case of ‘uptake of ULEVs in the UK’.

In addition, several demonstration cases are described for the policy modelling and simulation tool developed and executed by Sense4us end-user partners, including the promotion of electric cars (EU level), wind energy in North Rhine-Westphalia, Germany (local level), and housing market regulations in the UK (national level).

3.3.5 Evaluate the artefact

The goal is to determine how well the artefact is able to solve the explicated problem and the extent to which it fulfils the requirements.

*Paper VII* describes an evaluation use case of the deployment of fossil-free fuels for public transport buses in Sweden (national level).

*Paper VIII* provides an evaluation use case concerning immigration policy in Finland (national level).

A heuristic evaluation and moderated on-site and remote usability testing experiments were conducted for the Sense4us policy modelling and simulation tool between 4th and 11th May 2016, using health policy test cases for problem definition and simulation, in conjunction with a group of health policy researchers and students from the Master’s programme in Health Informatics, Karolinska Institute, Sweden.

3.4 Research Methods

Several techniques were used to collect data, including an iterative design process as a form of participatory research, focus group discussions, interviews and document studies. Contributions to the application of relevant frameworks and guidelines used in the design and development of the artefact were made through discussions among the research team members, formative evaluations of the intermediate outcomes of the artefact, and feedback from presentations of the results to the Sense4us project consortium, the EC’s review committee and in academic and policy-related outlets.

Many arguments for mixing methods centre on the concept of triangulation and its value in validating data or analysis, or in gaining a fuller picture of the
phenomenon under study (see the mixed-methods literature, for example Bryman (1998, 2004), Creswell and Clark (2007), Ridenour and Newman (2008), Lee and Hubona (2009)). The present author fully endorses the view of Mason (2006), who argues for the mixing of research methods as follows: (i) It offers enormous potential in exploring new dimensions of experience in social life, and can encourage researchers to see differently, or to think 'outside the box'; (ii) It can enhance a researcher's capacity to explore and frame questions with the aim of focusing precisely on how different dimensions and scales of social existence intersect or relate beyond the macro and micro levels; and (iii) It can enhance and extend the logic of qualitative explanation, since it extends the qualitative logic of comparison using standardised measures of quantitative longitudinal surveys in addition to the cross-contextual and contextual explanations of qualitative research.

Both qualitative and quantitative methods were used in this research, as part of a qualitatively driven approach, for the activities of problem explication and outlining and evaluating the artefact. The methodology used to identify requirements was determined by the end-user partners of the Sense4us project, who composed the main questions for the survey and interviews and for investigating the perceptions of the target audience regarding the proposed Sense4us toolbox. The methodology had three main steps:

- Target group identification: Target groups that are expected to be interested in the project and are considered to be key were identified and listed. As a starting point, the potential user definition was kept generic, and included anyone working in parliament or government who is involved in drafting legislative proposals or addressing certain policy developments.

- Actions to assess end-user requirements: These used both quantitative and qualitative methods.

- Requirement definition: This involved a description of requirements at each of the three levels of EU policymaking.

The analysis of end-user requirements was based on quantitative (a statistical analysis of survey results) and qualitative research (an analysis of interviews and focus groups). The actions taken in researching the requirements and the results of end-user engagement are discussed in detail in Section 4.1.

One of the benefits of investigating end-user engagement using both qualitative and quantitative methods is that the results could be cross-referenced, allowing us to check that the broader reflection of opinions we received from the survey was accurate. The use of interviews and focus groups permitted a more detailed understanding of problems and processes to emerge,
and enabled us to discuss practical options for creating digital solutions to policymaking problems. Meeting end-users face to face also gave us the opportunity to identify those who might be willing to help test and evaluate prototypes at a later stage of the project.

Qualitative inquiry begins with assumptions and the use of interpretive/theoretical frameworks that inform the study of research problems addressing the meaning ascribed by individuals or groups to a social or human problem (Creswell, 2012). Hammersley (2008) has identified two respects in which qualitative research has failed to take proper account of the processual character of human social life: firstly, through an understanding of people’s perspectives (“the researcher [is] able to see things in the same terms as participants, and thereby to recognize and document the internal rationality or logic of their perspectives”), and secondly, through a recognition of the extent to which social life is a contingent, and even emergent process, rather than involving the repetition of law-like patterns. Yet much qualitative research relies primarily on interviews in survey research. Interviews elicit responses in a distinctive context whose character is shaped through reactivity, and when used alone do not provide a reliable basis for inferring what people say and do in other contexts (Hammersley, 2008).

This research used semi-structured topical interviews, as recommended by Glesne (2003); this is a type of interview that is structured, open, and depth-probing. It is structured in the sense that there are specific questions to be asked, and open because new questions may need to be asked as unexpected directions arise. In the data collection process, we followed the steps for interviewing identified by Cresswell (2012), as follows: (i) identify interviewees who can best answer the research questions; (ii) use adequate recording procedures; (iii) design and use an interview protocol or interview guide; and (iv) refine the interview questions and the procedures further through pilot testing (Cresswell, 2012).

Group discussion is a research method in which several respondents may inspire each other in conversation to identify and define problems in a domain. Multiple group discussions were conducted in focus groups and facilitated workshop settings, as part of this research project. Focus groups are advantageous when the interaction among participants is likely to yield the best information and when participants are similar to and cooperative with each other, or when the time allowed for the collection of information is limited (Stewart and Shamdasani, 2014; Krueger and Casey, 2014). However, with this approach, care must be taken to encourage all participants to talk, and to monitor any individuals who dominate the conversation.

The interviews and focus group discussions were transcribed. Data reduction was achieved by analysing these documents and coding themes or
clusters of ideas, which were then stored as an annotated document. The themes or clusters of ideas were indexed using a coding system that allowed a final evaluation (Huberman and Miles, 1994).

There are a number of advantages to the inclusion of documents as a source of data in qualitative studies. Documents can be used to “furnish descriptive information, verify emerging hypotheses, advance new categories and hypotheses, offer historical understanding, and track change and development” (Merriam, 1988, p. 108). Documents were used in this work within the activities of problem explication, and the outlining and evaluation of the artefact. They included public policy documents, policy research and assessment reports from governmental departments, industry, research institutions and NGOs, and published literature (primarily from refereed journals). In addition, we used supporting materials such as agendas, meeting notes and minutes, presentation materials, and other documents identified during the interviews.

3.5 Ethical Considerations

Measures were undertaken to conduct this research ethically, and in particular ensuring that participants were informed about their rights, safety and freedoms during participation in the research. Consent was sought from participants via a formal research consent form. A participant information sheet was also made available during the interviews. The consent forms were provided to participants before the focus group discussions and interviews to accept the use of an audio recorder. The interviewees were made aware that no consequences would arise from declining to participate in the research project, and that no incentive or payment to participants was offered. The information collected directly from the research participants was de-identified. However, it was necessary to collect information in potentially identifiable forms, since face-to-face interviews with the policymakers and analysts were necessary to gain knowledge about the usability of the tool.

Although the results of the research were presented in academic publications and conferences by the researchers, no identifying details about the participants were disclosed in any publications. It is intended that the research data will be stored for a period of five years from the completion of the project, in order to allow sufficient time to publish the results.
3.6 Alignment with DSR guidelines

Hevner et al.’s (2004) guidelines for DSR in information systems (IS) research are used to ensure alignment of this research to the requirements for a rigorous DSR project, as follows:

1. **Problem relevance**: DSR must provide a solution to an important and relevant business problem. This research addresses the problem of a lack of operational approaches to facilitate the cognitive activity of structuring public policy problems and prescribing preferred policies. In an attempt to enable the adoption of a systems thinking approach in policy analysis, this research aims to design and investigate systems modelling, simulation and decision analysis tools for prescriptive policy analysis.

2. **Design as an artefact**: DSR must result in a viable artefact in the form of a construct, model, method or instantiation. The current work aims to develop a model-based decision support approach for policy analysis that is instantiated as a prototype system of DSS tools for policy-oriented modelling, simulation and decision analysis, such that the outputs are available to practitioners through a goal-oriented and evidence-based process.

3. **Research rigour**: Construction of the artefact must be justified using prior theory and the evaluation of the artefact must be conducted with rigorous research methods. The design of the policy modelling and simulation tool includes a careful justification of each phase, using a systematic literature review of prior theory and evidence from the policy use cases. The design, development, demonstration and evaluation of the research artefact followed an established research framework, and was overseen by end-user partners, research partners and reviewers involved in the Sense4us project.

4. **Design as a search process**: The ‘design as a search’ guideline suggests the use of an iterative search for an effective solution to the problem. Best practices in public policy analysis from literature are used as knowledge items to provide improvement recommendations through the design iterative search process, in addition to multiple demonstration and test cases from various policy areas at the different EU policymaking levels. During several iterations of the build-evaluate cycle, problems were encountered and solutions were found. Earlier iterations of method development and evaluation fed into further analysis and development of the subsequent phases. This approach gave rise to the studies making up this research.

5. **Design evaluation**: A well-executed evaluation must demonstrate the utility of the design artefacts, and the design must be evaluated rigorously.
in terms of its utility, quality and efficacy. Brown (1989) argues that the validation of prescriptive technology should be primarily external, that is, tools should be tested in real settings. However, internal validation, such as the testing of logical coherence and consistency with theory, has been the dominant approach. In the present research, theory and evidence from multiple policy use cases represent evaluation checkpoints for assessing the usability of the artefact.

6. **Research contributions**: These should be clear, verifiable and interesting. Hevner et al. (2004) noted that in the DSR paradigm, the artefact is itself a research contribution. The demonstration and evaluation of the proposed approach should indicate the method is transparent and efficient due to the use of a systems approach and DSS technology features. The evaluation of usability of the prototype system should show a benefit to policy makers, analysts, researchers and other process stakeholders in practice.

7. **Communication of research**: The research must be communicated to both a technology-oriented audience (design artefact) and a policy-oriented audience (in terms of its implications for policy decision support). For academics, this research provides an example of DSR applied to public policy decision support; for practitioners, it describes an easy-to-use tool for the conceptual modelling and quantitative dynamic simulation of policy problem situations.
4 The Artefact

This chapter provides a description of both the design artefact and the design search, which used an iterative design process. Section 4.1 defines the end-user requirements in relation to the data sources that were used to inform policy decisions and were included in a policy modelling and simulation tool that can be used within contemporary policy analysis practice. Section 4.2 describes the artefact, based on the proposed decision support framework and the choice of modelling approach. Section 4.3 presents the labelled causal mapping approach; this is a policy-oriented quantitative PSM proposed in this research. Section 4.4 presents a text analysis methodology to support policy modelling using causal mapping. Section 4.5 describes the policy modelling and simulation tool prototype. Section 4.6 presents the common policy appraisal format and rank-based preference elicitation method.

4.1 Requirements

End-user engagement in the Sense4us project involved examining the existing policy-making cycles and engaging directly with policymakers in both the executive and legislative spheres at the EU level, the national level in the UK and the local level in Germany. Sense4us does not seek to change existing policymaking practices, but rather to identify the needs of the institutions and individuals involved in the policy process and to facilitate their work by improving data accessibility and analyses, in order to support informed policy decisions. Given the differences between the processes and target groups at the different EU institutional levels, the research and analysis undertaken by each end-user partner was set out separately. The engagement of target audiences was ensured throughout the process, in both the initial requirement gathering stage and the subsequent development stages.

The target policymakers, analysts, researchers and politicians’ support staff were identified, and were emailed an introduction to the Sense4us toolbox and a link to the online survey. The aims of the survey were threefold:

1. To establish current practice and problems amongst target users and to develop a framework for further in-depth questions to be asked in interviews and focus groups;
2. To determine basic requirements and identify ways to address current needs across a broad range of users;
3. To act as the first point of contact with politicians and policymakers, allowing us to identify those individuals that were interested in this area and who were likely to further engage with the project.

Interviews and focus groups were carried out with targets who expressed interest in the project or who submitted contact details as part of the survey; other possible participants were identified by each of the partners through desk research and discussions with policymakers and decision makers as being an especially good fit for the project, in view of their role in the policy process. The aims of the interviews and focus groups were:
1. To build on the understanding of processes and practice in policymaking that was gained from the survey;
2. To increase the understanding of the project among target users;
3. To identify requirements and to understand how these requirements might be addressed by the DSS.

The questions were tailored to each individual interview or focus group, but addressed similar themes: information gathering, current use of digital tools, open data, policy IA and requirements for a policy modelling and simulation tool.

A total of 94 participants were involved in the survey from governmental institutions at the EU level (22 participants), national level in the UK (46 participants) and local and national levels in Germany (26 participants).

Between January and April 2014, six interviews were carried out with a range of senior and junior policymakers and officials at the EU level, and eight at the UK level; an additional thirteen parliamentary officials took part in two focus groups in April and May 2014, including Committee clerks, researchers from the Parliamentary libraries and the Parliamentary Office of Science and Technology. The themes discussed included the use of evidence, support for MPs, open data, public inputs, policy impacts and the Sense4us toolbox itself.

Between March and June 2014, three interviews were carried out with officials at ministerial level from the Ministry of Economy, Energy, Industry, Trade and Craft the state of North Rhine-Westphalia; from state chancellery level from the Senate Chancellery, Hamburg; and from the State Parliament of North Rhine-Westphalia.

For many of those taking part in our surveys or interviews, the issues under discussion represented a very new approach to data and policymaking. Many of them were consequently attracted to and fascinated by the idea, and were therefore keen to discuss it, as they felt that the challenge of obtaining correct data and improving their legislative practices was acute, in the age of big data and with limited time resources for analysis. The findings from the assessment of end-user requirements, done as part of the Sense4us project, were presented
The discussion of policy modelling mostly centred around the element of trustworthiness. It was felt that the tool should present a clear methodology. Policy researchers, in particular, were concerned that they needed to be able to understand how the tool worked and the assumptions on which it was based, as they would not be able to have confidence in it otherwise. The tool should be transparent about the information and factors it uses, and the user should have the opportunity to include new sources and factors, and to use scientific arguments if they apply, and public sentiments if possible.

- User functionality and customisability is a high priority in policy modelling, since this requirement strongly determines the success and believability of the tool. Most of the respondents indicated that problems in predicting the outcomes of a certain policy lay in the complexity of the issue and the dynamic range of factors that might affect it. The tool should allow inclusion of all the factors/variables considered relevant by a user, giving rise to the idea of a member account being incorporated into the tool to enable users to shape the policy simulation individually.

- Showing policy consequences across departments: In the same way as for searching across academic disciplines, there is a need for a tool that will show the policy impacts on a number of different government departments, rather than within traditionally defined boundaries. This is particularly important given that cross-cutting macroscopic issues are highlighted as being the most challenging to address.

- Usability: Tools for policy makers need to be easy to use.

- Training and support: This is necessary to ensure that outcomes are not overstated and that the limitations of the tools are made clear to users.

- Integration of different data formats from various internal and external sources of information used for the drafting of the policy: For example, at the EU level, these include legal documents, proposals from the EC, the OECD and the Committee of Regions, e-committee/working documents and EC and EP IAs, academic papers, studies from governments and key interest groups, relevant press articles, social media and other forums for public opinion.

The research challenges involved in developing tools and methodologies for model-based collaborative governance and the challenges for policymakers described in Section 1.1 were matched with the requirements of the surveyed end-users and translated into functional requirements for the proposed DSS, including:

1- User-created policy scenarios: The creation of the users’ own models of policy problems and clarification of the assumptions and hypotheses made
about the interrelationships and interactions among the different model components;
2- Support for reusable, customisable and integrated models;
3- Ensuring long-term thinking;
4- The possibility of linking to online evidence sources, global datasets and an assessment of the relevance of information;
5- Provision of procedures for sensitivity analysis and model validation (quality assurance), in order to provide feedback on the simulation process or on the initial modelling assumptions;
6- Facilitation of the engagement of a wide range of decision makers and stakeholders through a web-based, user-friendly graphical user interface (GUI), using animation and visualisation techniques to display the model’s operational behaviour graphically over time, as the model runs.

The following sections present some of the original contributions made throughout the design, development and demonstration of the DSS.

4.2 Decision Support Framework

The decision support framework is based on the adopted process model for policymaking, as described in Section 2.1. This is a systems model, in that it is organic, open, bounded and responds to the tenets defined in Easton’s systems approach. The model fits into both the rational-comprehensive framework and the incremental or bounded-rationality framework. It is an example of a rational-comprehensive framework since it relies on rational discourse, and in relation to decision making, it assumes a rational method of selection for the optimal proposal. It is also an example of the rational-comprehensive model in that the continuous nature of the model allows for a complete discovery of all possible solutions. Furthermore, the model is an example of the incremental framework, since the identification and development of problems relies on the status quo level of the system and acknowledges the continuous nature of the process, indicating that policymaking is an ongoing, continuous process requiring continuous assessment, evaluation, and reaction.

The framework involves a set of interrelated policy analysis tasks (or activities); these are listed below, alongside the proposed decision support methods and techniques to be employed in each task:
1. Problem structuring and modelling: A systems thinking approach combined with a quantitative multi-actor PSM.
2. Design of policy options and IA: Scenario simulation.
3. Multi-criteria evaluation of policy options: MCDA, MADM techniques, preference elicitation methods and stakeholder analysis.
Figure 2 illustrates the process model and a decision support framework for the policy formulation stage of the policymaking process. The channels conveying data or objects are related to these activities. The two types of channels are inputs/outputs (thick arrow), which describe which knowledge or object is an input/output of which activity, and resources (thin arrow), which describe which techniques and tools are used to support an activity.

We aim to define and implement an integrated model-based decision support approach, based on the following aspects:

![Decision support framework for policy formulation](image_url)
(i) Problem analysis using analytical causal mapping that supports graphical representation, scenario generation and quantitative simulation; and
(ii) Multicriteria evaluation, which enables the definition of decision makers, stakeholder groups, policy evaluation criteria and underlying attributes, and is equipped with a preference elicitation method.

The framework involves the assignment of tasks to the two main software modules of the DSS. The DSS should provide a user-friendly, web-based interface, visualisation and report generation capabilities.

1. **Policy modelling and simulation:**
   A systems modelling and simulation tool that enables users to:
   (i) Create, edit, store, load and analyse policy models;
   (ii) Simulate possible future scenarios and alternative courses of action;
   (iii) Collect the simulation runs in the DSS database, for use in further analysis to determine which policy-relevant statements can be supported (i.e., to determine the considered policy options);
   (iv) Produce visualisations of policy impacts;
   (v) Process the simulation results to calculate a relative ranking of the actors involved in a policy decision situation, based on their utility preferences for the possible outcomes (game theoretic analysis);

2. **Policy evaluation:**
   A MCDA tool that supports the multi-criteria evaluation of policy options through a procedure to define a common policy appraisal format and elicit preferential information from decision makers and stakeholders (e.g. relative importance of the evaluation criteria and preferences of policy options).

### 4.3 The Labelled Causal Mapping Method

Based on Acar’s (1983) causal mapping method, this research proposes a new policy-oriented quantitative PSM, called the labelled causal mapping method, as a systematic method for the structuring of public policy decision situations and simulation of the possible futures and consequences of alternative policies.

This method defines policy-oriented categories using iconic representation for the model elements. Figure 3 illustrates a framework for systems analysis for policy, based on the labelled causal mapping method, where a policy or governance system is conceptualised as a socio-economic or socio-technical system using the five tenets of Easton’s (1965) framework: *actors, variables, unit of analysis, level of analysis* and *scope*.

- **Actors:** These are decision makers who have control over components of the system and can trigger change in the system;
- **Variables:** These are abstract and concrete components of the system;
- Unit of analysis: This refers to the whole environment, and can be narrowed to specific parts of the environment, intra- or extra-societal components;
- Level of analysis: This is defined by the policy outcomes. We consider three European policymaking levels: EU, national and local levels;
- Scope: This is defined by the actors involved and the variables of interest (and is affected by the level of analysis).

The proposed systems analysis for policy provides decision support for the problem definition, ex-ante IA and the evaluation activities carried out at the policy formulation stage of the policymaking process. The rationale of the analysis is to identify effective policies by gaining insight from conceptual, empirical and operational analyses of the system, viewed in the context of future scenarios.

The conceptual analysis involves the construction of the underlying models of proposed policy actions or programmes, based on the specification of a theory of what is influencing the relevant outcomes. The analysis of the qualitative data available for the policy issue results in a mapping of the policy decision situation to a graphical representation of the actors involved, the key variables, control flows and causal dependencies. The aim is to support the policy model-building process, using information from decision makers, experts, evidence sources, consultation of interested parties and stakeholders and public consultation. The phase involving diagram construction and analysis is purely a qualitative modelling process; in order to allow for empirical analysis, quantification of the model is needed.

The empirical analysis involves quantitative methods for projecting future outcomes. These methods have in common the identification of key assumptions and the quantification of these assumptions, based on theory and past experience, and can run complex quantitative analyses of the most likely outcomes under different assumptions. Quantitative simulation of policy consequences is one of the primary features of the policy decision support approach introduced in this research.

The operational analysis involves an evaluation of the feasible options, encompassing different viewpoints and perspectives, multiple objectives, and multiple stakeholders using integrated assessments.

The following subsections provide a detailed description of the categories of policy model elements and the main concepts of the analysis processes involved in the labelled causal mapping method that aims to provide standards and a procedure for policy modelling.
Figure 3 A framework for systems analysis for policy
4.4.1 Actors
These are the institutions, organisations, committees or individuals involved in the decision-making process.
A. Official actors:
   (i) Legislative actors (parliament committees, political parties); and
   (ii) Executive actors (governmental bodies, departments and institutions, chief executives, staff/officials, agencies, bureaucrats and civil servants).
B. Unofficial actors: Interest groups, political parties, citizens’ representative bodies, NGOs, industry/trade unions, think tanks, the media.

4.4.2 Variables
Variables are factors or events that structure, constrain, influence and indicate the impacts of actions taken by actors. These are idealised as quantitative variables, or quantified using value scales, so that it is meaningful to talk about change in the form of increases or decreases in their levels. Variables can be divided into decision variables (policy instruments), state variables (external factors) and impact variables (as related to particular policy areas)
A. Independent variables (sources of change), including:
   (i) Policy instrumental variables:
       These are decision variables controlled by policy actors through various types of policy instruments (in the categories listed below). Scenarios of change in these variables represent action alternatives (policy options). These changes reflect the allocation of natural, human and capital resources, the regulatory role of the government, and regional and international cooperation. Represented policy instruments are:
       - Economic instruments (financial instruments e.g. public expenditure, investment or funding, public ownership and subsidies; fiscal instruments e.g. taxes, fees and user charges, incentives, loans and loan guarantees; and market instruments e.g. property rights, contracts, tradable permits, certificate trading and insurance);
       - Regulatory instruments (e.g. norms and standards, control and enforcement, liability);
       - Informational instruments (e.g. public information centres, sustainability monitoring and reporting, public awareness campaigns; consumer advice services, advertising and symbolic gestures);
       - Capacity-building instruments (e.g. scientific research, technology and skills, training and employment);
       - Cooperation instruments (e.g. technology transfer; voluntary agreements).
   (ii) External factors:
       These are state variables, which are not under the control of any of the actors. Scenarios of change in these uncontrollable variables reflect
uncertainties about possible futures. Represented external factors can be categorised as:
- Drivers and barriers: The drivers of and barriers to change are either associated with the political context (e.g. the political ideology and strategic priorities of the government of the day, the preferences and demands of politicians) or the economic context (e.g. the availability of resources, economic growth, the economic climate, current and future commitments);
- Disturbances and constraints: A policy or governance system is surrounded by physical, biological, social and psychological environments to which the system needs to adapt;
- Social, demographic and behavioural change (e.g. population growth, immigration, culture, attitudes and behaviours).

B. Dependent variables (impacts of change):
These variables represent the consequences of change in the independent variables, and are either direct impacts associated with the sources of change, or indirect impacts associated with the direct impacts. Furthermore, the use of different categories for policy impacts allows us to conduct a robust and relevant IA that implements the principle of sustainable development, which requires the determination of the social, economic, environmental, organisational, legal and financial implications of a new policy. Categories and examples of impact variables, related to various policy areas, are as follows:
- Economic impacts: Industry and manufacturing activity indicators, retail sales, new business startups, labour market indicators, income and wages, imports and exports, competition;
- Financial impacts: Costs and cost savings to government, businesses or citizens’
- Environmental impacts: Greenhouse gas (GHG) emissions, air pollution, water pollution, ecological footprints, waste and recycling;
- Community/social impacts: Living conditions/quality of life, poverty, social inclusion, unemployment, crime, social protection;
- Energy-related impacts: Energy consumption, efficiency, share of renewables;
- Infrastructure and service-related impacts: fresh water, road networks, ICT;
- Transportation-related impacts: Road, air and freight transport, rail lines;
- Health-related impacts: Health status (infant mortality, diseases), health determinants (regular smokers, consumption/availability of healthy nutrition);
- Education and training-related impacts: Adult participation in lifelong learning, tertiary educational attainment, vocational education and training;
- Science, innovation and technology-related impacts: Entrepreneurship, research and development (R&D), ICT investment/added value;
- Judiciary and legal impacts: Efficiency/independence of justice systems, simplicity of the regulatory environment; and
- Security and defence-related impacts: Cyber security, defence acquisition, terrorism and security.

If a possible future is defined in terms of changes in external factors, (state variables, variables that are not under the control of policy actors), a policy option can be defined as a scenario of change, that is, a particular combination of changes in levels and durations of policy instrumental variables (decision variables). Since the aim of the policymakers is to find an optimal combination of policy measures, it is easier to work with the main aggregate policy instruments in order to limit the number of possible combinations.

4.4.3 Change transmission channels

These links are cause-effect relationships connecting the model variables, and are defined by:
- Direction, from an upstream variable to a downstream variable;
- Sign, where a positive sign represents changes in the same direction and a negative sign represents changes in opposite directions;
- Change transfer coefficient, which is the intensity of the causal relationship in terms of the proportionality ratio of change transfer, that is, how much change is transferred to the downstream variable in the case of a 1% change in the upstream variable;
- Time lag (if the change transmission is not instantaneous), expressed in weeks/months/years; and
- Minimum threshold for the change in the upstream variable (if applicable).

Two types of change transmission channels are as follows (these are illustrated in Figure 4 below):

(i) Full channel: Represented by a double arrow from an upstream variable $X$ to a downstream variable $Y$, if $X$ is sufficient to induce change in $Y$.
(ii) Half channel: Represented by a single arrow from an upstream variable $X$ to a downstream variable $Y$, if $X$ is necessary but not sufficient to induce a change in variable $Y$. Half channels from a set of variables such as {U, V, W} to a variable $Z$ need to be all activated before the change can be transferred to $Z$.
The main assumption in the transmission of change is that the percentage relative change in a downstream variable $Y$ is a linear function of the percentage relative change in an upstream variable $X$. For full channels, the transmission is automatic, and as soon as a variable undergoes a change, the channels proceeding from it become activated and transmit to the downstream variables, according to the relevant time lags. The same applies to half-channels, as soon as all half-channels converging onto a node are activated. If we assume that $dX/X$ represents the relative change in a variable $X$, then the relative change $dY/Y$ in a downstream variable $Y$ is given by:

$$\frac{dY}{Y} = a \frac{dX}{X}$$  \hspace{1cm} (1)

where $a$ is the real valued change transfer coefficient for the link $XY$, representing the change in $Y$ relative to its baseline level $Y_b$, if $X$ changes by $+1\%$ relative to its baseline level $X_b$.

The causal link can be described as an instance of a linear regression model\(^\text{10}\) where both the dependent variable and independent variable(s) are log-transformed variables, that is, a log-log model: $\log Y_i = \alpha + \beta \log X_i + \epsilon_i$.

Given a set of activated channels $\{X_1Z, X_2Z, \ldots, X_nZ\}$ converging on $Z$, then:

$$\frac{dY}{Y} = \sum_{i=1}^{n} a_i \frac{dX_i}{X_i}$$  \hspace{1cm} (2)

“Additivity” and “transitivity” are the two main characteristics of change transmission in the model that allow simulating scenarios of change using the causal map. Once initiated in one or more of the independent variables, change is transmitted throughout the network, given the transfer ratio and the time lag for each channel.

In highly connected situations, closed loops of cause-effect relationships may exist. A feedback loop must be time lagged, since it transmits the change back to its starting node, causing a second wave of change to reach this node after the time lag; this change is in turn propagated through the network. The tool can also be customised to include more complex forms of the cause and effect relationships (e.g. two change transfer coefficients for increase and decrease in the upstream variable, or time- or value- dependent coefficients resulting in a piecewise linear function).

4.4.4 State of the system

The baseline or status quo level of the system is a projection of the characteristics of the system and the levels of the variables at the beginning of the analysis, and is used as a point of comparison. The changes/responses are expressed in terms of percentage changes relative to the baseline. Thus, change transfer coefficients are dimensionless, and the initial values of

\(^{10}\) Recall that in the linear regression model, $Y_i = \alpha + \beta X_i + \epsilon_i$, the coefficient $\beta$ directly gives the change in $Y$ for a single-unit change in $X$.\n
relative change for all variables in the system are set to zero, i.e. the initial state in terms of the relative change is the null vector \((0, 0, \ldots, 0)\). The simulation runs are based on discrete time points \((T_0, T_1, T_2, \ldots, T_n)\), and the user is required to define a time step \(T\) (the time period between two consecutive time points) in terms of a number of weeks, months or years, and the maximum number of iterations \(n\) for the simulation. The state of the system at time \(T_i\) is then defined as the values of all the variables in the system at time \(T_i\) in the simulation run, for a specific scenario of change. The desired state of the system is given by targeted changes in a set of impact variables of interest to the decision maker, represented as a goal vector. Each actor has a goal vector reflecting the targets of that actor. The simulation of different scenarios of change can reveal the vulnerabilities of the system. An analysis of the behaviour of the system under various conditions yields a much deeper understanding of the problem and can support the design of policy options.

4.4.5 Model validation

Here, the simulation model for policy analysis has an exploratory rationale rather than being a prediction model. The individual simulation runs are not treated as providing predictions or explicit answers to the policy makers’ questions. Instead, new information, which was implicit in prior knowledge and was used to define what is plausible, is generated to support an informed policy decision. The aim is to explore the implications of alternative actions, assumptions and hypotheses. Hypotheses concerning cause-effect relationships can be used to derive potential alternatives. (Eisenführ et al., 2010).

In order to ensure the reliability of the model and, consequently, of the policies involved, the tool should support validation of the model, which tests the agreement between the behaviour of the model and the real-world system being modelled. Validation of the model, which is done by the user, is reduced to the validation of sub-models or even individual causal links. Quality control for the model is limited to the plausibility and the degree of completeness of the model (i.e. the inclusion of all factors and phenomena that might influence the outcomes).

A model is valid if it was built using the relevant information from trusted sources, and the assumptions made by the modeller have been tested against real-world data to make sure it is able to reproduce historical behaviour. A model can be considered usable if it is understandable and plausible to both technicians and policymakers, economic in finding solutions, in terms of data collection and computation, and accessible to those who wish to use it.
4.4.6 Goal feasibility and compatibility and game theoretic analysis

In a policy decision situation, actors may cooperate to achieve common policy goals or may be involved in a situation where each actor tries to pre-empt or counter moves made by competitors. By estimating and quantifying the utility each actor has in the alternative courses of action, policy actors can shape and assess their moves.

If an actor can realise his or her goals through the use of policy instruments, assuming the inactivity of other actors, then the goal vector is said to be internally feasible. When the moves of other actors and the changing external factors are taken into consideration, if no scenario can be found to realise the actor’s goals, then the goal vector is said to be infeasible; if these goals were found to be internally feasible, then the problem facing the actor involves synchronising with the other actors. If a scenario can be found to realise this actor’s goals, then the goal vector is said to be feasible. If these were not found to be internally feasible goals, then the actor has benefited from interacting with the whole system, in terms of turning potential problems and constraints into opportunities.

The concept of compatibility is connected to the concept of feasibility. Components of a single goal vector and the goal vectors of different actors are said to be compatible if a scenario of changes can be found to realise them jointly.

The labelled causal mapping method provides a basis for game theoretic analysis using the idea of a tactic, i.e. a sequence of moves by an actor in order to achieve targeted changes in impact variables, expressed in his/her goal vector. The effectiveness of a tactic is a measure (or at least an evaluation) of the degree to which it helps the actor realise these goals, while the efficiency of the tactic is a measure of the use of resources necessary to realise these goals. The tactical effectiveness and efficiency need to be measured in comparison to the alternative tactics available to the actor and in comparison with competitors’ tactics for a given possible future.

4.4 Text Analysis to Support Policy Modelling

The application of the text synthesis algorithm in constructing a qualitative causal diagram of the policy problem allows us to incorporate scientific evidence when defining the causal links and quantification of the cause-effect relationships. We have developed an algorithm for the analysis of qualitative data from multiple information sources for a policy problem in order to construct a causal diagram of the problem. The analysis process aims to identify key variables, linking them via cause-effect relationships and mapping this structure to a graphical representation that is suitable for designing action alternatives (i.e. policy options).
Information searches on various sources are needed in order to identify policy-relevant evidence information, indicators and datasets. Examples of sources of keywords and terms, which can be used to search for evidence information in relation to EU policy domains, include:

(i) Thematic glossaries on the EC website\(^{11}\);
(ii) IATE, the EU's multilingual term base\(^{12}\); and
(iii) The glossary of financial terms\(^{13}\).

4.5 Sense4us Policy Modelling and Simulation Tool

The rich computational semantics of Acar’s causal mapping technique offer support for automated modelling and simulation in ways that other cognitive mapping approaches do not. The automated simulation capabilities for Acar’s causal mapping were explored by Acar and Druckenmiller (2006; Druckenmiller and Acar, 2009); no computation algorithm was explicitly given, and instead, rules for the transmission of changes between elements of the model were used. The computational complexity of the causal loops and successive waves of change transmitted through the model when the simulation was run presented a substantial design challenge for the development of automated scenario support using object-oriented techniques alone. A prototype system for the development and simulation of causal maps was implemented using RePast 2.0, a Java agent-based modelling (ABM) and simulation library. In this implementation, the individual nodes of the causal map are represented as agents, and links between agents constitute the environment of the system, in an analogous way to a communication network. This implementation focuses on business strategy development and the interaction and behaviour of the involved actors as autonomous agents (Druckenmiller and Acar, 2009).

Using the labelled causal mapping method, we have implemented a web-based prototype of the Sense4us policy modelling and simulation tool in a Node.js environment. The prototype can be accessed through both a GUI and a hosted API. The current technical specifications of the implemented online simulation tool are presented in Appendix I. The online GUI for the tool can be seen at \url{http://dev1.egovlab.eu:4001/}. The prototype tool provides a fully automated, object-oriented implementation of the model construction, scenario triggering, scenario simulation and visualisation processes.

This implementation of the tool also addresses the problem of computational complexity associated with the simulation of closed causal

\(^{11}\) \url{http://ec.europa.eu/eurostat/statistics-explained/index.php/Thematic_glossaries}
\(^{12}\) \url{http://iate.europa.eu/SearchByQueryLoad.do?method=load}
\(^{13}\) \url{http://www.afme.eu/Glossary-of-financial-terms.aspx}
loops (which must be time lagged) and the transfer of successive waves of change (changes in the scenario at successive time points). Discrete time steps are used to track the state of the system over time, by defining a time step (in terms of a number of weeks, months or years) and the maximum number of iterations as the time horizon of the analysis. Computation of the limiting behaviour of a causal loop is therefore unnecessary.

The tool follows a gaming simulation approach, in which a human interacts with a simulation model. Having identified a goal, the focal actor (in individual mode) or each participant (in a group/participatory mode) tries out different scenarios to reveal those that best achieve the goals or intended consequences; the unintended and unexpected consequences are used as a long-term learning method. The simulation-based IA of user-created policy scenarios results in a set of policy options for consideration and their simulated social, economic, environmental and other impacts.

Several test cases were developed using toy examples (including ones with multiple loops) to ensure that the tool correctly handles the semantics and processing of the labelled causal mapping method, including the actors, policy instruments, policy impacts, control flows, causal links, triggering and simulation of change scenarios.

**Demonstration use case: Ultra-low-emission vehicles**

The British government wants to increase the take up of ULEVs throughout the UK as part of its wider plans for reducing greenhouse gas emissions. Electric cars are recognised as being able to reduce CO$_2$ emissions, improve urban air quality, create new jobs, and provide other benefits to society. The set of initiatives that aim to improve the uptake of electric cars include the Plug-in Car Grant and Plugged-in Places schemes and the London congestion charge; many other such schemes have been proposed, such as the creation of exclusive city “green zones”, free parking for electric cars, investment in public recharging infrastructure, arranging hands-on trials for electric cars for citizens, and so on. Data related to the policy use case were collected from a number of evidence sources regarding plug-in cars in the UK, including peer-reviewed research publications and official governmental reports.

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14 For instance, a short-term policy analysis may consider a time horizon 2015 to 2020; in this case, the time step could be six months with a maximum number of iterations of 10.


The results from the content analysis include a set of key concepts (variables) reflecting the different aspects of the use of plug-in cars in society, and the objectives, assumptions and beliefs associated with them. An indication of causalities between the variables has also been derived. Table 2 summarises the concepts generated for this policy use case. The proposed approach to problem structuring provides a framework that can accommodate this information into a policy model that supports prescriptive policy analysis.

**Table 2. Concepts generated for policy use case: ULEV in UK**

| Sub-problems | • ULEV ownership costs.  
|              | • Charging infrastructure.  
|              | • Development of ULEV technology.  
|              | • Public awareness and consumer misperceptions.  |
| Actors       | • Department of Transport, Office for Low Emission Vehicles.  
|              | • Transport Committee, UK Parliament.  |
| Policy instruments | • Financial: Level of direct subsidies (purchase of EVs), public investment/subsidies (charging infrastructure).  
|              | • Fiscal: Tax incentives/benefits.  
|              | • Market: Incentivised ULEV makes and models.  
|              | • Regulatory: Emission standards, nonfinancial incentives, standardisation of access to public charging infrastructure.  
|              | • Informational: Public awareness and acceptance of ULEVs, information on support and services.  
|              | • Capacity-building: Public investment in R&D, workforce training.  
|              | • Cooperative: Technology transfer, public-private partnerships.  |
| External factors | • Maximum size of market for EVs (population, extent of road transport).  
|              | • Energy sources (oil prices, market share of renewable electricity).  |
| Policy impacts | • Economic: Economic value added, investments, net growth in jobs.  
| Policy impacts | • Financial: Cost to consumer (purchase price/taxes), operating costs (battery, electricity, chargers at home/workplace).  
|              | • Environmental: CO2 emissions, air pollution, cleanliness and noise level of the urban environment.  
|              | • Energy-related: Local demand for electricity (burden on the grid), demand for gasoline/diesel (oil imports).  
|              | • Infrastructure-related: Number of public charging points, off-street parking/charging facilities.  
|              | • Transportation-related: Consumer-level decisions (adoption rate of EVs/value of ownership), market share of ULEVs (annual sales of EVs as a proportion of new car sales).  
|              | • Technology-related: Battery range, lifetime performance and charging time, infrastructure innovation (e.g. smart grid).  |
The IA process requires the construction of a ‘business as usual’ (BAU) scenario, in which it is assumed that no change to the current policy instruments occurs, in order to show how a particular problem will evolve in the future in the absence of further policy intervention.

In addition, the impacts associated with each policy option should be compared against baseline levels. The development of a model baseline involves: (i) deciding on the assumptions governing how to represent the existing policy framework for the relevant sector; and (ii) making assumptions for a defined future time horizon regarding the evolution of important macroeconomic and socio-economic variables such as GDP, demographic structure, energy prices.

Figure 5 shows the GUI of the Sense4us policy modelling and simulation tool. This provides a user-friendly interface for:
- The ‘checklist editor’\(^\text{16}\), which allows users to edit a tree structure containing the different categories for the model elements, in order to populate it with concepts (actors and variables) resulting from the surveying or information searching processes;
- The ‘labelled causal map graphing canvas’, which enables users to build policy models by mapping model elements and their interrelationships to a graphical representation. This operates in two modes: a modelling mode and a simulation mode.

\textbf{Figure 5} GUI for the policy modelling and simulation tool

\(^{16}\) The checklist editor was developed within the Sense4us ‘Integration of proof of concept’ work package platform, in order to obtain input from the linked open data and sentiment analysis tools.
In modelling mode (see Figure 6), the user can create, edit, save, load and delete models. The user can add elements, i.e. actors and variables, to the model by clicking on the respective icon from the model elements toolbar in the left-hand panel. Clicking a node allows the user to edit its properties and perform the functions that appear in the right-hand panel, including: (i) for actors: name, description, delete actor, delete control flows, randomise colour of the control flow; (ii) for variables: name, description, baseline level, unit of measurement and delete node.

The user can refine the model structure, adding control flows and causal links, either by clicking on the red dot that appears beside the element or by right-clicking and dragging it to the respective downstream variable. Clicking on a causal link allows the user to edit the link properties (coefficient, time lag and minimum threshold). Each causal link is shown in green if the change transfer coefficient is positive, in red if the coefficient is negative, and in grey when the link is selected. In simulation mode (see Figure 7), the user can define the time step for the simulation model in terms of weeks, months or years, and a maximum number of iterations, which appears as the limit on the simulation time slider. A scenario editor is used to define scenarios of change for the independent variables (policy instruments and external factors), for which timely percentage changes relative to baseline levels appear in the properties of the node. The ‘simulate’ button populates the model variables throughout the model with the transferred changes, which are updated by moving the time slider.
The ‘line graph’ button shows a line graph for the simulation results for each of the model variables in different colours, by selecting the respective nodes. Figure 8 shows the visualisation of results using line graphs for the selected nodes.

To analyse the impact of different policy options, we need to define scenarios of change at the levels of the policy instrumental variables. These scenarios are compared to the BAU scenario. The changes in the variables are expressed as percentage changes relative to the baseline level at different
points of time. The chosen time step is six months and maximum number of
the simulation iterations is 10, (time points are of T0 to T10).
Here we consider two different policy options or scenarios of change in policy
instruments, and these are presented in Table 3.

Table 3. Scenario simulation of policy options for the case of ULEV\textsuperscript{s} in the UK

<table>
<thead>
<tr>
<th>Policy option</th>
<th>Policy instrument</th>
<th>Relative change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Plug-in grant: gradual”</td>
<td>Direct subsidies for ULEV\textsuperscript{s}</td>
<td>+10% at T0, +10% at T2, +10% at T4, −10% at T6, −10% at T8, −10% at T10</td>
</tr>
<tr>
<td>(Scenario 1)</td>
<td>Ownership tax benefits</td>
<td>+5% every two years</td>
</tr>
<tr>
<td></td>
<td>Subsidies for private charging points</td>
<td>+10% at T0 and +10% at T5</td>
</tr>
<tr>
<td></td>
<td>Investment charging infrastructure</td>
<td>+20% at T0 and +20% at T2</td>
</tr>
<tr>
<td>“Plug-in grant: once”</td>
<td>Direct subsidies for ULEV\textsuperscript{s}</td>
<td>+35% at T0 and −35% at T6</td>
</tr>
<tr>
<td>(Scenario 2)</td>
<td>Ownership tax benefits</td>
<td>+5% every two years</td>
</tr>
<tr>
<td></td>
<td>Subsidies for private charging points</td>
<td>+10% at T0 and +10% at T5</td>
</tr>
<tr>
<td></td>
<td>Investment/funding charging infrastructure</td>
<td>+20% at T0 and +20% at T2</td>
</tr>
</tbody>
</table>

In the ‘plug-in grant: gradual’ scenario, direct subsidies for ULEV\textsuperscript{s} are
introduced and then withdrawn gradually each year, while, in the ‘plug-in grant: once’ scenario, the direct subsidies are introduced in the first year and
then fully withdrawn at the beginning of the third year. Both scenarios involve
the same levels and durations of ownership taxes and fee incentives, subsidies
for the deployment of charge points at home or in the workplace, and public
funding for and/or investment in publicly available charging infrastructure. By
comparing the simulation results for these scenarios, we can observe how
different objectives benefit from different policy instruments. MCDE can
provide an assessment of these scenarios.

4.6 Common Policy Appraisal Format and Preference
Elicitation

Public policy decision processes are often characterised by the presence of
multiple and conflicting objectives and multiple stakeholders or decision
makers, who may have differing points of view. Using decision analysis
practices to provide informed public policy decisions is not a novel idea per
se; however, a policy option analysis may differ from a traditional decision
analysis endeavour in that the former does not explicitly aim to generate a
clear recommendation for a choice to be made, but instead aims to explore the problem and reveal conflicts (cf. Quade, 1982).

Prescriptive approaches for the study of such decision processes have been suggested within the field of systems thinking and in the field of MCDA. The design of the policy evaluation module aims to enable for policy makers, decision makers and policy analysts to provide preferential statements over their respective goals in a simple way.

MADM is an analytical process that brings together three components: the decision objectives, as measured by their associated attributes; the decision options or alternatives; and the decision maker’s preferences toward the importance of the attributes, as reflected by the attribute weights. When used in conjunction with a causal map, the structure and content of the map informs the building of the multi-attribute value model, in an ad hoc translation. In a similar way, the causal map can be used to elicit attributes and objectives.

Figure 9 illustrates the structure of a multi-attribute value tree, proposed as a criteria model for the evaluation of policy options. The evaluation criteria and their weights, and the underlying attributes and their weights, are used to calculate the overall performance of a policy option. The proposed evaluation criteria for the assessment of a policy intervention (or policy option) are the effectiveness, efficiency, coherence, relevance and added value of the intervention. A number of measurable attributes underpin each of these main criteria.

The attributes underlying the effectiveness and efficiency are defined by linking to the goal variables of an actor and the scenario simulation results of alternative policy options, (the dashed lines in Figure 9). For the other three criteria, a direct rating can be used, by defining value scales and/or qualitative descriptors.

**Effectiveness** measures the extent to which a policy option is successful in achieving or progressing towards its objectives. Attributes are obtained by comparing the observed changes (OC) in the goal variables (i.e. the impact variables) with the targeted changes (TC). For each policy option, the simulation results provide the OC in the goal variables, and these are used to calculate a ‘goal achievement’ score in relation to an impact variable or are aggregated for those impact variables within the same category (e.g. economic, social and environmental variables).

**Efficiency** is concerned with the financial impacts of a policy option, i.e. costs or cost savings. The evaluation of the efficiency of an option is expressed in terms of the costs and cost savings involved for governmental departments, costs to businesses (including small businesses), or costs to a stakeholder group, expressed in terms of various attributes. Efficiency evaluations can be carried out in a quantitative or a qualitative way, using the financial costs and cost benefits from the policy model and the simulation results for each policy option.
Figure 9 Common policy appraisal format

Relevance assesses the relevance of a policy option to several factors such as the policy objectives, the problems/needs, the technological advances and the citizens.

Coherence assesses the coherence of a policy option in the following ways: (i) internally, if it includes multiple policy instruments; (ii) compared to other similar interventions; (iii) compared to EU policy interventions; and (iv) compared to international obligations.
Added value assesses the policy option in terms of its increased effectiveness, legal impacts, complementarities and the need for continuing action.

By allowing for preference modelling, we can provide additional analytical insights into the controversy or acceptability of policy options, and consequently guide further policy formulation and the design of better options. The proposed preference elicitation method is a rank-based approach complemented with intuitive ways of generating a value function using proportional scores or direct ratings, in order to provide flexibility for advanced users. A prototype tool implemented by Larsson et al. (2018), called the ‘Preference Decision Wizard’17, was used for preference elicitation. It supports a hierarchy of criteria and is thus consistent with the proposed common policy appraisal format. The user interface is built upon a step-wise decision analysis process and a visual criteria hierarchy tree.

The relative global performance of a policy option for stakeholders can be calculated using the following steps:

(i) **Stakeholder groups and/or individual stakeholders:**

Stakeholder groups are represented as criteria nodes at the first level, followed by the individual stakeholders. Figure 10 shows the GUI of the prototype tool and an example that demonstrates how the stakeholder groups are defined.

![Preference Decision Wizard](image)

**Figure 10** Preference Decision Wizard: stakeholder groups

In the use case of ULEVs in the UK, identified stakeholder groups include: governmental departments, citizens who are/are not likely to switch to plug-

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17 This tool was developed as part of a national project in Sweden entitled “Decision support for municipal policy”, funded by the Swedish Association of Local Authorities and Regions. The prototype can be seen at [http://preferencedecisionwizarddevel.azurewebsites.net/](http://preferencedecisionwizarddevel.azurewebsites.net/)
in cars, electricity suppliers, manufacturers of plug-in cars, manufacturers of cars with an internal combustion engine, producers of renewable energy, producers of fossil fuel energy and power grid operators.

(ii) Evaluation criteria and the underlying attributes for each stakeholder group. Figure 11 shows the attributes underlying the effectiveness criterion for the stakeholder group governmental departments.

![Figure 11 Preference Decision Wizard: evaluation criteria](image)

(iii) Scenarios/alternative policy options common to all stakeholders. Figure 12 shows the alternative policy options that is common for all stakeholder groups and a tree representation of the attributes of interest for each group.

![Figure 12 Preference Decision Wizard: scenarios](image)

(iv) Scenario values. Alternatives are then ranked using cardinal ranking statements or surrogate value statements (using a point, an interval or both) by each stakeholder (as shown in Figures 13 and 14);
(v) Criteria weights. Figure 15 shows how cardinal ranking of the criteria weights is carried out.
(vi) Decision evaluation.
This is the last step of the process and involves an embedded sensitivity analysis. When complete, the decision evaluation is then visualised for each criteria node in the tree as a bar chart of the stacked part-worth values for the direct sub-criteria of the selected criterion, presented with the results of the embedded sensitivity analysis. Figure 16(a) shows the root node of the criteria tree, which allows the visualisation of the decision evaluation results for stakeholder groups. Figure 16(b) shows the governmental department stakeholder node, which shows the decision evaluation results for the underlying attributes. The degree of confidence is derived from the level of intersection between the given scenarios.

![Figure 16 Preference Decision Wizard: decision evaluation](image-url)
5 Artefact Evaluation

The evaluation of design artefacts was defined by March and Smith (1995) as “the process of determining how well the artifact performs” (p. 254). The central purpose of a DSR evaluation is then to rigorously demonstrate the utility of the artefact being evaluated. DSR design artefacts “are assessed against criteria of value or utility – does it work?” (March and Smith, 1995).

Pries-Heje et al. (2008) described a demonstration as a light-weight evaluation to demonstrate that the artefact can work to “solve one or more instances of the problem”, i.e. to achieve its purpose in at least one context. In contrast, a full evaluation is more formal and extensive, and takes the rather positivistic stance that the activity should evaluate “how well the artifact supports a solution to the problem” (p. 57). The authors proposed a two-by-two framework of strategies for evaluation using DSR, and provided some guidance on how to choose between them. Their framework includes one dimension that contrasts naturalistic with artificial\(^{18}\) evaluation, and a second dimension contrasting ex ante with ex post\(^{19}\) evaluation (Pries-Heje et al., 2008).

Venable et al. (2012) developed an extended and comprehensive framework and method for designing the evaluation method(s) used in a particular DSR project. Their extensions are in three parts: (i) a framework extension that maps the purpose and goals of the evaluation and the artefact type, as contextual aspects that set the criteria for the design of the evaluation, to a potential evaluation strategy or strategies; (ii) a framework extension that maps a chosen evaluation strategy or strategies to candidate evaluation methods; and (iii) a process or method for using the two extended frameworks (Venable et al., 2012).

\(^{18}\) Naturalistic evaluation explores the performance of a solution technology in its real environment, and therefore embraces all of the complexities of human practice in real organisations. Artificial evaluation involves abstraction from the natural setting, and is necessarily “unreal” according to one or more of the three realities defined by Sun and Kantor (2006): real users, real systems, or real problems. The extent to which an artificial evaluation setting is unreal determines the applicability of the evaluation results to real-world use. In contrast, naturalistic evaluation offers a more critical face validity (Pries-Heje et al., 2008).

\(^{19}\) Ex post evaluation is the evaluation of an instantiated artefact, while ex ante evaluation is the evaluation of an uninstantiated artefact such as a design or model.
Prat et al. (2014) have proposed a holistic view of artefact evaluation in information systems DSR, considering the IS artefact as a global system, and have developed a hierarchy of evaluation criteria for IS artefacts (see Figure 17), organised according to the dimensions of a system (its goal, environment, structure, activity and evolution).

![Hierarchy of criteria for evaluation of IS DSR artefact (Prat et al., 2014)](image)

Figure 17 Hierarchy of criteria for evaluation of IS DSR artefact (Prat et al., 2014)

The evaluation of the prototype system implemented in this research is ex post evaluation, since it is an evaluation of an instantiated artefact. Due to the difficulty in accessing an environment suitable for a naturalistic evaluation (e.g. a governmental department), an artificial evaluation was performed by unreal users in order to demonstrate the efficient use of the tool in addressing
a real problem. The DSS tool prototype was assessed based on the following
criteria related to the ‘goal’ dimension of the evaluation model proposed by
Prat et al. (2014): (i) efficacy (the degree to which the artefact achieves its
goal); (ii) validity (the degree to which the artefact correctly achieves its goal,
which also encompasses the artefact’s reliability); and (iii) generality (the
broader the goal addressed by the artefact, the more general the artefact).

This chapter is structured as follows. Sections 5.1 and 5.2 describe the
evaluation results and present an assessment of the user benefits, using two
evaluation use cases. Section 5.3 describes the heuristic evaluation and
presents the usability testing results for the web-based prototype of the
Sense4us tool.

5.1 Evaluation Use Case 1

Paper VII presents a policy analysis of the transition to fossil-free fuels of
public transport (PT) buses in Sweden, in which an end-user, (Maria Xylia,
energy policy researcher, Department of Energy Technology, KTH Royal
Institute of Technology, Stockholm, Sweden.), tries to build a simplified
illustration of the real complexity of the policy system. The actors, policy
instruments and policy impacts that were the most relevant and had the highest
influence in relation to the scope of this paper were included. Based on
document analysis and the research done by the end-user into the problem, the
relevant concepts were identified, and a checklist of the model was developed,
based on the categories defined for the model elements, the different policy
instruments and their impacts on the volume, quality and sustainability of PT
by bus. The Sense4us policy modelling and simulation tool was used to build
a model of the policy problem in the form of a graphical representation of the
actors involved, the key variables, the control flows and the causal
dependencies (see Figure 18). The impacts of two policy options were
simulated, and the relative global performance was calculated for each option,
using the proposed common policy appraisal format and preference elicitation
method. The end-user evaluation emphasised that the tool allowed to tackle
the complexity of the system, and that the impacts of a variety of policy
instruments could be incorporated into the model. Moreover, the process
allows the involvement of the key stakeholders, in order to reflect their diverse
priorities and preferences.
Figure 18 Policy model for evaluation use case 1
5.2 Evaluation Use Case 2

Paper VIII presents an evaluation study of the policy modelling and simulation tool and its integration with MCDA, through a demonstration of the efficient use of the tool in an analysis of Finland’s immigration policies in response to sharply increasing numbers of asylum seekers in recent years. The study is based on a unique dataset, generated through a series of expert workshops facilitated by Dr. Leena Ilmola of the Advanced Systems Analysis Programme, International Institute of Applied Systems Analysis (IIASA), Austria.

The use of the model element categories of the Sense4us tool played an important role in the reduction of the system and the identification of the relevant policy instrumental variables and policy impact variables. The resulting checklist reflects the actors and variables of interest to the user, which may exclude certain concepts that are difficult to measure or have a minor influence on the impacts of a policy decision.

This policy use case provided an example of a politicised and contested policy decision situation, in which the tool can: (i) take into consideration multiple perspectives on the problem; (ii) show how the available knowledge and scientific evidence can utilise in many different ways; (iii) reduce the enormous variety of influences to relatively few, and a manageable number of indicators; and (iv) incorporate the contextual influences on policymaking (e.g. political and economic environments, community sentiment etc.). Various models can be built for a policy problem using an agreed-upon checklist, and it is therefore possible to analyse these models and to assess their differences, creating the perfect conditions for public debate and collective intelligence.

5.3 Heuristic Evaluation and Usability Testing

A heuristic evaluation and moderated usability testing experiments (both on site and remote) were conducted on the Sense4us policy modelling and simulation tool by James Salisi, a health policy researcher, as part of his Master’s thesis in Health Informatics (Salisi, 2016). This formative evaluation study of the Sense4us tool prototype user interface was conducted between 4th and 11th May 2016. The participants included health policy researchers and students from the Master’s programme in Health Informatics, Karolinska Institute, Sweden.

The study used the public health policy case of childhood obesity in the UK, at a national level. The UK government is considering imposing a tax on sugar-sweetened beverages (SSB) (carbonated drinks, energy drinks, etc.). The goal of the UK government is to create a sustained downward trend in the
level of excess weight in children by 2020. Taxation is expected to drive up the prices of SSBs and to reduce their consumption, thereby reducing calorie intake and thus the prevalence of obesity. In addition to these measures, the UK government is also considering doubling the subsidy for physical education classes in schools, which is expected to increase the average physical activity of children and thus drive down the rates of obesity; however, the potential impact of physical activity is not well understood, although the direction in which it affects obesity is known.

A literature search was conducted in order to understand and define the chosen health policy problem of the prevention of childhood obesity and its impacts. Based on the research results, a causal map or model of the obesity problem was constructed (see Figure 19).

Figure 19 Policy model for the children obesity use case (source: Salisi, 2016).

In order to add quantifications to this model, the change transfer coefficients were estimated based on assumptions rooted in the available scientific literature and policy reports, in order to define the baseline levels of the model variables and quantify their interrelationships. Examples are given below of causal inferences and evidence information on possible policy impacts from studies in different countries:
- In Ireland, a 10% tax on SSBs is found to result in a lower energy intake of 2.1 kcal/person/day. This is predicted to reduce the percentage of the obese adult population (BMI > 30 kg/m2) by 1.3% (Briggs et al., 2013).
- Elasticity estimates and a hypothetical 20% effective tax rate (or about 0.5 cents per ounce) were applied to beverage intake data from a nationally representative survey, and an average daily reduction of 34–47 calories among adults and 40–51 calories among children were found (Colchero et al., 2015).

- In Berkeley, an assessment of the short-term ability to increase retail prices using a US excise tax of one cent per ounce on the distribution of SSBs revealed that the tax indeed resulted in higher retail prices. Overall, the pass-through rate for for SSBs was 0.47 cents per ounce, or 47%. A pass-through rate of 69% was found for the price of soda in Berkeley, in comparison with other cities (0.69 cents per ounce). For fruit-flavoured beverages, the pass-through rate was 0.47 cents per ounce, while for sweetened teas, the pass-through rate was the lowest at 0.32 cents per ounce (Falbe et al., 2015).

- An excise tax of one cent per ounce, or a 20% tax on SSBs, is estimated to raise UK revenue by 1 bn per year, or an increase of 1/500 or 0.2%, based on average annual revenue of 500 bn (Mason and Clarke, 2015).

- Physical education classes can increase the average time spent on physical activity by 31 minutes per week or 37%, based on a baseline average of 84 minutes per week (Cawley et al., 2007).

- A 10% increase in income is associated with a 0.5 percentage point decline in obesity rates, from 17.5% to 17.0% (Chou et al, 2004).

In general, the most common usability issues can be grouped into the following categories:
(i) issues concerning feedback and user freedom, including limited user control and freedom, poor visibility of the system status and poor consistency and standards; and
(ii) issues related to help and documentation, including a lack of help and documentation, poor error prevention and poor levels of help in recognising, diagnosing and recovering from errors.

Table 4 presents an assessment based on Nielsen’s (1995), ten usability heuristics for user interface design, which are general principles for interaction design in software systems.

<table>
<thead>
<tr>
<th>Usability heuristics</th>
<th>Issues identified by evaluators and selected comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visibility of the system status</td>
<td>Two contrasting opinions were expressed. Although one evaluator felt that the “the system was responsive enough and gave the users an appropriate amount of feedback”, another wrote “I did not recognise any feedback given”.</td>
</tr>
<tr>
<td>Match between system and the real world</td>
<td>The evaluators generally agreed that the tool follows real-world conventions in terms of language. They found the language used in naming the actors and variables familiar. The tool also allows for a certain amount of customisation</td>
</tr>
</tbody>
</table>
in naming these. However, another evaluator pointed out that “technical knowledge is needed to understand what the icons represent, e.g. financial versus fiscal instruments”.

| User control and freedom | All evaluators had difficulties in cancelling and/or undoing an action. E4 suggested a design improvement involving “[a] single click instead of a double click to select an element in the model”.
| Consistency and standards | Two evaluators had problems with the icons: one wanted “clarity about some of the icons” in terms of what they represent and how they differ, while another found the icons to be “too small”. One evaluator pointed out that “the link between the actor and the instrument is not... intuitive”, in contrast to the causal links between variables.
| Error prevention | One evaluator highlighted the lack of error messages in this prototype.

**Recognition rather than recall**

Most evaluators found that the tool satisfied this heuristic. Spending time with the tool and the brief provided on how to use it helped many evaluators in familiarising and recognising the functions easily “Once familiar with the system, recognising the functions is easy. I read the brief more than a couple of times before getting the finer details, specifically for the transmission channels and simulation”. An evaluator suggested adding tool tips, such as “pop-up labels on the side bar where different elements can be added”.

**Flexibility and efficiency of use**

Three of the evaluators found that the tool satisfied this heuristic to a certain degree. Based on the limited setting of the test, they found the system sufficiently flexible and efficient.

**Aesthetic and minimalist design**

All evaluators found the design simple and aesthetically pleasing: “the icons are intuitive; the design allows flexibility and specificity at the same time”.

**Help users recognise, diagnose and recover from errors**

In general, the evaluators noted the lack of error messages in the tool. One of them suggested that “a visual cue should pop up for a first-time user” when an error is made.

**Help and documentation**

All evaluators felt that this aspect of the tool should be addressed and that it would be helpful to do so. E2 reported that “Help information was not accessible (outside of the briefing document, there is none)” and suggested that “pop-up information can help in the first couple of tries, as in Google/Facebook (e.g. the system should try to predict the common relationship between icons)”.
The tasks involved in usability testing included: (i) the creation of a labelled causal map (policy model) for the problem (creating actors and variables, and renaming labels, control flows and causal links); and (ii) the simulation of a scenario of change (navigating to the ‘scenario editor’ and create a new scenario, adding rows/steps to policy instruments, navigating to the ‘simulate’ button, running the model, advancing a certain number of time steps using the slider, and describing the results).

Salisi (2016) performed an assessment of the usability issues of the Sense4us modelling and simulation tool in terms of its task ratings, task completion success rate, time spent on the task and the errors made. Upon completion of the tasks, the usability testers provided feedback in regard to what they liked most and least about the Sense4us tool, and offered recommendations for improving it.

The participants liked the simple design and aesthetics of the user interface and the relative ease with which they could learn the tool. However, many of the problems that they identified were related to the poor visibility of the system status, poor feedback, and limited user freedom.
6 Discussion

This chapter lays emphasis on the interpretation and importance of the findings by raising a number of discussion points for each research question, following the research principles of abstraction, originality, justification and benefit of design-oriented IS research (Österle et al., 2011). In Section 6.1, the findings of the three research questions are discussed in order to explicate the design knowledge based on the four research principles. Section 6.2, provides a reflection on research work conducted to highlight how this research addressed the challenges in practice through an academic endeavour. Section 6.2 presents the author’s contributions to each of the papers published during the course of this research.

The context for discussion of the findings from this research is driven by the principles of design-oriented IS research. Chapter 1 presented the background to the research, the research problem, research questions and justification of the research along with an introduction to the methodology, definition of key terms, scope delimitations and key assumptions of this research. Chapter 2 identified research opportunities based on the literature review findings. Based on the justified research problem, a research gap that suggests the lack of operational approaches and/or formal methods of facilitating the cognitive activity of structuring public policy problems and prescribing preferred policies. To address the research gap, a policy-oriented PSM to conduct policy IAs facilitated by a DSS is a novel research opportunity that is explored in this research. The proposed systems modelling, simulation and decision analysis approach is operationalised as a DSS prototype tool in this research.

Chapter 3 described and justified the research philosophy, research design and the DSR methodology applied in this research. The design knowledge presented in this research includes description of the model-based decision support framework, the labelled causal mapping method, text analysis to support policy modelling, multi-criteria evaluation of policy options using a common policy appraisal format and a preference elicitation method. The design knowledge in this research, however, had not yet evolved to the stage where it could be termed “design theory”. Further, it had undergone only limited testing.
The interpretations in this chapter are provided within the context of the study findings from chapters 4 and 5 and prior research findings reviewed in Chapter 2. Based on the design knowledge obtained, the contribution of the study to research and practice in the area of ICT for governance and Policy modelling is presented in chapter 7, the conclusion chapter.

6.1 Discussion of Research Questions

RQ1: How to support the structuring of public policy problems, design of policy options and impact assessment using ICT tools?

This research confirmed the advantages of the use of formal methods in policy IAs for answering sensitive, far-reaching and controversial questions, including:

(i) The ability to identify, consider and apply the body of available knowledge and reducing the risk of overlooking contradictory evidence.

(ii) Allowing more precise statement of the degree of uncertainty, (e.g., we are 90-percent confident that the number of jobs will increase by 1,000 to 1,500 for each increase in business start-ups by 100). The more precisely we state the degree of uncertainty, the more complete, and the more useful, our prediction will be.

(iii) The ability to review other people’s projections, make our own and replicate analyses. Thus, raise confidence in findings and promote quality. Formulating and understanding the situation and its complex dynamics is key in finding holistic solutions. This indicates a systems approach to policy analysis that is integrative, holistic, and inter-subjective. In order to identify policy alternatives addressing the underlying problem situation, policy makers need a problem definition that: (i) reflects the systemic nature of some central policy areas, for which a regulation/policy needs to be based on a view of the system as a whole; and (ii) provides a visual problem model, in order to clearly explain complexity and interrelationships, communicate policy makers’ thoughts and bring together different policy actors.

Based on the process model for the policymaking process presented in Section 2.1, the underlying activities for the policy formulation stage and the task challenges were identified. Research opportunities were identified through a literature review of the systems thinking approach, systems science methods, model-based decision support and OR methods for policy analysis. With the help of the end-users requirements and the DSS technology features to address such requirements, design principles were developed for the proposed policy modelling, simulation and decision analysis approach. A DSS can be used to automatically store and analyse data and models. The knowledge-based DSS can efficiently draw on expert knowledge of process
improvements from its knowledge base. In this way data analysis can be low cost and happens in real time for each assessment. Moreover DSS can extend the bounds of rationality for decision makers through their capabilities. The structure of the DSS that facilitates the research artefact was presented in Section 2.2.

There are three elements in Chapter 4 that explicitly answered RQ1. First, the decision support framework (Section 4.2) established a concrete set of design principles in order to develop the research artefact. Second, the labelled causal mapping method, a policy-oriented quantitative PSM (Section 4.3). Third, the Sense4us policy modelling and simulation tool (Section 4.4) illustrates how the solution was developed and how it is intended to be used. These findings are discussed in Chapter 4. Based on this premise, four discussion points related to the findings of RQ1 are presented next.

The effectiveness of PSMs based on cognitive maps in general, in terms of the structuring, modelling and simulation of strategic problem situations, is an area for further research. Acar (1983) investigated the pragmatic usefulness of the causal mapping and situation formulation method for problem framing and systems analysis in both group (dialectical) and individual causal graphing and learning. Acar’s causal mapping method satisfies the following design conditions:

(i) Capturing the problematic situation providing the problem context;
(ii) Identifying key variables, distinguishing between the controllable (decision) and uncontrollable variables, and acknowledging the existence of key actors and tracking their objectives;
(iii) Clarifying implicit assumptions about the causal relationships among large networks of interacting elements (objectives, variables, qualitative factors and constraints);
(iv) Using a graphical support (representation), as a dialectical process for analysing assumptions and scenario implications;
(v) Being simple, robust, easy to control, adaptive, easy to communicate with and as complete as possible;
(vi) Accommodating several concepts of strategic consulting such as positioning, vulnerability, competitiveness, strategy, tactics; and
(vii) Conceptualisation: Employing OR concepts such as notions of feasibility, probability, cardinal utility, optimality and linearity assumptions (Acar, 1983).

The modelling of policy problems deals with complex systems that are usually characterised by insufficient knowledge and unresolvable uncertainties. Thus, the modeller needs to deal with imperfect or uncertain data and to make simplifications, estimations and assumptions in terms of details and mechanisms. A critical assessment of the assumptions used in the
construction of the model is recommended, in order to determine whether they are realistic and relevant to the problem at hand and to identify misjudgements or bad estimations of model parameters.

Transparency of the models and modelling approaches can enhance the quality of the models and their outputs. Highly complex models can result in a very high number of equations, and can therefore be difficult to solve computationally (Ferrara et al., 2010). The basic linearity of the system may be a focus of criticism, but this allows the level of detail of the model to be increased by adding as many elements as necessary to represent the relevant factors affecting the outcome of a decision. This increases the model’s capability for use in policy analysis, without affecting its feasibility in terms of mathematical tractability and data requirements. In addition, the definition of time lags, the use of minimum threshold quantifications for the change transmission channels and the existence of the half-channels add a meaningful dimension of nonlinearity to the model.

Sensitivity analysis measures how the uncertainty in the model input variables contributes to the uncertainty in the model output, and is therefore a numerical analysis which requires uncertainties to be quantified. Sensitivity auditing, on the other hand, is a wider consideration of the effects of all types of uncertainty, including the structural assumptions embedded in the model and the subjective decisions taken in the framing of the problem. Sensitivity auditing contains sensitivity analysis as part of its procedure.

**RQ2: How to support a multi-criteria evaluation of policy options, based on impact assessment results and taking into account the preferences of policy makers and stakeholders using ICT tools?**

This research integrated a MCDA approach to the scenario construction and dynamic simulation of policy consequences of the ‘labelled causal mapping’ PSM. This allows to reveal key uncertainties related to the evaluation criteria for policy options that will be implemented in the future and their importance to stakeholders. Further, the use of a preference elicitation method should then allow decision makers to provide preferential information on policy impacts, enabling the building of MCDA models. Section 4.6 explicitly answers RQ2. A MCDA approach was used to develop a common policy appraisal format in conjunction with the causal mapping model. A MADM model was developed using main evaluation criteria linked to a set of measurable context-dependent attributes (impact variables of interest from the policy simulation model). Data formats are defined using both the simulation results for assessment of the effectiveness and efficiency of policy options; and direct rating using value scales or qualitative descriptors for assessment of the relevance, coherence and added value of policy options. The proposed preference elicitation method is a rank-based approach complemented with intuitive ways of generating a value function using proportional scores or direct ratings, in order to provide
flexibility for advanced users. The rationale for the choice of a method is that it should: (i) not require substantial formal decision analysis knowledge; (ii) not be too cognitively demanding by forcing people to express unrealistic precision or to state more than they are able to; (iii) not require too much time; (iv) make use of the information the decision-maker is actually able to supply, and (v) be supported through a GUI accessible from different client operating systems.

**RQ3: How fit for use are these decision support tools in problem analysis, impact assessment, and evaluation activities related to policy formulation?**

Although evaluation plays a major part in DSR, very little guidance and examples have been provided in literature on how one could actually discuss evaluation in DSR. This research developed evaluation strategies and protocols based on the DSR strategic evaluation framework presented by Pries-Heje et al., (2008) and Prat et al. (2014). Two use cases were employed for the evaluation of the proposed approach and the DSS tool prototype. In addition, a formative evaluation of the Sense4us policy modelling and simulation tool was conducted through heuristic evaluation and moderated usability testing experiments (both on site and remote) by Salisi, (2016). The results of usability evaluation and outcome evaluation (reported in Chapter 5) answered RQ3. Furthermore, with the aid of longitudinal data from repeated use of the DSS prototype, it would be possible to conduct more extensive outcome evaluation of the approach. Due to temporal constraints, this is beyond the scope of this research project.

### 6.2 Reflection on Research Work

A critical reflection on research activities can create unique connections between disparate sets of research knowledge and consequently new perspectives about this research can be developed (Jasper 2005).

The DSR methodology was found to be highly suitable to develop an artefact to solve a research problem and to evaluate the practical utility of the artefact. The focus on practical utility provides researchers with results that are more readily endorsed, thus maximising the impact of the research findings in practice. This allows dissemination of research results; provides a strong evidence of relevance of the research artefact, Sense4us DSS tools for prescriptive policy analysis based on the ‘labelled causal mapping’ approach and thereby illustrates an example of effective rigour-relevance balance in DSR (Kuechler and Vaishnavi, 2011). The two aspects of DSR activity, academic rigour and industry relevance (Straub and Ang, 2011), enabled this
A participatory research approach was undertaken by the research team to combine their shared knowledge and collective experience in policy IAs domain in order to develop the proposed approach. The most prominent experience while developing the artefact was the advantage of working in a multi-disciplinary team comprising academic staff, practitioners and experts on the EU policymaking. This researcher learnt that good teamwork is the key to success in DSR activities when time and resources are limited. An excellent working relationship with the Sens4us project’s research and end-user partners, key insights and ongoing support from academic supervisors ensured that the research artefact was developed to meet the research objectives. In addition, the co-operation with policy researchers in two use-case evaluation studies on two different policy areas allowed to evaluate the usability and outcome of the approach and the DSS tool prototype according to the three usability criteria used: efficacy, validity and generality.

6.3 Author’s Contributions

The author’s contributions to each paper are as follows:

**Paper I: “An integrated decision support system framework for strategic planning in higher education”**

As first author, I contributed to this paper by:

(i) Designing the modules of a DSS to be used by higher educational institutions to implement their strategic planning processes, based on the adopted process model for strategic planning.

(ii) Designing a collaborative framework for coordination of the planning activities at the different institutional levels.

**Paper II: “A causal mapping simulation for scenario planning and impact assessment in public policy problems: The case of the EU 2030 Climate and Energy Framework”**

As first author, I contributed to this paper by:

(i) Highlighting the challenges facing the policymaking process and the research gaps related to the concept and application of modelling and simulation techniques for policy analysis.

(ii) Proposing a decision support framework for policy formulation.

(iii) Introducing Acar’s causal mapping as a systematic method for the structuring of policy problems.
(iv) Developing a methodology for text synthesis (the grammatical and semantic analysis of text-based information), in order to support the construction of a causal mapping model of the problem.
(v) Designing a simulation tool based on the causal mapping method.
(v) For the case study of the EU 2030 Climate and Energy Framework, building a qualitative causal diagram of the problem based on textual data from an assessment report and two research papers.

*Paper III: “Text analysis to support structuring and modelling a public policy problem: Outline of an algorithm to extract inferences from textual data”*

As a co-author, I contributed to this paper by:
(i) Formulating the research problem, lack of text analysis algorithms that support structuring of policy problem situations using causal mapping.
(ii) Proposing the analysis of text-based information on the policy problem, using NLP and text analysis techniques, as a solution;
(iii) Defining the approach, based on the methodology developed in Paper II.
(iv) Participating in defining the algorithm framework and implementation modules.

*Paper IV: “Modelling for policy formulation: Causal mapping, scenario generation, and decision evaluation”*

As a co-author, I contributed to this paper by:
(i) Developing the three-stage process model for policy-making;
(ii) Defining an approach for problem analysis through problem structuring using causal mapping, in which multiple perspectives of the problem from different actors are represented and debated;
(iii) Proposing the change transfer analysis of the causal mapping method for the design and generation of policy options;
(iv) Proposing the integration of MCDA techniques to evaluate the considered policy options based on their simulated impacts.

*Paper V: “A systems tool for structuring public policy problems and design of policy options”*

As first author, I contributed to this paper by:
(i) Formulating the research question and design objectives for the policy modelling and simulation tool;
(ii) Carrying out a literature review of the systems approach to policy analysis and discussing the feasibility of systems science methods, system dynamics and agent-based simulation modelling;
(ii) Designing the labelled causal mapping technique as a policy-oriented version of Acar’s causal mapping;
(iii) Developing the model-building process;
(iv) Designing the tool, based on the model components of the labelled causal mapping approach, and addressing the problem of complexity of causal loops in the models and the calculation of successive waves of change in an object-oriented implementation;
(v) Developing demonstration policy use cases.

**Paper VI: “Multi-stakeholder preference analysis in ex-ante evaluation of policy options - Use case: ultra low emission vehicles in UK”**

As a co-author, I contributed to this paper by:
(i) Designing a common policy appraisal format.
(ii) Choosing a preference elicitation method.

**Paper VII: “Fossil-free public transport: Prescriptive policy analysis for the Swedish bus fleets”**

The paper presents an evaluation study of the DSS tools of ‘policy modelling and simulation’ and ‘policy evaluation’.
As a co-author of the paper, I contributed to this work by:
(i) Introducing the policy researcher to the approach and to the Sense4us modelling and simulation tool prototype, the MCDA evaluation model and preference elicitation method;
(ii) Participation in the conceptual, empirical and operational analyses of the problem.


This paper also presents an evaluation study of the policy modelling and simulation tool prototype and the application of the common policy appraisal format.
As a co-author of the paper, I contributed to this work by:
(i) Introducing the policy researcher to the approach and the Sense4us modelling and simulation tool prototype and the MCDA evaluation model;
(ii) Participation in the conceptual, empirical and operational analyses of the problem.
7 Conclusion

Contributions made from a DSR study can be in the form of viable artefacts and at more abstract levels. Using the DSR contribution types presented by Gregor and Hevner (2013), Level 1 and Level 2 contributions are evident in this research. Table 7.1 presents the contribution types in this research. At level 1, situated implementation was constructed as a DSS for policy formulation. Likewise a more general artefact in the form of a policy-oriented PSM is proposed as the level 2 contribution.

<table>
<thead>
<tr>
<th>Contribution Type</th>
<th>Research artefact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 3. Comprehensive design theory</td>
<td>None</td>
</tr>
<tr>
<td>Level 2. Nascent design theory – knowledge as operational principles</td>
<td>Labelled causal mapping method and integration to MCDA</td>
</tr>
<tr>
<td>Level 1. Situated implementation of artefact</td>
<td>DSS tools for policy modelling, simulation and decision analysis</td>
</tr>
</tbody>
</table>

The DSR knowledge contribution framework has four quadrants according to the maturity of research problem and solution: *Invention; Improvement; Exaptation;* and *Routine Design* (Gregor & Hevner 2013). The contribution of this research resides in the *Improvement* quadrant since this research proposed new solutions for known problems. The goal of this research is to create better solutions in the form of a formal method to conduct problem analysis, IA and evaluation activities related to policy formulation. One of the key challenges in this quadrant is to clearly demonstrate that the improved solution builds upon previous knowledge. Chapters 2, 4, 5 and 6 demonstrated how the proposed approach can be positioned to build design knowledge.

This research makes several contributions to the existing knowledge of policy modelling, simulation and decision analysis, both through the prescriptive (design) knowledge developed using an iterative design process and the IS artefact itself. Firstly, it uses a unique combination of a systems thinking approach, problem-structuring methods, scenario planning and MCDA. Secondly, it proposes a solution that can mitigate the cognitive overload involved in representing complex mental models using system dynamics simulation modelling. Thirdly, it contributes to the use of PSMs
based on cognitive maps to model complex strategic decision-making problems using a graphical representation, as both a knowledge representation technique and a system analysis tool. Finally, the method provides a basis for integrating such maps with modern decision evaluation techniques for further computational decision analysis, game-theoretic analysis and negotiation analysis.

Further, this research makes an important contribution to design science theory by demonstrating a DSR approach to develop a method as a research artefact that is also operationalised as a DSS. The detailed explanation of prior theories, expository examples, and use-case evaluations provide an example of how to confront the challenges of presenting design work for a novel approach. Drawing upon extant DSR methodology, the approach is well suited for IS research to balance the dual requirements of rigor and relevance.

The proposed decision support framework adapts several frameworks, resulting in a new construct that gives policymakers the ability to be more successful in achieving societal goals and dealing with societal problems. It provides the following benefits to decision makers:

- A deep understanding of the embedded learning process, as they move from perceiving a situation ‘fuzzily’ to ‘qualitatively’ to ‘quantitatively’ while mapping their policy decision situation;
- Capture of the time delays and systemic effects of policies or actions for change, due to the fact that cause and effect are often distant in time;
- An understanding of the policy implications through the quantitative simulation of various scenarios of change, assessing policy consequences and thus refining the model (the planning of change from the current situation);
- A guide for prioritisation, planning for resource efficiency, contextual orientation and realistic change stimulation;
- A framework for future research and evaluation of policy implementation;
- Facilitation of cross-sectoral communication and synthesis of knowledge;
- A representation of the social dynamics of the multiple actors involved in the policy context (relationships, interests, powers, goals) and the modelling of these as a cooperative or a competitive (game theoretic) situation.

In addition to a knowledge contribution, effective DSR should make clear contributions to the real-world application environment from which the research problem or opportunity is drawn (Hevner et al., 2004).

An assessment of the benefits to the user offered by the DSS tools gives rise to the following points:

1- Although the development of user-created scenarios is a serious and time-consuming task, it helps the user to develop advanced skills and gain a deeper understanding of the problem;
2- Users can create more complex models with a wider perspective using the sub-models or blocks developed here;
3- Users can identify how the information obtained from governmental open data and an analysis of political discussions on social media can contribute to an increased understanding of the problem;
4- The data requirements for the quantification, sensitivity analysis and validation of models define which information is relevant in evaluating policy scenarios, in addition to engaging users in cumulative learning through experimentation. Validation of the model, which is done by the user, is simplified to the validation of sub-models, the determination of model parameters from validated sources and ensuring the plausibility of outcomes. The quality control of the model is limited to the plausibility and the degree of completeness of the model (the inclusion of all factors and phenomena that may influence the outcomes of a decision);
5- The problem definition is shared among the different governmental departments and involved parties;
6- An understanding of the problem is facilitated using a graphical representation and visualisations of the impacts over time;
7- New knowledge is synthesised about the system when a satisfying result is achieved or when a complete understanding of the system is gained.

Possibilities for future work include:
- The integration of text analysis algorithms for causal inference extraction from textual data, using NLP at the implementation level.
- The implementation of the chosen preference elicitation method, and its integration into the policy modelling and simulation tool.
- The stakeholder analysis relevant analytical applications and the formats for the profiling and segmentation of stakeholders can enable an appraisal of the policy from the perspective of multiple stakeholders with different priorities and preferences, and offer systematic tools for eliciting preferences from stakeholders and decision makers.
APPENDIX – Technical Specifications

Infrastructure

The implementation of the simulation tool is split between two servers; the first pushes the front-end to a client, and the second calculates and stores simulation calculations. In this way, we separate computationally expensive (cycle-eating) tasks from the user’s client. Since a server is doing these calculations, we already have access to networks or similar structures, and can save relevant data as we see fit. The front-end client, which runs in any modern browser, can fetch and push information to the back-end server, e.g. loading networks, saving networks, and simulating change. This is done through AJAX calls. Both servers currently operate without any type of authentication, meaning that anyone with sufficient knowledge could gain access to extra tools and thus create a denial of service. However, it would probably be more likely that for this person would abuse NTP servers or something similar. This tool should therefore not be hosted or advertised publicly without user management. These repositories are intended as a proof of concept.

Front-end server

Description: This server exposes all the public JavaScript relevant to the front-end. It runs behind an MVC framework, since this makes it easier to organise and split up entry points for pre-loading models etc. The client is based on a framework called Immutable, which encourages ‘data in, data out’. Almost all of the interface is generated from settings files. The core of the client is within the file main.js, which initialises the environment.

Language(s): Javascript running through Node.js in the back-end; JavaScript running in the client’s browser; CSS3/HTML.

Libraries (as seen in package.json)

/* External */
body-parser
cookie-parser
connect
ejs
express
iconv-lite
browserify
immutable
uglify-js
watchify

/* Developed in-house */
rh_config-parser
rh_cookie-cutter
rh_fe
rh_fe-controller
rh_logger
rh_router
**Back-end server**

**Description:** The purpose of this server is simply to expose an API, without any kind of coupling. The reference sheet may be found in the Resources section below. Currently, the primary functions of this server are to save and load data and to simulate changes in a network. The API’s entry points are exposed using an MVC design. All calls are REST-based, and comply with the relevant standards. GET requests receive data, POST saves data, PUT/PATCH updates data, and DELETE removes data. The structure of these requests and responses is available in the reference sheet.

**Language(s):** Javascript running through Node.js

**Libraries (as seen in package.json)**

/* External */

- body-parser
- connect
- cookie-parser
- debug
- ejs
- ejs-locals
- express
- iconv-lite
- pg-sync

/* Developed in-house */

- rh_config-parser
- rh_cookie-cutter
- rh_database-layer
- rh_fe
- rh_fe-controller
- rh_logger
- rh_model
- rh_model-layer
- rh_router
- rh_user-manager

**Resources**

- Node.js [https://nodejs.org/](https://nodejs.org/)
- Front-end repository [https://github.com/eGovlab/sense4us-simulation](https://github.com/eGovlab/sense4us-simulation)
- Back-end repository [https://github.com/Rhineheart/sense4us-simulation-server](https://github.com/Rhineheart/sense4us-simulation-server)
- Back-end API reference sheet [https://docs.google.com/document/d/1HtITy9CV7yrXSIGCr8ITJKj0H-XlbZ7c-SolNFI/edit?usp=sharing](https://docs.google.com/document/d/1HtITy9CV7yrXSIGCr8ITJKj0H-XlbZ7c-SolNFI/edit?usp=sharing)
References


REFERENCES


Tsadiras, A.K., Papadopoulos, C.T. and O’Kelly, M.E. (2013). An artificial neural network based decision support system for solving the buffer allocation problem


