



DECIPHER

Holistic decision-making for climate & environment

D5.1

Contours of a novel framework of Risk-
Opportunity Analysis

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Scope of the document	This task first reviews (empirical) decision-making framework and then assesses relevant aspects of a holistic process framework for decision-making, based on systems thinking, that address limitations and opportunities of current decision-making frameworks. We will first review current decision-making frameworks (cost-benefit analysis, Multi-criteria, cost-effectiveness and impact assessments) used for policy appraisal in the EU and beyond in the context of new arising policy questions. We will further develop an innovative decision-making framework, Risk-Opportunity Analysis (Mercure et al 2021, Sharpe et al 2021, see www.eeist.co.uk). The Risk-Opportunity Analysis framework developed in Task 5.1 will be

	adapted for use in the context of existing processes at the Commission and Member States level with a practical set of steps designed to develop convincing evidence
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EXECUTIVE SUMMARY

In this report, we evaluate different decision-making frameworks for policy-making, including a new decision-making tool: risk-opportunity analysis. We assess these decision-making methods in the context of transformative change, particularly the transition towards green energy. We highlight limitations of common methods, with respect to their inability to deal with risk, heavy-tailed uncertainty and opportunities.

Furthermore, we discuss the policy background in Europe, reflect on differences with the UK and the US, and highlight how risk-opportunity fits within the regulatory environments of the EU and Norway.

We examine one case study—the transition towards electric vehicles in Norway—and compare cost-benefit analysis with risk-opportunity analysis. The key question to answer was whether a cost-benefit analysis would have been able to capture opportunities arising from the transition. We conclude, in a classical cost-benefit analysis, costs far outweigh benefits.

We then perform risk-opportunity analysis on the same Norwegian case study. The 5-step ROA focusses on systems mapping, policy outcomes, risk and resilience, opportunity and option creation, and communicating these to policy-making. Through systems mapping, we identify key causal loops, both self-reinforcing and balancing. We quantify a key opportunity, showing that induced innovation from Norway's EV policy, at a global scale, outweighs climate benefits. We reflect on wider benefits, not all of which can be captured quantitatively.

This case study is one of the first applications of ROA. We conclude that ROA seems to be well-placed to assess policy options, given its emphasis on economic and innovation opportunities and on integration of risks that require qualitative and quantitative judgments.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Long text
CBA	Cost-Benefit Analysis
ROA	Risk-Opportunity Analysis
CEA	Cost-Effectiveness Analysis
MCA/MCDA	Multi-Criteria Analysis/Multiple Criteria Decision Analysis
RA	Risk Assessments
FCM	Fuzzy Cognitive Mapping
PA	Portfolio Analysis
IA	Integrated Assessment
SCC	Social Cost of Carbon
EV	Electric Vehicles
CLD	Causal Loop Diagrams
VAT	Value Added Tax

Introduction

In this paper, we discuss the current decision-making frameworks used for policy appraisal in the context of both the EU and Norway. The goal is to review what policymaking frameworks exist, which ones are used in the EU, and possible drawbacks of these frameworks in the context of transformational change. We describe key frameworks such as Cost-Benefit Analysis, Cost-Effectiveness Analysis, Multiple Criteria Decision-Making, Portfolio Analysis and Fuzzy Cognitive Mapping. We detail the opportunities and limitations of these policies in the assessment of transformative change.

Many of these methods were developed with marginal changes in mind, and a policy appraisal method developed for transformational change may benefit policy domains where policy seeks to reshape sectors significantly, such as those related to climate change and energy.

We further develop Risk-Opportunity Analysis, a novel framework of decision-making initially proposed in the UK context. We first compare ROA to existing decision-making tools in the EU. We suggest in which context ROA is a sensible choice for decision-making. We then introduce a case study applying Risk-Opportunity Analysis parallel to CBA. This forms the direct comparison between ROA and CBA. We discuss under what circumstances the tools provide differing conclusions.

Policy appraisal in Europe

Policy-making in Europe is subject to continuous calls for improvement. A large set of “better regulation” and “high quality regulation” initiatives have been launched since the 1990s. Initially focussed on policy formulation, since the 2010s these agendas have also included retrospective analysis and regulatory offsetting, in which new policies require old policies to be scrapped (Dunlop and Radaelli 2022).

The 2001 Better Regulation initiative was an early EU project which sought to improve decision-making. Key objectives were simplification of regulation, reducing red tape and a larger role for key stakeholders (Wiener 2006). At this point in time, the European Commission lagged behind in terms of regulatory rigour compared to individual European countries (Dunlop and Radaelli 2022). The Impact Assessment Guidelines, launched as part of this initiative, require the use of impact assessments, which can be either cost-effectiveness analysis, benefit-cost analysis (fully quantified and monetized analysis), or multi-criteria analysis (partially quantified and partially qualitative analysis) (Wiener 2006). The impact assessments needed to include

social, environmental and economic analysis; this template for impact assessment developed at that time is still in use today (Dunlop and Radaelli 2022).

Continuous tensions are present in the agendas for regulatory reform. Some countries, notably the Netherlands and the United Kingdom, put the focus on deregulation and the removal of red tape. Others argue for more governance from the European Commission. A second major area of disagreement is present between the Commission and the Council and Parliament, where the Commission's vision on strong impact assessment is not fully shared by the two other institutions. In the 2010s, the European Parliament started adopting their own impact assessment procedures (Dunlop and Radaelli 2022).

Key developments after 2015 involved a “closing of the policy cycle”. That is, a stronger emphasis on ex-post analysis. New proposals now required an evaluation of preceding proposals. Consultations with stakeholders were also given a larger role. Finally, a Regulatory Scrutiny Board was established. The adoption of a new principle of “One In One Out” in 2019 aimed to cut down on regulatory burdens, findings outlined in Dunlop and Radaelli's analysis.

The policy cycle of the EU is described in detail in the “Better Regulation” guidelines and toolbox (European Commission, 2021). Each stage of the policy process, including policy planning, design, adoption, implementation, evaluation, and revision, is governed by six relevant instruments outlined as follows:

1. Forward planning and political validation requires prior planning, evaluation of existing policies as well as seeking political endorsement and approval.
2. Stakeholder consultation corresponds to active engagement with stakeholders, for instance collecting information and gathering practical experience and views, all aimed at delivering high quality policy initiatives.
3. Evaluation and fitness of existing regulation checks if a policy is efficient, effective, and coherent. These checks also test if the EU is the best administrative level for the policy. Evaluations support decision-making and can be conducted prior to impact assessments or launched at the same time. The evaluations judge whether the policy needs adjusting and is still needed, and checks if a policy is performing as anticipated by the impact assessment. Fitness checks involve identifying overlaps and inconsistencies in regulations and how regulations help achieve policy objectives.
4. Impact assessments assess whether policy is justified and what the best policy design is. It requires an assessment of social, environmental and economic impacts of the policy under considerations. The assessment also includes the results from the evaluation check. Formally, determining the impacts of different policy options using different methodologies, and comparing different policy options. As indicated in the guidelines, the choice of the methods to use depends on the principle of proportionate analysis.

5. Quality control involves an independent quality control body, namely the Regulatory Scrutiny Board, which reviews the quality of impact assessments, fitness checks, and evaluations.
6. Compliance support and implementation involve defining an implementation strategy to ensure that the legislation is efficiently applied.

This report develops and evaluates a novel impact assessment methodology. Notably, the exact method of impact assessment is not prescribed in the Better Regulation Guidelines. The chosen method must comply with the following:

“This assessment should inform policymakers of the extent to which different options would meet their objectives, with what benefits, at what cost, with what implications for different stakeholders, and at what risk of unintended consequences.”

In the following, we will introduce the key decision-making frameworks, and we will discuss how these tools can be relevant in assessing environmental policies in Europe.

Review of existing decision making frameworks in the context of transformational change

Various decision-making frameworks are in use or proposed for environmental policy appraisal. These policy appraisal frameworks often make use of economic models, such as integrated assessment models, and can therefore inherit the strengths and limitations of these models (Doukas and Nikas 2020).

In this section, we review common decision-making frameworks, such as cost-benefit analysis and multi-criteria analysis, as well as appraisal methods that have been suggested to mitigate weaknesses in these two methods, such as fuzzy cognitive mapping. This analysis is used in section 4 and 5 to further develop risk-opportunity analysis, a policy appraisal method designed for transformative change.

Cost benefit analysis

One of the most commonly used policy appraisal methods is Cost-Benefit Analysis (CBA). CBA assesses the impact of policy options, which are defined as benefits and costs, and derives a valuation unit (monetized measure) for each (Bateman and Department of Transport Großbritannien 2002, Treasury 2020). Ultimately, after total costs and benefits are computed, the cost is subtracted from benefits or a ratio between the two is computed. Policymakers and stakeholders can then assess the outcomes of different policy options under consideration.

In the mid-20th century, this approach was first used as a project evaluation tool and as a policy evaluation tool since the 1980s. This tool has been continuously developed and widely used in the US and the EU. To give a concrete example, the European commission formulated a policy proposal in 2013, the Clean Air Policy Package, based on a CBA methodology that employs the economic welfare-maximising emissions levels and identifies emissions targets for the year 2025. This marked one of the novel uses of CBA for policy appraisal within the EU context (Åström 2023).

In practice, the most prevalent policy assessment approach is CBA. In the EU, the norm is that policy options are compared with each other using both multiple criteria analysis and CBA (Sartori et al. 2014). CBA has been explicitly mentioned in EU regulation (Åström 2023).

Despite the broad application of CBA, there is a large literature on the many limitations of this method. In a recent study, Åström (2023) highlighted these limitations. CBA has a tendency to delay debated regulations, to inflate the costs and most importantly it underestimates health and environmental benefits of policy options, as they are often difficult to estimate accurately (Wiener 2006). In general, there is an asymmetry between costs, which are easier to measure, and more difficult-to-measure benefits (Omura 2004). For instance, it is highly difficult to quantify the economic benefits of an industry you seek to create by policy. The assumptions required to evaluate costs and benefits are essentially ethical issues (Baram 1979) (Ackerman and Heinzerling 2001). In fact, the fundamental concern with CBA is that the level of arbitrariness in estimating the costs can produce misleading monetary values, either by exaggerating or underestimating the costs, and thus, it may fail to provide accurate information (Mercure et al. 2021) (Sunstein 2005).

Doukas and Nikas (2020) emphasise the need to build a broad framework that incorporates uncertainty and environmental distributional implications, which are currently missing in CBA.

Similarly, Wise et al. (2022) list several challenges associated with the use of CBA in climate change decision-making. These challenges include, first, accounting for social and environmental benefits that can affect the results of the CBA. The difficulty in accurately measuring these benefits is discussed in (Ryu et al. 2019), who presents

a detailed description on the integration of environmental and social benefits in CBA. Second, the issue of using discount rates to evaluate benefits and costs remains a critical issue as it affects the overall results (Stern 2008, Nordhaus 2007, Arrow et al. 2013). For instance, in the EU, the official European Impact Assessment guidelines recommend a time-constant discount rate of 4 percent under the EU Industrial Emissions Directive (Donnelly, Dalal-Clayton, and Hughes 1998).

Third, the sensitivity of benefits and costs to the chosen time horizon of the analysis that has major implications. O'Mahony (2021) presents a detailed discussion of the impact of the timeframe of the costs-benefits analysis. Further, technological learning is typically not represented fully in CBA (Åström 2023). The relationship between cost and diffusion of technology is complex, as emphasised by Ha-Duong, Grubb, and Hourcade (1997) and Nordhaus (2009). These limitations, especially the limitation around the representation of innovation, were the key motivation for the development of Risk-Opportunity Analysis, which seeks to address these issues (Mercure et al. 2021).

Lastly, the statistical distributions for both costs and benefits are frequently naturally heavy-tailed and as such preclude accurate estimation of expected values, due to either or both system complexity and uncertainty. This is notably the case for the damages associated with the impacts of climate change (Weitzman 2009, Coronese et al. 2019).¹ This then implies that the real uncertainty over both costs and benefits can be so significant to render those values meaningless.

Most importantly for this report is what pertains to climate change policy, technological change, infrastructure developments and other path-dependent processes. By estimating expected values, CBA makes the assumption that parameters used are well-known and have well characterised probabilities. For instance, one expects that the willingness to pay of agents is normally distributed, therefore its average can reliably be used. However, for situations involving irreversible path-dependent system transformations, this assumption does not usually hold. The common outcome of path-dependent transformations is that probability distributions also become heavy-tailed. We explain this further below.

For example, the willingness to pay (WTP) for an electric vehicle may gradually increase as more and more electric vehicles are observed in vehicle fleets and as charging infrastructure improves, resulting in a greater proportion of agents inclined to buy them. This effect has been shown for environmental protection, where WTP increases with increased policy ambition (He and Zhang, 2021; Wang, Wang, and Xiao, 2022). This then means that the benefits of policy action depend on the ambition of the action itself, and may have multiple solutions. As the willingness to pay becomes

¹ Coronese et al. (2019) show that the probability distribution of climate damages is highly heavy-tailed, and the expected value is a highly uncertain and unreliable metric to use.

multi-valued, the benefits of action are not readily estimated as they become highly uncertain.

Other examples arise with major infrastructure spending, such as on new railway lines, which may induce transformative private sector spending on re-development, or new roads that counterintuitively induce worse traffic and exacerbate issues that the action intended to mitigate. CBA is likely to generate widely wrong assessments.

More generally, tail risk may be of interest to decision-makers. In particular, financial and fiscal risks are of increasing interest to central banks and ministries of finance (Prudential Regulation Authority 2015, Bolton et al. 2020). This requires looking beyond mean expected costs and benefits, a problem that can only be partly solved using scenario analysis. Notably, investment can be made to improve the resilience of an electricity network, but valuing resilience may be impossible if the risks are heavy-tailed, as they commonly are in complex systems. Conversely, minimising resources spent on resilience, on the basis that resilience cannot be appropriately valued in CBA, may make systems actually become more unstable and less reliable. Solving requires incorporating some representation of resilience in the decision-making framework, and no method to our knowledge exists to do so.

Cost-effectiveness analysis

Cost-effectiveness analysis (CEA) is a similar approach used to assess policy impacts. As opposed to CBA, CEA only focuses on the costs incurred to achieve a certain objective. It either seeks the cheapest option to achieve an objective, or it maximises the objective based on a fixed budget (Balana, Vinten, and Slee 2011). This method identifies the “least-cost” way to achieve a specific objective given alternative options, and helps prioritise between many proposals (Dodgson et al. 2009).

This method can inform assessments of value for money among different policy options or spending proposals, as it evaluates the affordability and feasibility of policies (Balana, Vinten, and Slee 2011).

In CBA, there is an asymmetry between costs and benefits, where costs are easier to quantify than benefits. Less certain benefits may therefore be omitted from the analysis. CEA, by having a set goal, may suffer less from this issue. This does restrict the application of the methodology to policies for which co-benefits are deemed unimportant. Other limitations of cost-effectiveness analysis are shared with CBA, as described above.

Multiple criteria decision-making

Another popular policy appraisal method is multi-criteria analysis (MCA), also called multi-criteria decision analysis (MCDA). In this framework, policy is assessed on

multiple criteria, which can be quantitative or qualitative. In contrast to CBA, the metrics are not translated into monetary values (Dodgson et al. 2009). This framework has garnered considerable attention, and is widely used in energy planning and sustainable development. It requires the engagement of policymakers and stakeholders. Konidari and Mavrakakis (2007) provide an in-depth and detailed discussion of the multi-criteria analysis, as they propose an evaluation tool for climate policy.

In the mid-1960s, the new approach was developed in France to support public authorities decisions by ranking alternatives (Roy and Vanderpooten 1996). This early work has been widely developed and used and represents the core of the modern multi-criteria analysis.

A multi-criteria analysis for climate policy as proposed in Konidari and Mavrakakis (2007) involves the following steps:

- First, defining a three-level criteria tree.
- Second, after defining all the criteria one can assign weight coefficients for each criterion according to their relevance, using the Analytic Hierarchy Process (AHP) method, and can also test the consistency of these coefficients.
- The third step involves grading each criterion using a mix of observed data and subjective choices.
- The final step involves computing the results and running a set of robustness checks to assess the sensitivity of the results to changes in the weight coefficients.

This approach also allows users setting up priorities based on a chosen balance between economic, social and environmental factors. Recent studies in this vein include the work of Shmelev and Van Den Bergh (2016), who focus on a combination of renewable energy technologies and take into account social, economic, and environmental criteria to achieve sustainable energy supply in the UK. This approach can also incorporate both quantitative and qualitative criteria, see for example Hussain Mirjat et al. (2018), who consider four scenarios for long-term electricity planning in Pakistan, and account for both quantitative (economic, technical) and qualitative (environmental, social) criteria.

Multi-criteria decision analysis also provides flexibility in accommodating various methods for assessing weights. In practice, the weighting of each criterion is performed by experts based on their significance as emphasised by Dace and Blumberga (2016), and consistency checks on the weights are often carried out to improve their validity (Hussain Mirjat et al., 2018; Ribeiro, Ferreira, and Araújo, 2013).

This methodology presents some challenges. First, practical managerial limitations might arise when the number of attributes is significantly large (Govindan, Rajendran, Sarkis, Murugesan, 2015). For instance, a large number of decision attributes or levels can make it difficult to manage and implement the analysis, especially in the

presence of superfluous, infeasible, or contradictory attributes. Secondly, the final ranking is sensitive to extreme values of the variables of interest and changes in weighting (Dace and Blumberga 2016). One way to deal with the issue is to perform a sensitivity analysis by considering various scenarios to assess the robustness of the results (Vögele et al. 2023).

Some consider the subjectivity of determining the relative importance of each criterion a drawback (Baležentis and Streimikiene 2017). While we acknowledge that this can create bias and inconsistency, we consider the advantages of engaging stakeholders in this way to outweigh the disadvantages.

For the purposes of this paper, MCA has comparable limitations as CBA when it comes to problems involving path-dependence and irreversibility. The problem lies in whether the estimations for one or more criteria will come out heavy-tailed and impossible to reliably estimate. If analysts recognize this, they can opt to make a qualitative estimation of the criterion instead, but attempts to estimate outcomes quantitative risk being misleading.

Portfolio analysis

The Portfolio Analysis (PA) approach was developed to choose an optimal portfolio of assets to invest in. It assesses risks and uncertainties, and selects a portfolio that is best aligned with preferences from the investor. The seminal work by Markowitz (1952) offers a parametric optimization model that deals with the dilemma of conflicting objectives: high profit versus low risk. Although traditionally applied to investment portfolios, this approach has also seen some applications in policy design. It uses a set of well-developed mathematical methods, based on the idea that investor preferences depend mainly on the first two moments, the mean and the variance of asset returns. Perhaps surprisingly, the use of PA in climate policy is relatively limited (Doukas and Nikas 2020).

The idea of employing modern portfolio theory to deal with the risks and uncertainties related to climate policy is not recent. A substantial body of literature has focused on evaluating climate policy investments by using portfolio analysis methods, given the convenience of this method to assess different scenarios. The seminal work of Black and Scholes (1973) assumes a log-normal distribution of outcomes; this assumption is not always true. In practice, the probability distribution of possible outcomes tends to be highly skewed, reflecting a small but substantial probability of extremely adverse outcomes. Using a portfolio analysis approach, Westner and Madlener (2010) show that diversification in CHP investments can reduce risk exposure, using a mean variance portfolio model. The two key advantages of this approach is that it takes into account uncertainty and relies on diversification in order to reduce the risk.

Other related studies include van Zon and Fuss (2006), who provided an assessment using the vintage portfolio model that takes into account eight key technology

families. They showed that when a cap on CO₂ emissions is introduced, nuclear energy and gas shares in the overall electricity mix increase considerably rather than renewable technologies. Lemoine et al. (2012) analyse optimal policy portfolios when negative emission technologies are deployed and find that anticipated negative emission strategies can shift optimal research and development funding from carbon-free technologies into emission intensity technologies. These studies indicate how the portfolio analysis can be used to identify an “optimal” policy option and the risk associated with each of these options.

The approach has limitations. For example, a mean variance portfolio model ideally allows for portfolio diversification and selects the portfolio with the highest return and lowest variance, but this type of model is solely based on a single time horizon and does not change the allocation of assets once chosen (Curtis 2004). The results of the mean variance approach will depend on the individual preferences, meaning how risk-averse, neutral or risk-seeking the decision maker is. Moreover, when the portfolio’s expected return is computed using the portfolio weights, it neglects the potential of economies of scale (Cochrane 2007). A final limitation is that it is not always clear how to apply the method to policies rather than asset investments (Doukas and Nikas 2020).

Critically, for the purposes of this paper, PA makes assumptions over probabilities that may not remain true through the application of the chosen policy. For example, the cost of renewables has been coming down due to the renewables policy itself, changing the profile of the renewables options in the portfolio. Carrying out a portfolio optimization of recursively changing prices and risks is highly complex and does not always have a single solution (Way et al. 2019). More generally, PA and real options theory assume that price movements are normally distributed following a distribution exogenously defined, and this is not generally true with dynamically changing technologies and industries.

Fuzzy cognitive mapping

Fuzzy Cognitive Mapping (FCM) is a modelling approach based on cognitive mapping and seeks to capture beliefs and assumptions in a diagrammatic representation (Doukas and Nikas 2020). FCM is a system mapping method that depicts causal relationships believed to exist in systems, and captures both qualitative and quantitative aspects of the system under consideration. This method provides flexibility around system assumptions, and puts significant power in the hands of stakeholders (Barbrook-Johnson and Penn 2022b). In a cognitive map, a node corresponds to a specific concept within a system, which is linked by an arc that reflects the interconnections between these concepts. As clarified in Stach, Kurgan, and Pedrycz (2010), the development of FCM requires three main steps: identifying the key concepts of interest, establishing relevant causal-effect direct relationships

between these concepts, and estimating or measuring the strength of these relationships.

This approach, which is also known as a semi-quantitative modelling approach, is used by experts for formulating and designing environmental and energy policies. For instance, stakeholder inputs are formulated as concept nodes, typically representing policy-defined goals, factors, events, risks, and uncertainties. These nodes are then connected through causal links. Ideally, FCM allows the modeller to perform simulations under different scenarios and compare the outcomes, which is important to support decision-making. Building scenarios requires changes in the structure of the map, in the weight of links and in the initial state vector. The interconnection and concept are assigned with values, while the function that determines and measures the influence of one node on other nodes is defined separately by the modeller's assumptions (Barbrook-Johnson and Penn 2022b).

One of the principal strengths of this method is that the concepts represented as variables can be measured even within data-poor context. That is, when constructing a system map, practitioners can identify causal connections between factors using stakeholder narratives and perceptions. Through a flexible approach, practitioners can account for all relevant aspects whether they are quantitative or qualitative to construct the map and explore how changes are propagated through the system, as elicited from stakeholders.

An illustrative example that uses empirical data to construct a map and its connections can be found in Anezakis et al. (2016). They explored fuzzy cognitive maps to analyse air pollution in the urban centre of Athens. They project the evolution of pollutant concentrations between 2020 and 2099 based on the climate change scenarios. Another example that uses expert elicitation is (Papageorgiou and Kontogianni 2012), who used a fuzzy cognitive maps model for eliciting stakeholder perceptions about risks facing the Black Sea over the next 20 years. They employed the Centre of Gravity defuzzification method to transform the degree of causality described by the experts into numerical values.

The FCM approach can determine the factors that are most important, typically those most vulnerable to changes or those that substantially influence other factors. For instance, Reckien (2014) focused on evaluating climate change impacts and the effects of adaptation options by employing the FCM method. This method serves to assess the effects of extreme weather events and adaptation measures in a changing climate. The study carried interviews in the urban area of Hyderabad region in India. Respondents, including street sellers, wholesale farmers, and planners, reported their perceptions of extreme weather events such as rainstorms and heatwaves and their impacts. In addition, the nodes represented the impacts of these events, and weighted edges characterised the causal links between these nodes. They identified the causal relationships between extreme weather effects and determined the most effective adaptation options for local communities.

FCM has multiple limitations. It strongly relies on experts for the design of Fuzzy Cognitive Maps (Mpelogianni and Groumpos 2018), and experts can induce biases that originate from their interests and beliefs (Meng et al. 2021). For instance, experts may disagree strongly on how to prioritise important feedbacks and disregard less impactful ones to ensure the FCM is sufficiently easy to interpret.

Further difficulties lie in the difficulty in establishing causality relationships, especially with high reliability (Mpelogianni and Groumpos 2018). Furthermore, model output, which is very sensitive to model assumptions, may be overinterpreted (Barbrook-Johnson and Penn 2022b).

Method	Output	Model used	Stakeholders	Risk & Resilience	Opportunities
CEA/CBA	Ranking based on costs	Typically marginal change models	Not involved	Resilience usually not included	Asymmetry between costs (known) and opportunities (unquantifiable)
MCA	Ranking, based on various metrics (not always monetary), weighted. Decision-maker sees ranking and individual metrics (Mouter 2021).	Typically marginal change models	Involved in priority-setting	Resilience sometimes included	Typical application has similar asymmetry, but qualitative assessments allowed
PA	Optimal portfolio of investments (policies)	Investment choice models	Not involved	Resilience and risk strongly quantified	
FCM	Systems map	Semi-quantitative	Highly involved	Resilience assessed qualitatively	Opportunities assessed qualitatively

Table 1: Summary of key policy-appraisal methods and their strengths and weaknesses with respect to stakeholder engagement, risk & resilience and opportunity identification.

Risk Opportunity Analysis

Risk-Opportunity Analysis was developed as an attempt to address the limitations of Cost-Benefit Analysis (CBA), Cost-Effectiveness Analysis (CEA), Multi-criteria Analysis (MCA) and other methods, in the context of decision-making situations involving irreversible and transformative change in the economy. The UK's Green Book identified the need to use a different decision-making framework in the case of non-

marginal change (HM Treasury 2022). The internationally recognised Green Book (Treasury 2020) states:

“Social CBA and Social CEA techniques are “marginal analysis” principally employed to consider changes between alternative options, and compare alternative options based on a static model of the world. (...) it may therefore be necessary to undertake appraisal from several perspectives in order to produce balanced advice.”

This recognition of the limitations of cost-benefit analysis is not unique to the UK government. In fact, CBA use in the European Union is limited when compared to the US (Wiener 2006). Between 2003 and 2005, there were 70 extended impact assessments performed by the European Commission. According to Wiener (2006), only 17 percent of extended impact assessments were cost-benefit analysis, and 40 percent estimated either benefits or costs.

ROA is designed to give information for three types of policy-makers, specifically, the strategist, the regulator, and the accountant. The role of each of these actors involved in decision-making systems are well-defined (Grubb, et al. 2021). For instance, strategists make sure that a policy can align with desired directions and can match the objectives, and are interested in the chance of success of the policy. Regulators guarantee the compliance of how the system evolves within certain bounds and regulatory norms, and are interested in stress-test results. Accountants ensure that the costs related to certain policies fit within existing budgets, such that targeted outcomes are achieved. It is also worth mentioning that the central objective of the ROA requires that the interaction between these three actors is enforced, and that their actions are coordinated (Mercure et al. 2021).

The steps of ROA

Risk Opportunity Analysis (ROA) aims to generalise cost-benefit analysis used for the evaluation of alternative policy options, for the particular cases where the objective is irreversible transformative change (Mercure et al. 2021).

Risk Opportunity Analysis includes the following steps: Firstly, it requires an understanding of the way the targeted system evolves (e.g. a transport network, a financial market), whereby relevant feedback loops (e.g. the deployment-innovation loop), system boundaries and policy levers are identified and represented into a qualitative system map that captures evolution and interactions between system components. Using this map, appropriate models are developed or chosen for the next three steps.

Secondly, policy outcomes are estimated, and sensitivity analyses are conducted to compare the model results under various storyline scenarios with and without policy levers activated. Uncertainty analysis is performed to establish a confidence interval

in this step too. Thirdly, a stress-test is applied to explore the various ways in which the policy strategies under analysis may fail, deliver worse outcomes or degrade the resilience of the system. Fourth, an analysis of opportunities created by the activation of the policy levers is done, in particular, regarding unintended co-benefits or the inducements of innovation or new industries.

Finally, the projected impacts of the various policies, risks and opportunities are communicated to policymakers, along with uncertainty ranges associated with these policies. Communication takes into account the numerical literacy of stakeholders, for instance by using natural frequencies in communication of uncertainty (Figure 1).

ROA emphasises the broad direction of evolution of systems and how it can be re-oriented using policy instruments. It recognises that while the exact destination in a system transformation, triggered by the use of particular policy levers, is highly uncertain, it abandons the common practice in CBA of estimating exact final outcomes, focusing instead on the direction of change. For example, the assessment of a policy with objective to produce an electric vehicle market share of 50% by 2035 will focus on whether the rate of uptake, expected to be put in movement by the policy, is consistent with the target, but avoiding to make predictions with false certainty such as an exact cost or a cost range associated with achieving the target. The reason for this emphasis is the recognition that the outcomes of policy action, in such nonlinear system transformations, are surrounded by deep uncertainty and that communicating false certainty in policy assessments is unhelpful to the decision-maker. Thus, one may decide in ROA to compare forces and feedbacks triggered by policy action instead of exact outcomes.

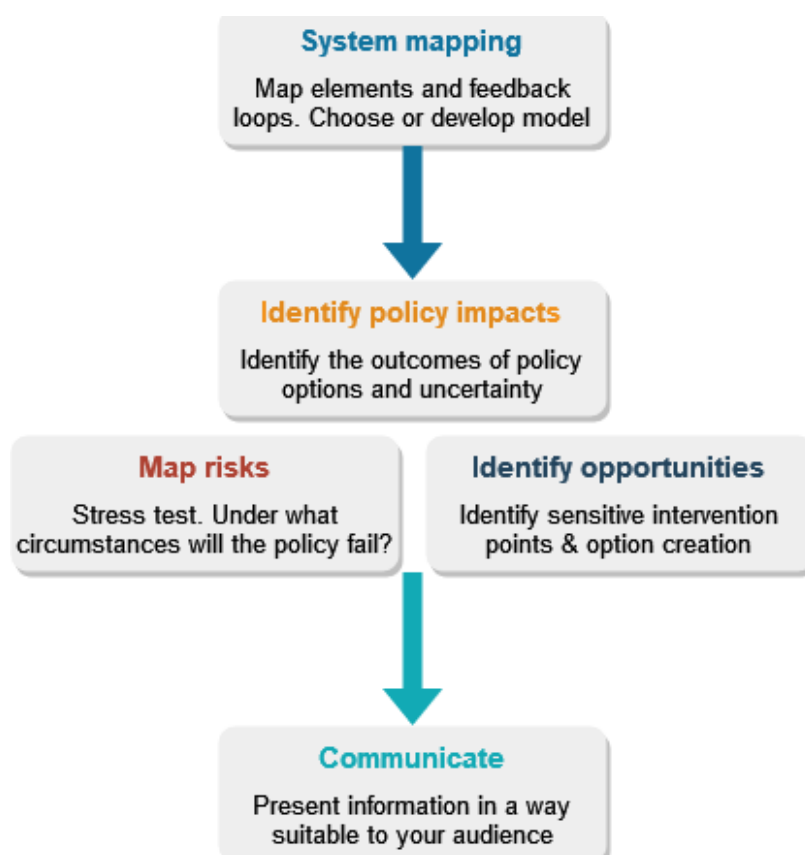


Figure 1: steps of Risk-Opportunity analysis

ROA also adds a new dimension to policy analysis related to system resilience. In CBA, recommending the “least-cost” way forward to a policy-maker may inadvertently also put forward a strategy with low-resilience and a higher likelihood of failure, or a strategy that puts a system at risk. For example, loosening financial regulation around capital requirements can accelerate investment while creating systemic risk in financial markets. Similarly, reducing power line redundancy in electricity networks, in order to save on infrastructure costs, can lead to more frequent power blackouts. Inadequate regulation of self-driving electric vehicles could increase rates of accidents. In ROA, the stress-testing of strategies is incorporated into policy-design in order to help avoid fatal design flaws that could become expensive to fix. This then requires looking beyond the mean expected outcomes of policy action, and exploring the various possible risks of failure. At equal costs and benefits, a strategy with stronger resilience may be preferred.

Lastly, ROA recognises the deep asymmetry between the reliability of knowledge and data over costs compared to benefits. Costs can generally be estimated with relative certainty, as they pertain to what well-known existing assets or resources would be expended through the policy. This knowledge does not strongly depend on the assessment itself. Meanwhile, benefits pertain to putative assets and resources that would be created by the policy action proposed, knowledge that depends critically on the assessment itself, and is therefore inevitably much more uncertain than costs.

In CBA, there is no recognition of this asymmetry, whereas in fact, for complex system transformations or environmental issues, a majority of the benefits accounted for in CBA accrue indirectly and not in monetary form, such as through assessments of the appreciation of beauty in surveys. These are typically estimated using highly subjective and uncertain willingness to pay methods, which mix up subjective values with more objectively measured economic quantities. The resulting substantial uncertainty in outcomes is not usually conceded. In ROA, the estimation of subjective values is simply not included in any quantitative assessment, as it is considered inconsistent to mix subjective and objective values.

The creation of positive economic externalities is a particular case in point, given that innovation and business creation is notoriously difficult to predict, but often is the result of policy action. For that reason, ROA emphasises a dedicated exploration of plausible economic opportunities that could be created by the activation of policy levers, whether quantifiable or not, and reported separately. All else equal, policies that open more opportunities for innovation and business creation may be preferred as they may be considered to create resilience.

ROA in Europe

Compared to decision-making in the United Kingdom and the United States, the policy-making tradition in the European Union focuses less on cost-benefit analysis since the analytical method to be used within the impact assessment process is left open (Wiener, 2006). As discussed above, impact assessment must talk to the environmental, social and economic impacts of policies, which makes an IA focusses on multiple criteria a logical option.

Risk assessment is already mandatory in some policy domains in the EU, for instance in drug and food policy. RA is also mandatory for certain climate policies, such as those related to floods and large infrastructure spending (European Commission 2023). The precautionary principle underlying this focus on risk plays a stronger role in European policy-making compared to the US (Kirilenko, Romsdahl, and Stepchenkova 2020). ROA may therefore fit well within current decision-making processes in Europe. ROA takes a wide view of risks, in addition to the risks mentioned in the EU Better regulation toolbox document, explicitly considers risks around industrial decline.

Risk-Opportunity Analysis will likely involve more input from stakeholders than cost-benefit analysis, as it provides meaningful information for three types of policy-makers. As ROA seeks to inform multiple types of stakeholders, the engagement process is likely more demanding. The EU's principle of proportionate analysis (European Commission, 2021) requires impact assessments to be proportionate in depth. This principle ensures that there is a balance between the actions undertaken to achieve an objective and the intended outcome. Policies with larger impacts, such as transformative policies, require a more in-depth analysis than policies with a likely

marginal change. As such, ROA fits within the EU's framework for policies with transformative intent.

The case of electric vehicles in Norway

The growing concern over climate change has proven to be a catalyst for policymakers to design and implement policies to adopt innovative technologies, such as electric vehicles (EVs). EVs offer a sustainable alternative to the transportation system with reduced energy usage and CO₂ emissions. Norway leads the world in rapid uptake of EVs. It has introduced public policies that have induced high domestic demand for EVs and contributed to global technological advancements (Sharpe and Lenton 2021).

The EV market share of new car sales in Norway has continued to grow in recent years, reaching an annual market share of 86% in 2021 (Fridstrøm and Østli 2021). Figure 2 shows the growing number of new and used electric cars in Norway between 1990 and 2023. This uptick in the number of electric cars, either battery electric cars, plug-in hybrid, and non-plug-in hybrid cars may slow down given that the EV incentives will be removed in the future (Figenbaum and Kolbenstvedt 2015).

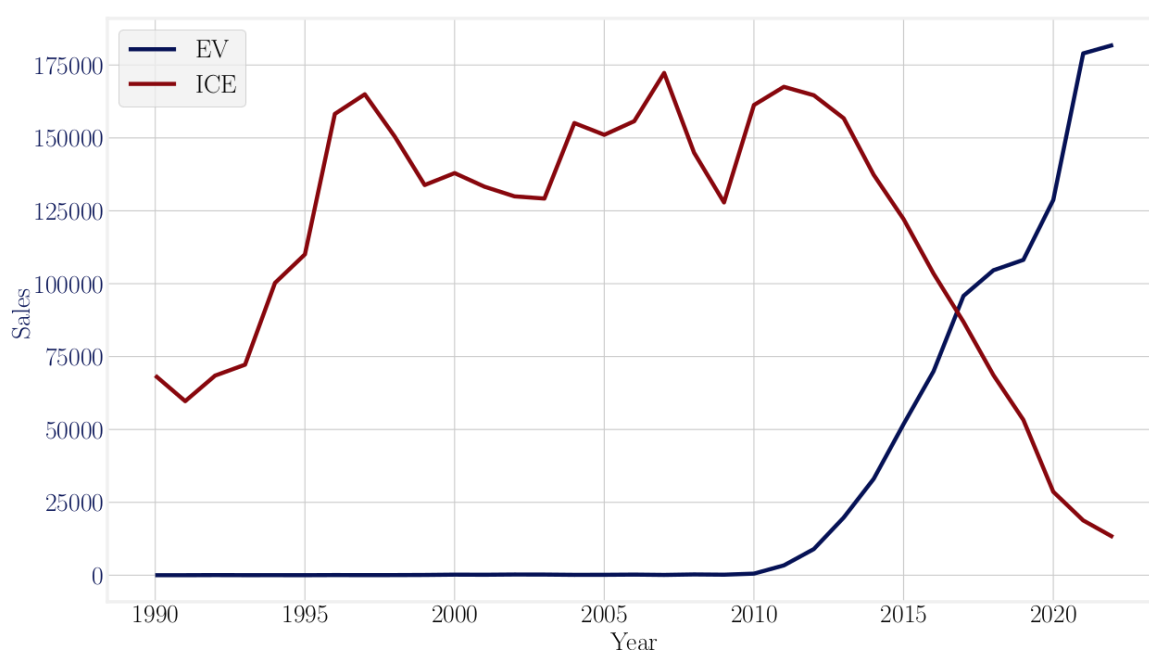


Figure 2. Sales of EVs in Norway

Note: The figure depicts the dynamics in car sales in Norway over the period 1990–2022. The blue line includes BEV, non-plug-in hybrid, and plug-in hybrid cars. The red line includes petrol only and diesel only cars. Source: Norwegian Public Roads Administration

Policy background

Several policy incentives have been implemented in Norway since the early 1990s, ranging from tax exemptions to subsidies.² These policies were mostly implemented without an impact assessment, and the decisions were rarely formally justified (Figenbaum 2023). All these attributes make Norway an ideal case study for understanding how the adoption of electric cars can be propelled by policy action, and investigating the mechanisms of impact of these policies.

In 1996, electric vehicles were exempted from a one-time registration fee, which was approximately set at 50 percent of the manufacturer's retail price. Initially, it did not lead to an increase in the demand for EVs at that time. In that same year, further tax exemptions benefited EV users, where no annual road tax was imposed on electric cars, as opposed to fuel and diesel based cars. From 2001, EV users enjoyed even further tax exemption, where this time EVs were made exempt from the value-added tax of 25%, which is applied to all new vehicle purchases (Springel 2021). An important reform implemented by the Norwegian government in 2007 concerns the vehicle registration tax (Ciccone and Soldani 2021), which now considers CO2 intensity instead of engine size.

In 2009, the government began providing financial incentives allocated to support the establishment of charging stations to transition to a less polluting transportation system. From the 2010s, large car manufacturers began bringing EVs on the market and EV sales started taking off (Figenbaum 2017). The government also formulated a National Transportation Plan between 2010 and 2019. In 2014, additional EV supply equipment subsidies were offered, targeting the expansion of normal and fast charging stations under the National Transportation Plan for the period 2014-2023.

A number of incentives were implemented by central and local governments to facilitate the expansion of electric vehicles in Norway. An example of these incentives is the import tax exemption, which was one of the first tools (Schulz and Rode 2022). There have been additional measures to accelerate the expansion of electric vehicles. These include the reduced EV tax, subsidies for the expansion of electric cars charging stations, and a VAT reduction to zero percent (Springel 2021). High government subsidies and tax exemption can keep the price of EVs competitive and affordable for consumers. It is well known that the EVs industries benefited not only from generous public subsidies but also from the decline in manufacturing costs due to technological advances and increasing returns to scale (Lee and Clark 2018). In a recent study, (Springel 2021) investigates the impacts of tax exemptions and subsidies on the adoption of electric vehicles in Norway. This study reveals a strong and positive relationship between subsidies for normal charging stations and electric vehicles sales, and a positive association between tax exemptions and electric vehicles sales.

² See Appendix B.

Appraisal of Norway's EV policies

Most policies introduced by Norway before the 2010s to stimulate electric vehicles were not accompanied by any formal policy appraisal process (Figenbaum, 2023). The goal of early stage technology policies were to allow market experimentation and to attract an EV industry to Norway. Generally, the EV market was so small in Norway that the risk associated with these policies was considered very minor. This started to change from the 2010s, even though some key policies were initiated by Parliament and not subject to formal policy appraisal. There are reasons to believe that, under such an ad hoc policy process, political pressure, NGOs, and lobbying acted as catalysts for EV policy adoptions.

Figenbaum (2023) argues that the lack of a proper impact assessment might be one of the reasons that made Norway a leader in the transition to a green vehicles fleet. Another factor that could explain the rapid greening of the vehicle fleet is the involvement of stakeholders, for instance, NGOs and industry actors that influenced the Norwegian government to introduce several reforms and regulations into the National Budget document. The Norwegian parliament can also petition the government in favour of one policy over another.

The policy appraisal process can be summarised as a sequence of phases: Stakeholders such as NGOs, businesses, municipalities can be involved by lobbying and influencing upcoming reforms. Policymakers can take up the issue and prepare a proposal through parliamentary petitions, government proposals or political parties programs. The reforms can be formalised in a government proposal, an impact assessment, or the national budget document, which require the involvement and endorsement of expert study groups and various stakeholders. The proposal or the national budget document is then made public and debated in the parliament and eventually revised. The government then resorts to the EFTA Surveillance Authority (ESA) to seek approval, and finally sends the proposal to the parliament for approval. The government then begins implementing the policy and establishes the procedures needed to turn the reform into practice.

In the early 1990s, most of the tax exemptions were endorsed by the parliament without any impact assessment. This was justified by the experimental nature of the policies. Between 2000 and 2010, a prime interest of policymakers was supporting the Norwegian EV industry. Figenbaum (2023) argues that this goal may explain the lax processes. EV policies were typically introduced by parliament directly or introduced by parliament via amendments to the national budget; neither process involves government impact assessments.

Norway enjoyed high financial resources from the oil sector, which facilitated the introduction and maintenance of the incentives for ambitious EV policy objectives. Market experiments in the Oslo-area between 2003 and 2005 were initiated by policymakers to test the ban of minibuses from bus lanes. Market experimentation

was an alternative for policymakers to understand how incentives will affect consumers, instead of conducting a full impact assessment.

From 2010, proper processes were usually followed. In 2012 an impact assessment was carried out for the 2012 Climate policy bill. A separate expert report, Klimakur (2020), was published in 2010, which was also used as an evidence base for policies.³ Specific impact assessments were sometimes also done, for instance for the 2018 law which introduced an exemption on the re-registration tax.

Notably, two policies to keep incentives as is in 2012 and 2013 were introduced without government policy appraisal. At this point, production of electric vehicles was starting to ramp up, and without assessment, it was no longer clear what the outcome would be on tax income (Figenbaum, 2023). This raises an interesting question: would Norway's policy success in electric vehicles have taken place if standard assessments had been carried out by the government?

According to the regulations on impact assessments which are outlined in the Planning Building Act of 2017, the Norwegian Environment Agency must be notified if a specific plan has a substantial societal and environmental impact.⁴ The regulatory framework further explains that the impact assessment should include how the plan is vulnerable to climate change, in addition to comparisons of the impact of different alternatives on both the environment and society. Recently, there have been policies to reduce or remove incentives, again introduced without a full impact assessment. It is not yet clear what the repercussions of these reforms will be on the Norwegian EV market.

Cost-benefit analysis

In this section, we do an ex-post cost-benefit analysis on key policies supporting EVs. The question we want to answer is whether this type of analysis would have been able to capture the success of Norway's transition.

To proceed with our analysis, we first consider the benefit from GHG emission mitigation and the benefits from avoided damages due to air pollution. One key implication of the greening of the transport fleet is the benefit to the environment, indeed, the transport emissions in Norway decreased by 8.9% from 2005 to 2019, and they are expected to decline by 30% from 2019 to 2030 (OECD 2022). While most cost benefit analysis would typically consider the implication of these policies on job creation, the estimates of economic benefits in our analysis does not include the

³ Climate cure 2020. Measures and instruments for achieving Norwegian climate targets to 2020; Klimakur 2020. Tiltak og virkemidler for å nå norske klimamål mot 2020. Norway: N. p., 2010. Web.

⁴ See the Norwegian Ministry of Local Government and Modernisation and the Ministry of Climate and Environment (2017).

value of jobs, as in Lopez et al. (2021). The health and environmental benefits induced by EV policies were calculated using Norwegian data.⁵

Relevant to our analysis, Carlsson and Johansson-Stenman (2003) focus on the case of Sweden. In their study, they evaluate the present value of costs and benefits per car, including incremental price, tax revenues, subsidies, cost of saving fuel, and environmental benefit. Two important distinctions relative to their approach is that we perform an ex-post analysis using Norwegian data rather than an ex-ante analysis. They consider both private and social profitability of EVs, whereas we solely focus on social costs and benefits. Furthermore, Eskeland and Yan (2021) measure the impact of the vehicle registration tax that has been rectified to account for CO2 intensity of the vehicle instead of engine size, starting from 2007. They focused on the external costs associated with climate, air pollution, accidents, congestion, noise, as well as fiscal costs. Lopez et al. (2021) examine different manufacturing routes for EVs deployment in the Philippines. They consider the implications of different scenarios for tax generation, job value, balance of payments, energy security cost, health cost, and eventually, GHG mitigation cost.

We closely follow Eskeland and Yan (2021), who conduct a cost benefit analysis on two policies in Norway: the CO2-differentiated registration tax introduced in 2007 (making ICE cars more efficient), and the VAT and registration tax exemption for EVs. Our analysis focuses on the policies specific to electric vehicles, specifically, the VAT and registration tax exemption, along with government investments in charging infrastructure.

Turning to the estimation of cost of EV policies, we consider the cost associated with tax revenue losses and subsidies for charging stations, as in Carlsson and Johansson-Stenman (2003). The costs included in our analysis were estimated using different data sources for Norway. These costs include tax revenues losses, subsidies for charging stations, and costs of incidents.

To estimate government spending on subsidies for both fast and normal charging stations, we use the International Energy Agency Global EV Data Explorer for the number of charging units and we use estimates from (Springel 2021) on the subsidy amount per charging unit.

$$Subsidies_t = N_t^n \times S^n + N_t^f \times S^f$$

⁵ Data sources are reported in Appendix A.

Where N_t^n and N_t^f represent the number of normal and fast charging stations, respectively. S^n and S^f denote the average subsidy amount per normal and fast stations.⁶

For tax revenue losses, we consider the vehicle registration tax, which is a one-time registration tax and VAT exemption. Data on new electric cars is from the Norwegian Public Roads Administration, and data on the prices of electric cars are collected from the Norwegian Tax Administration. For simplicity, we disregard tax revenue losses due to other tax incentives, such as the exemption from the annual road tax. Fridstrøm (2019) highlights that the primary sources of government revenue from vehicle taxation are the one-time registration tax and the VAT tax. In our computation, the registration tax rate is estimated to be 50%, whereas the value added tax rate equals 25%, similar to the values reported by Springel (2021). We measure the tax revenue losses as follows:

$$\begin{aligned} \text{tax revenue loss}_t &= \tau_{50\%} \times \text{ice price}_t \times \text{new bev units}_t + \tau_{25\%} \times \text{ice price}_t \times \text{new bev units}_t \end{aligned}$$

Where $\tau_{50\%}$ denotes the registration tax rate and $\tau_{25\%}$ is the value added tax on electric cars, ice price_t is the average price of conventional cars, and new bev units_t is the number of new BEV. Due to tax incentives and downward trend in EV prices, the EV market has become highly competitive, this resulted in the uptake in the number of EV purchases and contributed to a significant reduction in tax revenues (Figenbaum 2017).

We now turn to the computation of the climate benefit associated with the decline in emissions, we use the following specification:

$$\begin{aligned} \text{Avoided GHG emission from EV cars}_t &= \text{GHG emi}_t / \text{non EV units}_t \times \text{EV units}_t \\ \text{Climate benefit}_t &= - (\text{Avoided GHG emission from EV cars}_t) \times \text{SCC} \end{aligned}$$

where SCC is the social cost of carbon and GHG emi_t is the GHG emissions in CO2 from cars. We simply use annual greenhouse gas emissions in CO2 equivalents from cars for Norway using the European Environment agency data.

For the SCC we use a social cost of CO2 emissions of 80 USD per ton, which is consistent with the estimate provided by (Cai and Lontzek 2019). They present average estimates of the social cost of carbon, which are 87 USD in 2020. These estimates are lower than those by Ogden, Williams, and Larson (2001), who find that the damage cost of GHG emissions is equal to 100 USD per ton of carbon, by (Eskeland and Yan 2021), who offer an estimate of social cost of CO2 emissions at 96 USD per

⁶ Springel (2021) documents that EV supply equipment subsidy for normal charging is equal to 7000 NOK and EV supply equipment subsidy for fast charging is approximately 181000 NOK.

tonne, and by Rennert et al. (2022) who report a social cost of CO2 emissions of 185 USD per ton.

We also compute the benefit for the decline in air pollution as follows:

Pollution due to cars

$$= NOx\,emi_t \times CNOx + SO2\,emi_t \times CSO2 + NMVOC\,emi_t \times CNMVOC \\ + PM2.5\,emi_t \times CPM2.5$$

Where $NOx\,emi_t$, $SO2\,emi_t$, $NMVOC\,emi_t$, $PM2.5\,emi_t$ are the air pollutant emissions due to cars for pollutants such as $CNOx$, $CSO2$, $CNMVOC$, $CPM2.5$. The data is from the European Environment agency, whereas for each pollutant the specific cost per units estimates, $CNOx$, $CSO2$, $CNMVOC$, $CPM2.5$ are from (Eskeland and Yan 2021).

Compared to traditional vehicles, the maintenance cost of an EV is very low, as this type of car requires much cheaper and simpler maintenance. In the UK, the average maintenance cost of a petrol and diesel car is estimated to be £449, while it is only £288 for an EV, thereby saving 36% of the maintenance costs (Piao, McDonald, and Preston 2014). Malmgren (2016) explains that maintenance cost savings is 42% over the life of a vehicle in the US. We employ the estimates of (Piao, McDonald, and Preston 2014); we believe that the maintenance cost savings will not significantly differ from the Norwegian one. We use the following specification:

$$Maintenance\,cost\,savings_t = (M^{D/P} - M^{EV}) \times bev\,unit_t$$

Here, $M^{D/P}$ represents the average maintenance cost of a petrol and diesel car, M^{EV} is the average maintenance cost of an electric vehicle, and $bev\,unit_t$ denotes the number of electric vehicles.

	Costs in Millions NOK			Benefits in Millions NOK			
Year	Charging station subsidies	Registration tax revenue loss	VAT tax revenue loss	Air pollution benefit	GHG emissions	Maintenance cost savings	B-C
2008		11.35	5.67	25.62	3.65	2.31	14.56
2009		42.87	21.43	24.64	3.71	2.55	-33.40
2010		214.88	107.44	27.99	4.26	3.51	-286.56
2011	2.10	416.50	208.25	50.97	7.67	7.95	-560.26
2012	11.44	916.76	458.38	101.63	15.47	16.38	-1253.09

2013	12.48	2100.60	1050.30	217.65	33.67	34.67	-2877.38
2014	7.43	2991.69	1495.84	447.52	73.11	74.93	-3899.41
2015	39.82	3021.01	1510.51	716.67	129.39	130.73	-3594.55
2016	43.37	4193.26	2096.63	925.70	174.97	184.30	-5048.29
2017	85.12	6741.39	3370.70	1235.83	227.13	255.94	-8478.32
2018	57.68	9757.92	4878.96	1626.81	322.31	359.62	-12385.82
2019	511.70	14382.73	7191.37	2039.43	391.47	493.49	-19161.41

Table 2: Cost-benefit analysis time series, assessing the costs of charging subsidies, VAT exemption, registration exemption in terms of cost. In terms of benefits, we assess air pollution benefits, climate benefits and maintenance cost benefits.

Through the lens of this analysis, we measure the social costs and benefits incurred by the society as a whole, rather than only measuring the benefits and costs borne by the government or consumers. Table 2 shows the cost and benefit included in our assessment between 2008 and 2019. We list the cost associated with tax exemption for EVs and the charging station subsidies. We consider the environmental benefit related to the decline in air pollution and GHG emissions, we also account for maintenance cost savings due to EV.

Two main observations jump out. Firstly, the costs outweigh the benefits. Using standard CBA metrics, we do not include opportunities. On the other hand, we also do not evaluate systemic risks in this exercise. Secondly, Norway lost significant tax income, as the number of cars subject to tax were narrowed. Two key policies implemented to promote EV adoption in Norway, namely registration tax exemptions and VAT exemptions, have become increasingly expensive. This, in combination with achieving the policy objective, has prompted the government to plan the phase-out of incentives.

According to our cost-benefit analysis, the impact on the environment is both significant and gradual. Assigning a monetized economic loss to atmospheric carbon remains a challenge, as climate risk is heavy-tailed, and an infinite social cost of carbon cannot be excluded (Weitzman 2014). The metric itself is not constant, but varies and depends on economic and climate scenarios. Overall, these results indicate that an assessment based on estimation of benefit and cost alone, even if exhaustive, can lead to misleading results as many aspects are missing in our analysis.

Risk-opportunity analysis

In this section, we compare the previous CBA analysis with a wider analysis of risk and opportunities in the EV transition in Norway. Risk-Opportunity Analysis has the following five steps:

Step 1: Establishing objectives, options, key system characteristics and system feedbacks.

Step 2: Identifying the impacts of policy options on processes of system change.

Step 3: Assessing risks and resilience.

Step 4: Assessing innovation and opportunity creation.

Step 5: Engaging decision-makers on impacts and uncertainties in multiple dimensions.

Step 1: Systems mapping

Step 1 or Risk-Opportunity Analysis involves systems mapping and model selection or development. Systems mapping is used to take stock of the dynamics of the system, including feedbacks. This allows us to select or develop appropriate models, and identify elements that are less amenable to modelling. These elements require a qualitative evaluation (Mercure et al. 2021).

A large set of system mapping techniques are available. We use Barbrook-Johnson and Penn (2022) to choose the systems mapping technique suitable to our needs. In ex-ante analysis, a participatory method of systems mapping is most suitable, to ensure we capture correctly the policy goals and policy instruments under consideration. Our analysis takes place after the fact. While participatory systems mapping still has benefits in ex-post analysis, our primary goal here is to understand the system and explore dynamics and path dependency.

Barbrook-Johnson and Penn (2022) identify Causal Loop Diagrams (CLD) and System Dynamics techniques as the most suitable models for capturing nonlinearities, tipping points and possible 'leverage points'. Another option, regularly applied in this field, is fuzzy cognitive mapping, which can capture feedbacks, but puts less emphasis on dynamics related to tipping. As ROA seeks to understand opportunities that often arise from nonlinearities, we choose CLD in this exercise. CLD can be a step on its own, or be the first step in the design of a Systems Dynamics model (Barbrook-Johnson and Penn 2022a).

We construct the systems mapping in an iterative process. Three of us (Nijse, Kharazi and Edwards) create an individual map. We then compare and discuss our maps, and argue for or against inclusion of elements, feedbacks and loops. In a next step, we amend our individual maps to incorporate new elements, feedbacks and loops

based on the preceding discussion. A final map was constructed from the components that occurred in two or more of our individual maps.

The final map is displayed in Figure 3. Four types of loops are identified, two of which are self-reinforcing feedback loops and two of which are stabilising feedback loops. The self-reinforcing loops involve “innovation”, “choice of EV” and “ease of use” of cars. The “ease of use” loop represents how EVs become more attractive when others already drive EVs as this results in better charging infrastructure. Uptake of EVs also drives innovation, leading to cheaper vehicles and to a larger brand choice.

The stabilising feedbacks involve public finances and inequality. In the short term, costly policies that promote EV uptake can have negative knock-on effects on unrelated policy objectives. For instance, there may be less spending on health, the social support system and inequality. These knock-on effects may decrease policy support. A longer-term risk involved oil income. If the policy in Norway helps trigger a global transition towards EVs, future oil demand may shrink significantly, leading to further pressures on public finances.

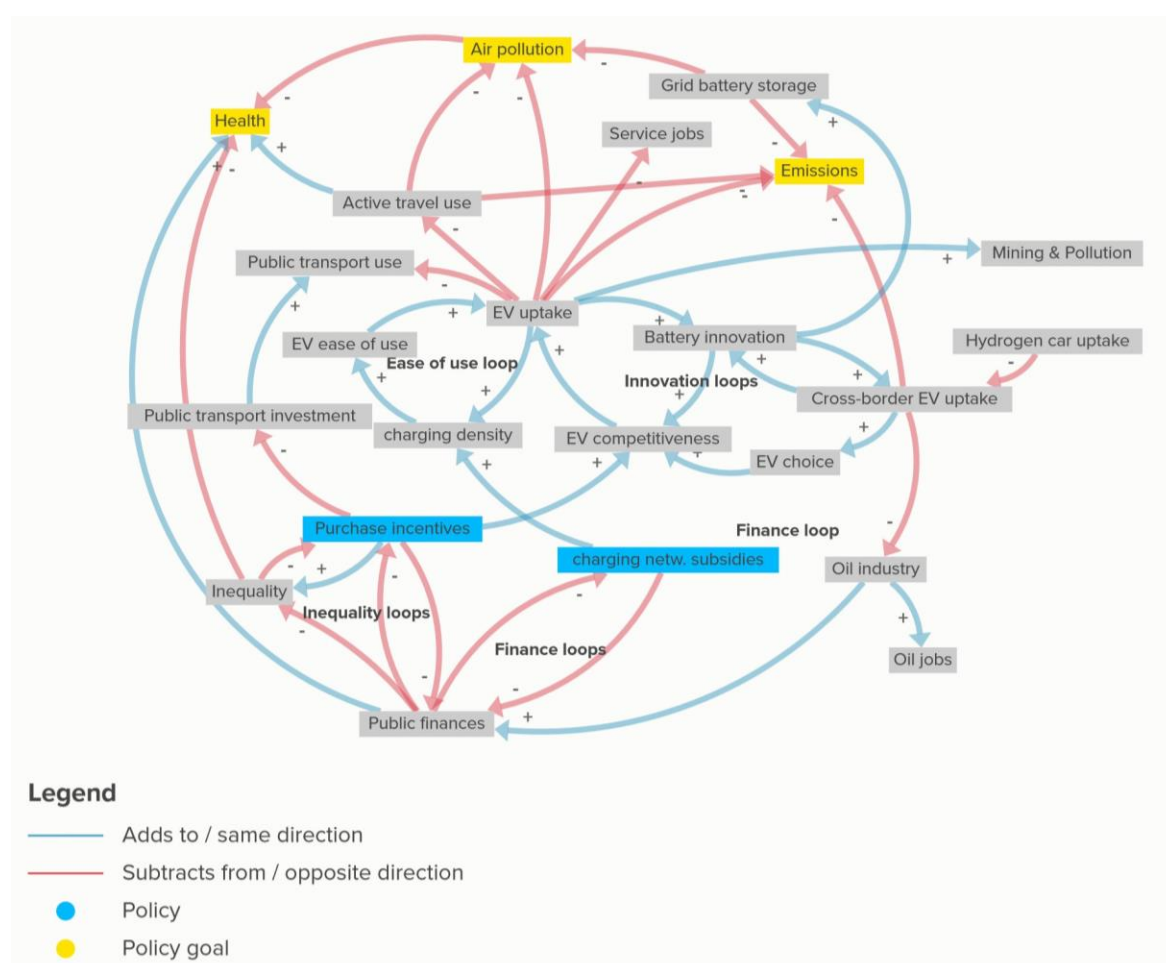


Figure 3: Causal Loop Diagrams, systems mapping of the EV transition in Norway.

We adopt a simple mapping system to trace out the feedbacks associated with the adoption of EVs and EV policies in Norway. We focus on the most significant effects of these policies. In comparison with the map made for the UK 10-point plan (HM Government 2021), our map is simpler and does not contain as many intermediate steps or details.

Step 2: Impact estimation

The second step of ROA requires the estimation of (median) outcomes of the policy (mix) under consideration. Typically, we would use a model for step, but here we keep it simple and analyse the most likely outcomes based on the systems mapping exercise in the previous step, displayed in Figure 3.

Positive impacts:

EV policies yield a direct positive impact on greenhouse gas emissions, given their higher efficiency compared to ICE vehicles and the clean electricity production in Norway based on hydropower. Local air pollution would also be positively affected as tail-pipe emissions of NO_x, PM_{2.5} and CO are absent from EVs. Non-tailpipe emissions (from tires and brakes) still remain.

More indirectly, EV policies have positive cross-border effects. By creating sustained demand for EVs, the policies raised investor confidence for EV manufacturing businesses. Furthermore, as mentioned above, increased demand is a tool which can induce innovation, in this case innovation and experience in battery production, electric engine production and in charging infrastructure. Finally, the policy experience provides an example for other regions.

Negative impacts:

The main negative direct effect of EV policies is pressure on public finances. Uptake of EVs may also drive environmental impacts via the expansion of mining for battery production, as recycling is insufficient when markets are growing rapidly. Finally, the uptake of EVs is likely to have a direct impact on service jobs, as EVs have fewer moving parts and require less maintenance.

Figure 3 highlights further impacts of EV policies through indirect effects. We assess the impact of EV policies on two key social policy objectives: health and equality. Inequality can be directly exacerbated by EV policies, as car ownership is concentrated among more well-off people, who benefit from generous tax exemptions. It is also indirectly impacted through the constraints on public finance, which puts pressure on social assistance programs.

Healthcare in Norway is paid from taxes (Saunes, Karanikolos, and Sagan 2022). Therefore, constraints on public finance may have direct negative effects on health spending. Inequality itself also negatively affects health (Pickett and Wilkinson 2015).

Health is also indirectly affected through the uptake of EVs via air pollution. On the other hand, subsidies on EVs may encourage car ownership, and thereby discourage active travel, resulting in a negative health impact. The Norwegian Public Transport budget is also partly funded by road tolls which EV owners were exempted from paying (Odeck and Bråthen 2001).

Expansion of mining activities beyond Norway's borders raises ethical and environmental concerns in low and medium income countries. For instance, there is a growing concern about the risk of mineral shortages, as irresponsible mining practices can lead to exhaustion of the supply of minerals and can have severe impact on the environment.

Step 3: Risk and resilience

We examine the risk of three scenarios: policy failure, betting on the wrong horse, and overly rapid success, as illustrated in Table 3.

In the early days of the policy package, risk of policy failure was high but the value at risk was low, since the EV industry did not yet exist. The policies were self-limiting, in the sense that in case of failure, little money would be lost by the state. Alternative policies to bring down air pollution and emissions (for instance around public and active transport) could have been implemented to partially meet these policy objectives.

In the longer run, however, the value at risk would have been higher. Both the “betting on the wrong horse” and “overly rapid success” scenarios examine these.

Risk and resilience	Quantification or qualitative description
Failed policy	This brings the largest environmental risks, as alternative policy may be insufficient to reach net-zero emissions
Betting on the wrong horse	While EVs are strongly outcompeting hydrogen fuel cell vehicles now, this was not a done deal. There was a risk Norway had to transition twice.
Rapid success and transition risk	A rapid transition brings a fiscal risk related to EV incentives. If a fast global transition is achieved, demand for oil will decrease, risking industrial decline in oil regions.

Table 3: Summary of risks

In the “betting on the wrong horse” scenario, Norway manages a successful but expensive (partial) transition towards EVs. Policy or industry developments in an alternative technology, most likely hydrogen fuel cell vehicles (HFCVs), would outpace the shift to an EV-dominated future. This was a realistic scenario around 2003 when the EU launched its European Hydrogen Roadmap (HyWays) project (EU Commission

2008) and the Bush administration rolled out a \$1.5 billion research programme aimed at creating affordable fuel cells and lowering the cost of hydrogen (Service 2009). In this scenario, HFCVs become cheaper than EVs and Norway has to transition twice, with stranded assets in charging infrastructure. Norway's policy was partially technology-neutral (hydrogen cars were exempt from registration tax too), but also contained EV specific policies around the charging network.

This risk relates to the debate between mission-oriented (Mazzucato 2018; Kattel and Mazzucato 2018) and technology-neutral policy-making (Greenberg 2015). Mission-oriented policy-making accepts that the government can be a risk-taker to achieve missions which require transformative change and innovation. This contrasts with the literature on technology-neutral policy-making which argues that the government should not choose winners. Attempts to create policy-neutral policy often result in the government benefiting incumbents (Azar and Sandén 2011).

The third scenario, which is closest to the current situation, is a rapid success. In this scenario, EV uptake is much stronger than anticipated. This quickly puts fiscal pressure on the government, as higher CO₂ taxes on ICE vehicles cannot keep up with lost revenues in registration tax and VAT. Larger fiscal pressure means that the operating space for the government becomes smaller and that it has less ability to respond to crises. A faster-than-expected uptake of EVs also raises the possibility that the government could have achieved their objectives in a less costly way.

In our causal loop diagram, we identify various policy domains which may come under pressure, including the EV policies themselves, but also public transport investments or less directly health (Figure 4).

When this success is repeated cross-border, global oil demand may start declining. In Norway, 6% of total workers are directly or indirectly employed in the petroleum sector in 2021, as reported by Statistics Norway. To prevent industrial decline, the government may seek to invest heavily in reschooling, taking lessons from Germany's successful transition in the Ruhr area (Lynch et al. 2023). This is more challenging when finances are under pressure.

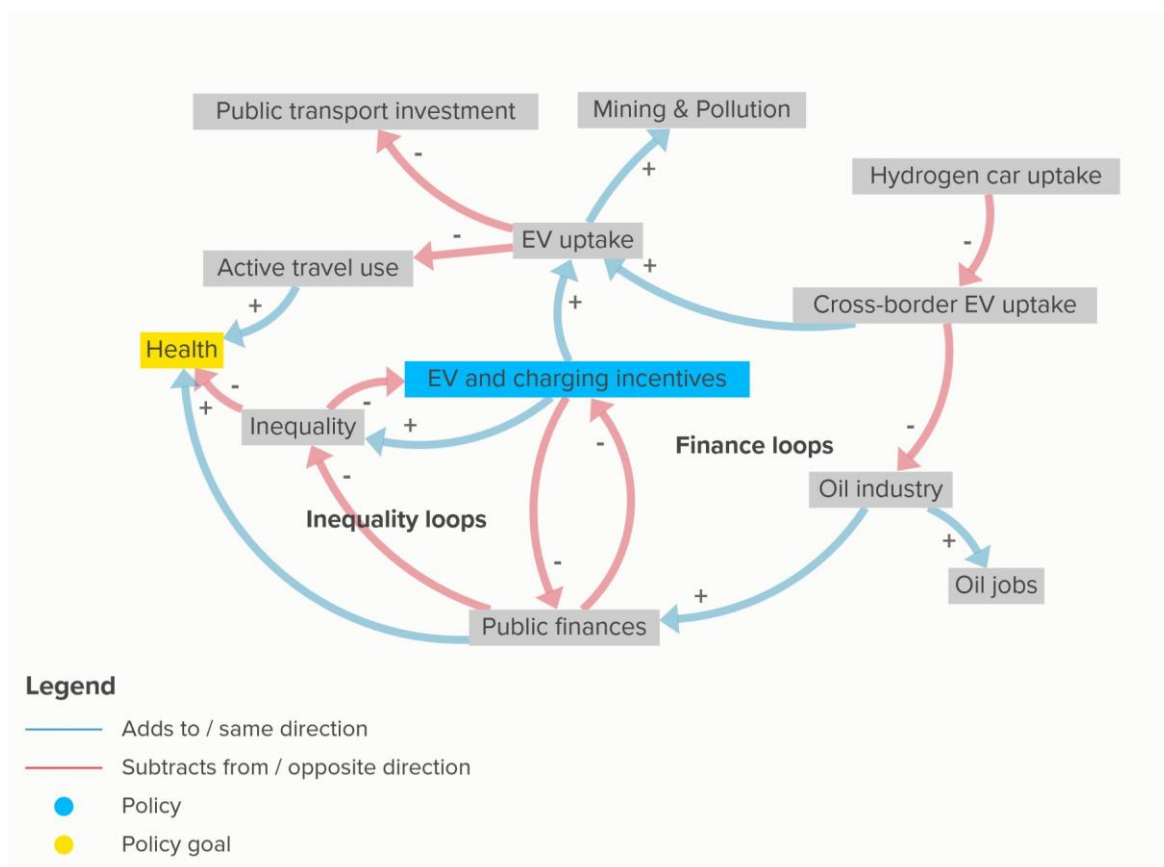


Figure 4: Subgraph of the systems mapping focussing on risk

Step 4: Opportunities

Multiple opportunities have been identified in the systems mapping and the literature. Here, we discuss the opportunities around creating a domestic car industry or battery industry in Norway, reaching a tipping point within Norway, tackling air pollution and climate damage, and the opportunity around contributing a global tipping point towards electric vehicles. Opportunities are by nature more qualitative than risks, especially ex-ante. Here, we benefit from hindsight, and quantify one aspect of the opportunity (contribution to induced innovation).

We will keep the discussion of job creation opportunities brief. In the early days of the EV transition, Norway had hoped to create their own EV industry and develop Norwegian EVs (Figenbaum, 2023). Two local EV brands, Think and Kewet, were developed; however, they could not compete with international automotive companies since these vehicles were too expensive for the market.

In the systems mapping, we identify a set of self-reinforcing feedback loops. We now highlight the three loops related to potential tipping behaviour (Figure 5). Two of the loops are related to domestic uptake of electric vehicles (the ease of use loop via charging infrastructure, and the left-hand innovation loop), whereas the right-hand innovation loop represents the feedbacks around the global EV market.

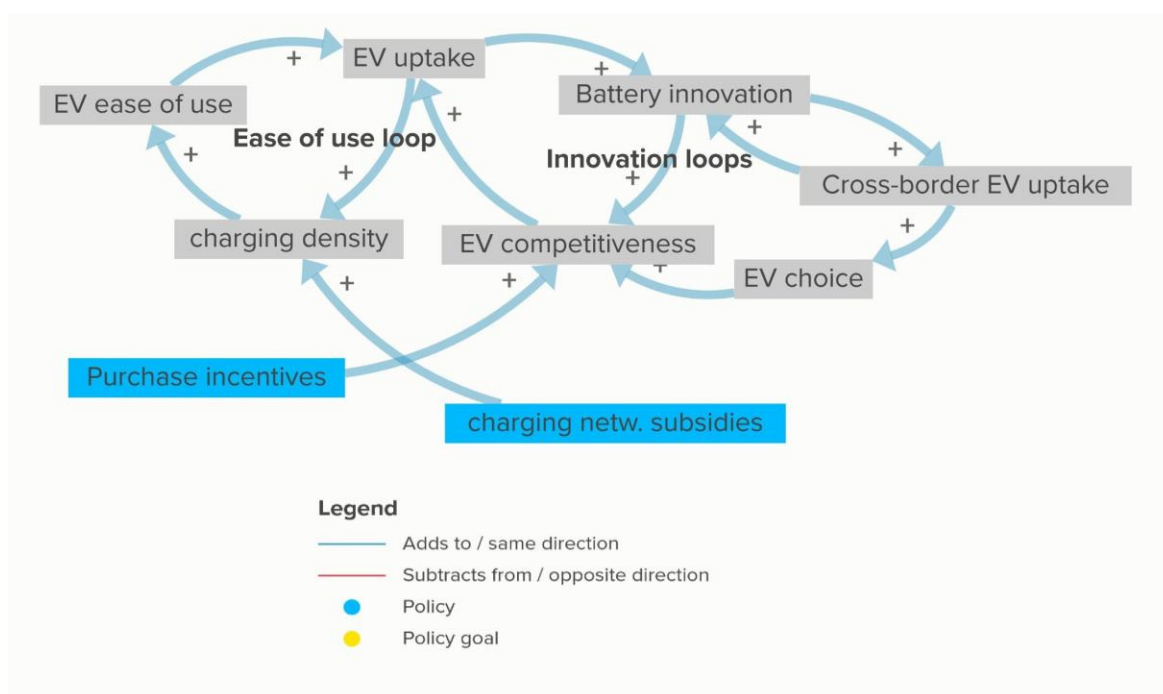


Figure 5: the part of the systems map related to tipping behaviour. We identify one 'ease of use' loop and two innovation loops: one related to battery innovation, and the second to consumer choice in a larger EV market.

A key opportunity created by the EV policies in Norway is the possibility of creating a global EV market, bringing down costs sufficiently to help trigger tipping points towards EVs in other countries (Table 5).

Here, we quantify this opportunity by using a set of simple assumptions. Firstly, creating a Norway EV car market induces innovation. Some of the cost reductions are from learning-by-R&D, whereas others are from learning-by-doing. We focus on the latter, as it's directly related to the cumulative number of cars. Following Lafond, Greenwald, and Farmer (2022), we assume that half of induced innovation comes directly from stimulating demand.

Costs of batteries have come down by over 85% from 2010 to 2020 (Lam and Mercure, n.d.). Batteries make up a declining share of total costs of electric cars. In 2014, cost shares from batteries were around 25% for two popular models, Tesla model S and the Nissan Leaf (Nykqvist and Nilsson 2015). Lower battery costs are not fully translated into lower vehicle prices, as car manufacturers can also opt for product differentiation, in particular a move to cars with larger batteries and ranges. We assume half of cost reductions are translated into lowered costs of vehicles. I.e, we assume battery innovation impacts 12.5% of car costs.

In 2021, EV costs were 27000 USD in China, 48000 in Europe and 51000 USD in the US (International Energy Agency 2022). We assume the average of these three regions is

representative. As historical EV prices were typically higher, taking 2021 values underestimates the contribution of Norway to price savings.

Norway has been an early leader in EV uptake. Based on data from the IEA's Global EV Data Explorer, 16% of the world stock in electric vehicles in 2010 were vehicles in Norway. Between 2011 and 2017, this share hovered around 7%, and reached 3% in 2022 with other EV markets growing rapidly (see Appendix A).

To summarise the above, we do a back-of-the-envelope estimation of how much the world has saved on electric vehicles due to the policy by Norway:

1. Compute EV market size by multiplying sales by average EV price
2. Take 12.5% of these costs as potential for costs declines (assuming half of innovation leads to improvements in range), and no innovation in other elements of the EV
3. Compute the cost declines in batteries using Wright's law
4. Compute the costs declines in the absence of Norway EV sales using Wright's law
5. Multiply (2) by the ratio of (4) and (3) to get the cost declines from induced innovation attributable to Norway
6. Half the value again to take into account that not all innovation is induced by sales

Project	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Global savings in million NOK	33	47	86	195	318	384	578	813	823	1199	2250	2854

Table 4: Back-of-the-envelope estimation

The global benefits here in terms of induced innovation on price are about three times the size of the climate benefits (Table 4). This is a conservative estimate, as we ignore the increased quality of EV batteries and the indirect climate benefits that stem from a small reduction in cost. From a more qualitative perspective, Norway's policy ensured a certain market for car manufacturing, raising investor confidence.

Of course, the creation of the EV market was an opportunity opened up by multiple countries together.

Opportunities	Quantification or qualitative description
Creation of domestic market	This opportunity did not materialise
Creation of international EV market	Norway played an important role in the creation of a market by given investors certainty
Induced innovation	In a conservative estimate, these costs saved via Norway's share of induced

Opportunities	Quantification or qualitative description
	innovation were three times the climate benefits.
Reaching a domestic tipping point	Norway showed that a tipping point towards EVs can be reached, reaping climate and air quality objectives

Table 5: Summary of opportunities

Step 5: Summary for decision-makers

We used a systems mapping approach to map out expected policy outcomes, risks, and opportunities. We conclude that environmental benefits are significant, but the policy may also have negative social and economic impacts related to health and inequality, directly and indirectly via decrease in government income. The impact, risk and opportunity categories are estimated qualitatively, based on the narrative review and systems mapping above; quantitative modelling may help further justify these categories.

Impact	Quantification or qualitative description	Impact
Environmental impacts	Significant reduction in CO2 emissions and air pollution, cross-border impacts due to mining	High
Social impacts	Some impacts on health and inequality, due to differences in transport mode based on income	Medium
Economic impacts	Significant decreased tax income	High

Table 6: Policy impact

In terms of risk, we identify three scenarios (Table 7). A failed policy scenario in which EVs do not take off despite generous incentives has strong environmental risks, given that alternative policy may not reach net-zero emissions. A low-probability medium-risk scenario is one where hydrogen fuels would have outcompeted EVs, leading to the necessity of a second transition. Finally, an overly rapid transition can see rapid declines in government income, limiting government operating space.

Risk and resilience	Quantification or qualitative description	Risk
Failed policy	Environmental risks: alternative policy may be insufficient to reach net-zero	Medium
Betting on the wrong horse	Hydrogen fuel cell vehicles could have won the race	Low
Rapid success and transition risk	Rapid declines in government income	High

Table 7: Scenarios

Two domestic and two international opportunities were identified (Table 8). The first one relates to the opportunity to fully clean up the vehicle fleet via self-reinforcing feedbacks. There were hopes to create a domestic market, based on opportunities of start-up. This was always challenging, given the lack of large incumbents in Norway. The other two are international, and relate to the creation of an international industry and international tipping points. Norway's policies can have ramifications far beyond its borders. We estimate the contribution to international cost declines is larger than the climate impact.

Opportunities	Quantification or qualitative description	Opportunity
Domestic tipping point	A majority of sales were EVs	High
Creation of domestic industry	Two small car makers had growth potential if they acted as first-movers	Medium
Creation international EV market	Sustained demand creates investor confidence for this industry to be created	Medium
Induced innovation	Contribution to innovation, and related costs savings overseas can be significant	Medium

Table 8: Opportunities

Discussion

Curiously, the policies leading to a successful transition to EVs in Norway were initially not appraised. The transition took place thanks to social movements, rather than formal policy appraisal. This is not uncommon, as decades of research, for example in policy studies, has shown that policy-making is influenced by factors such as ideas, interests, institutions, narratives, and policy activities of other jurisdictions (Weible 2023). Other key technology for the green transition can be found in the power sector, in particular onshore and offshore wind, and solar power. Here, we compare the policy appraisal methods involved in those transitions.

Similar to the case of electric vehicles in Norway, the policy surrounding a preferential treatment of solar PV in Germany was more based on activism than on solid economic analysis. The policy is now considered to have been key in making solar electricity the cheapest form of electricity in many countries in the world (Nemet 2019; Nijssse et al. 2023). Only in 2016, a report by the German Council of Economic Experts said these types of “planned economy” policies would be unable to drive innovation and unnecessarily raise costs for consumers (German Council of Economic Experts, 2017).

In the United Kingdom, initial support for the offshore wind industry took place via Renewables Obligations, which were banded by maturity of technologies. Later, support was changed to a Contract-for-Difference scheme, relying on competition via auctions. The goals for offshore wind were based on achieving the legal obligations for renewables as part of the European Renewable Energy Directive. This was initially fiercely criticised by economists within and outside the government (Grubb, et al. 2021). Notably, the National Audit Office expressed concern about the generous subsidies in the early stage, saying it did not provide sufficient value for money (Comptroller and Auditor General, 2014). Cost were forecasted to decline from £140/MWh to £100/MWh (Offshore Wind Cost Reduction Task Force, 2012), a decline slower than what had been observed in onshore, and much lower than the observed declines to £40/MWh observed in the 2019 auctions (Grubb, et al. 2021).

We performed a cost-benefit analysis on the EV transition as well as a risk-opportunity analysis. Unsurprisingly, for an expensive transformative policy, the cost-benefit analysis did not result in a positive result for the policies: costs were higher than benefits. Eskeland and Yan (2021) noted in their extended CBA that the policies “imply” a CO₂ tax over 10x higher than the EU ETS.

We then perform a Risk-Opportunity Analysis. The three elements of ROA are estimating likely outcomes, identifying risks and opportunities. In our example, we performed ROA using qualitative and semi-quantitative methods, noting that a typical application also involves more detailed modelling. We identified risks not typically included in CBA, and estimated that opportunities related to global cost savings via induced innovation are larger than direct climate benefits.

Many of the key opportunities in the green transition are related to induced innovation (Grubb, et al. 2021). A small country like Norway can have a disproportionate impact on the creation and maturation of a new industry. To capture these opportunities collaboratively, 40 countries signed up to the Breakthrough Agenda at COP26 in Glasgow. Here, sector-specific coalitions of the willing are seeking to drive these tipping points towards lower costs together (Sharpe 2023).

Our analysis suggests that imbalanced quantification of costs and benefits often results in wrong answers. This is in agreement with the above-mentioned discussion, which stresses how CBA often overlooks induced innovation. Even if the CBA involves many quantitative techniques and measures various aspects of policy options, it tends to bias against transformative policy.

Risk-opportunity analysis addresses some of these limitations. As a semi-quantitative method, uncertain benefits and risks can be included explicitly. The three-prong analysis around impact, risks, and opportunities makes ROA a potentially resource-intensive method, which is therefore more suited to areas of large transformative policies than to small. While we see stakeholder engagement and input into the process as a fundamentally positive aspect, we do recognise this may introduce bias.

Risk-opportunity analysis is designed to provide flexibility to the preferences of different stakeholders. When policy-makers make decisions, they often consider the possibility of credit and blame, to ensure they retain legitimacy to govern (Leong and Howlett 2017). These concepts are highly linked to risk, and can be transparently incorporated into ROA.

Conclusion

In this paper, we have assessed the policy appraisal landscape in the European Union and Norway. In contrast to policy appraisal in the United States and the United Kingdom, a wider set of methods is commonly used. Specifically, multi-criteria analysis often complements cost benefit analysis. We identified limitations of these policy appraisal methods, and explored alternative existing methods in the literature. Few methods have been developed that capture systemic risk and opportunity.

We examined one policy package in more depth: the transition to electric vehicles in Norway. This transition is lauded internationally as a highly successful example of a rapid sectorial transition. Policies to support electric vehicles were initially implemented as an experiment championed by activists. Policy appraisal was largely absent between the 1990s and 2010. The question we sought to answer is whether the successful policy would have been implemented if cost benefit analysis had been performed. In other words, would a cost benefit analysis have been a proper policy appraisal method?

We first perform a cost benefit analysis. The costs, specifically the exemption on registration tax VAT and subsidies for the charging network, far exceeds the effects in a cost benefit analysis.

In the next step, we further develop a newly proposed policy appraisal method: risk opportunity analysis. We then re-evaluate Norway's EV using risk opportunity analysis. We show, using a conservative back of the envelope estimation, that the opportunities around global induced innovation alone are three times the size of local climate benefits. In conclusion, risk opportunity analysis may be more appropriate than cost benefit analysis for evaluating highly transformative change.

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Appendices

Appendix A: Data sources Policy background

Variable	Description	Source/Value
N^n	Number of normal charging stations	International Energy Agency https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer
N^f	Number of fast charging stations	International Energy Agency https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer
S^n	Average subsidy amount per normal charging stations	International Energy Agency https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer
S^f	Average subsidy amount per fast charging stations	(Springel 2021)
<i>new bev units</i>	New electric cars	(Springel 2021)
<i>bev units</i>	Number of electric cars	Statens vegvesen, the Norwegian Public Roads Administration https://robbieandrew.github.io/EV
<i>av bev price</i>	Average price of BEV: 534771 NOK	International Energy Agency. https://www.iea.org/data-and-statistics/charts/price-distribution-of-electric-cars-compared-to-overall-car-market-in-the-european-union-2021-2022
<i>bev price</i>	Car prices	Norwegian Tax Administration https://www.skatteetaten.no/en/rates/car-prices---list-prices-as-new/
τ_{50}	One-time vehicle registration tax	50% (Springel 2021)
τ_{25}	VAT	25% (Springel 2021)
SCC	Social cost of carbon	(Cai -and Lontzek 2019)
$GHG\ emi$	Annual greenhouse gas emissions from cars in kt CO2 eq	European Environment Agency https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer
$M^{D/P}$	Average maintenance cost of diesel and petrol car	(Piao, Mcdonald, and Preston 2014)
M^{EV}	Average maintenance cost of EV	(Piao, Mcdonald, and Preston 2014)
	Registered vehicles	https://www.ssb.no/en/statbank/table/07849/tableViewLayout1/
EV stock global share	Norway's share of EV stock compared to the global stock	https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer
	Air pollutants	https://www.eea.europa.eu/data-and-maps/dashboards/air-pollutant-emissions-data-viewer-5

Appendix B: List of key policies in Norway's EV transition

Years	Incentives (taxes and subsidies)
1996	One-time registration fee (~50%)
1996	Annual road tax
2001	Value added tax (25%) exemption
2007	Reform of vehicle registration tax
2009	Station subsidies
2010–2019	Station subsidies
2014–2023	Station subsidies