14
Transport futures research

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14.1 INTRODUCTION

It has often been said that 'to govern means to foresee'. This adage is also valid for transport policymaking. For example, an increasing transport demand in the future could lead to politically unacceptable future levels of congestion, air pollution, and traffic casualties if no additional policies are taken. Thus, it is important for governments to know about possible future transport expectations in their region in order to be able to implement new policies in time. For several decades, governments have been developing policies to reduce the negative impacts of transport (see Chapters 9–13). Chapter 13 discusses criteria for 'sound' policies. But how to explore the future impacts of candidate transport policy options? To do this we enter the area of transport futures research – this area is the scope of this chapter. Chapter 15 will then discuss how to evaluate ex ante all impacts via a cost–benefit analysis or multi-criteria analysis. Chapter 16 discusses the use of transport (impact) models.

Research can map *possible* futures and transport policymaking strategies. Here, it is very important to note the term 'possible'. In fact, the future is unknown and is largely determined by non-predictable developments (Taleb, 2007). This implies that future outcomes are surrounded by a lot of uncertainty. In our view, in proper transport futures research this uncertainty should be adequately taken into account and clearly communicated to the decision-makers. In poor transport futures research, the opposite is true. The analysts in poor quality transport futures research often seem to think that they are able to predict the future, which is, of course, impossible. An example of sometimes huge inaccuracies in future studies is given by Cruz and Sarmento (2020). Based on an extensive international review study on the accuracy of traffic demand forecasts for road and rail projects over the past decades, it is shown that there can be (huge) inaccuracy in traffic/ridership forecasting with a tendency to be over-optimistic in futures studies. In particular, a (weighted) average deviation of -23.6% (meaning that the real traffic was lower than forecast) was found for railways and -9.3% for roads. The authors also found that over the last couple of decades the accuracy in the futures studies they reviewed had not improved.

This chapter is written from the perspective of transport policy analysis. The aim is to specify research approaches to the study of transport futures, and to explain the role of futures research related to transport policy analysis. Generally speaking, futures research in transport policy analysis is carried out for two reasons: (1) to identify the types and magnitudes of future transport problems (and/or opportunities), and (2) to identify ways to reduce these transport problems (and/or take advantage of these opportunities).

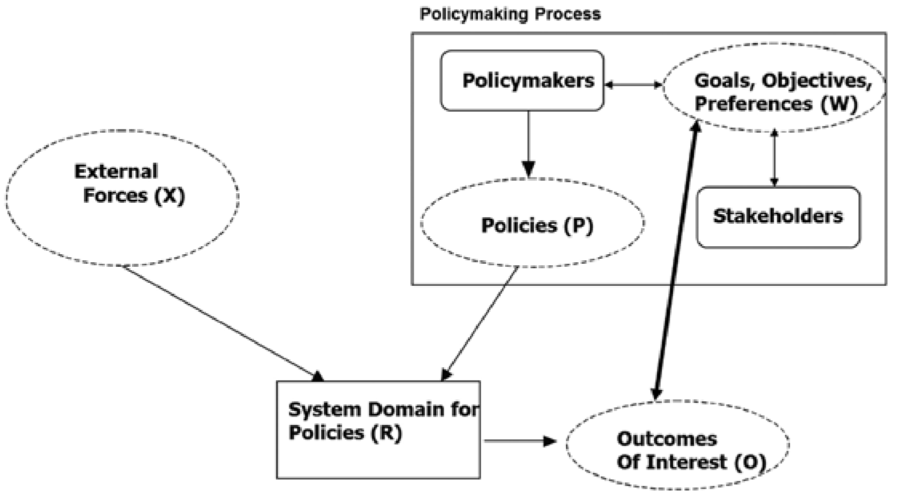
With respect to future transport problems, an increase in future transport could result in societally unacceptable levels of air pollution, congestion, and traffic casualties, for example (see Chapters 9–11). Here, transport futures research supports estimating the future levels of these problems. By doing so, policymakers may decide to implement new policies, for example. On the other hand, futures research on economic and demographic developments, for example, might show that transport demand will decrease. As such, problems could be solved, or at least reduced, without intervention.

Next, if future transport problems are identified, policymakers often desire to know the policy options that could help solve the problems, their effects, and their costs and benefits (see Chapter 15). The specification and analysis of current and future options is not trivial. For instance, some options might currently be under development (e.g. new vehicle technologies) or even unknown. In addition, most transport policy options have a long-term character. For instance, building new infrastructure often takes a long time (including the period from the initial discussions to the final decision, the time needed to start building after a decision has been taken, and the time the building itself takes). Furthermore, the benefits from new infrastructure will be realized over decades from when it is opened. Finally, it takes years before the full impacts of pricing and technical measures for new vehicles are reached. Transport futures research can help to specify current and future options, and to estimate their long-term impacts.

In Section 14.2, futures research in relation to the transport policy domain is explained and a framework for futures uncertainty is discussed. This framework distinguishes different levels of uncertainty, including Level 3 (or scenario) uncertainty and Level 4 (or deep) uncertainty. In Section 14.3, scenario planning approaches are explained to handle Level 3 uncertainty. Next, in Section 14.4, flexible and adaptive approaches are presented to handle Level 4 uncertainty. Finally, Section 14.5 contains the conclusions.

14.2 FUTURES RESEARCH AND TRANSPORT POLICY ANALYSIS

Futures research to help public decision-making starts with an understanding of the policy domain. As detailed by Walker (2000a), a common approach to a rational-style policy analysis is to create a model of the system of interest (in this book: the transport system) that defines the boundaries of the system and describes its structure and operations – i.e. the elements, and the links, flows, and relationships among these elements (see Figure 14.1).



Source: Walker (2000a).

Figure 14.1 A framework for policy analysis

In Figure 14.1, different elements and links can be distinguished:

1. **External forces** (X) are forces that work from outside the transport system, i.e. are not under the control of the problem owner. These forces have influence on the demand for transport and the supply of transport (e.g. technical developments for vehicles and infrastructure, oil price, cultural changes, etc.).
2. The **transport system** box (R) represents the elements of the transport system (e.g. drivers, operators, vehicles, infrastructure) and their interactions. These elements and their interactions are affected by the external forces and future policies (see below), and result in intermediate transport system outputs (such as the amount of transport in passenger-kilometres and/or ton-kilometres per transport mode in a future year).
3. The **outcomes of interest** (O) box represents policy relevant outcomes from the transport system – output such as traffic congestion, air pollution, and traffic casualties. In a future estimation, these amounts are the transport system output levels as estimated by the transportation model (see Chapter 16 on transport modelling).
4. The estimated outcomes of interest for the future may not be in accordance with policy goals or preferences. This produces a need for new future transport **policies** (P), such as new infrastructure, road or fuel pricing, stricter vehicle emission standards, etc., which can be fed into a new estimation of outcomes via the link from policies to the transport system.
5. The **valuation of outcomes or weights** (W) involves the relative, subjective importance given to the outcomes of interest by crucial stakeholders. It involves how stakeholders value the results of the changes in the transport system, such as improved traffic efficiency, fewer fatalities, reduced emissions, etc. (see Chapter 15 on evaluation methods).

To be most useful (and to increase the chances of the results of a policy analysis actually being used) a policy analysis study should be carried out as a partnership between the policymakers and the researchers. The four main steps in performing a policy analysis are summarized below. Note that this will generally not be a linear process, and there will often be feedback between the steps, particularly from Step 3 to Step 1.

1. Formulate the transport problem: Problem definition, setting goals, specifying options (often done in close partnership between the researchers and the problem owners/policymakers).
2. Estimate the future impacts (outcomes of interest (O) of the various policy options for different futures using transport system models and scenarios, for example (done mainly by the researchers).
3. Compare options (done mainly by the problem owners/policymakers, but often supported by the researchers through quantitative, analytical tools (e.g. cost–benefit analysis, multi-criteria analysis)).
4. Choose and implement the chosen option (done mainly by the problem owners/policymakers).

This chapter focuses on methodological approaches to estimate the future impacts of policies and external forces (using e.g. scenarios) on the transport system. An essential criterion for choosing an approach is how uncertain the future is assumed to be, i.e. the level of future uncertainty assumed. In general, uncertainty can be defined as limited knowledge about future, past, or current events. Formally, as defined by Walker et al. (2003), we consider uncertainty in this chapter to be 'any departure from the (unachievable) ideal of complete determinism' (p. 8). Or, in mathematical terms:

Let Y be some event. If Probability (Y) $\neq$ 0 or 1, then the event Y is uncertain.

This abstract formula can be illustrated with an example of a future transport outcome of interest. Suppose Y is the estimate produced by a model of the carbon dioxide (CO_2) emitted by road transport in 2030 in some country. The model estimates that Y = 25 billion kilograms. The probability of this event actually happening in 2030 is not 0 or 1. In fact the probability is unknown. Thus, the estimate of 25 billion kilograms of CO_2 emitted by road transport in 2030 is uncertain.

Based on the policy analysis framework (Figure 14.1), a classification of uncertainties with respect to policymaking can be made. Such a classification was developed by Walker et al. (2003). For the purposes of this chapter, we do not need to elaborate on the issue of uncertainty (for this, we refer the reader to Marchau et al., 2019; Lyons and Marsden, 2019). Here, the most important notion is to realize that transport policy analysis problems can be characterized by different levels of uncertainty about the external forces (X), the transport system and transport system models (R), the outcomes of interest (O), and valuations of the outcomes (W).

A way of representing different levels of uncertainty is shown in Figure 14.2 (Marchau et al., 2019). Level 1 uncertainty is often treated through a simple sensitivity analysis of transport model parameters, where the impacts of small perturbations of model input parameters on the outcomes of a model are assessed. Level 2 uncertainty is any uncertainty that can be described adequately in statistical terms. In the case of uncertainty about the future, Level 2 uncertainty is often captured in the form of either a (single) forecast (usually trend based) with a confidence interval, or multiple forecasts ('scenarios') with associated probabilities.

Many (quantitative) analytical approaches for transport policy analysis deal with future uncertainties as being Level 1 and Level 2 uncertainties, which is highly questionable because the future is in almost all cases 'not clear enough' (as is assumed by Level 1) or it is hardly possible to attach probabilities to different possible futures (as is assumed by Level 2). As an example of a Level 1 mistaken attribution, Figure 14.3 gives figures for forecasted investment costs of High Speed 2 (HS2)[1] in the UK that had initially been given.

Uncertainty Level / Location	1	2	3	4
Context (X)	A clear enough future	Alternate futures (with probabilities)	A few plausible futures	Unknown Futures
System (R)	A single (deterministic) system model	A single (stochastic) system model	A few alternative system models	Unknown System Models
Outcomes (O)	A point estimate for each outcome	A confidence interval for each outcome	A limited range of outcomes	Unknown Outcomes
Weights (W)	A single set of weights	Several sets of weights, with a probability per set	A limited range weights	Unknown Weights

Source: Marchau et al. (2019).

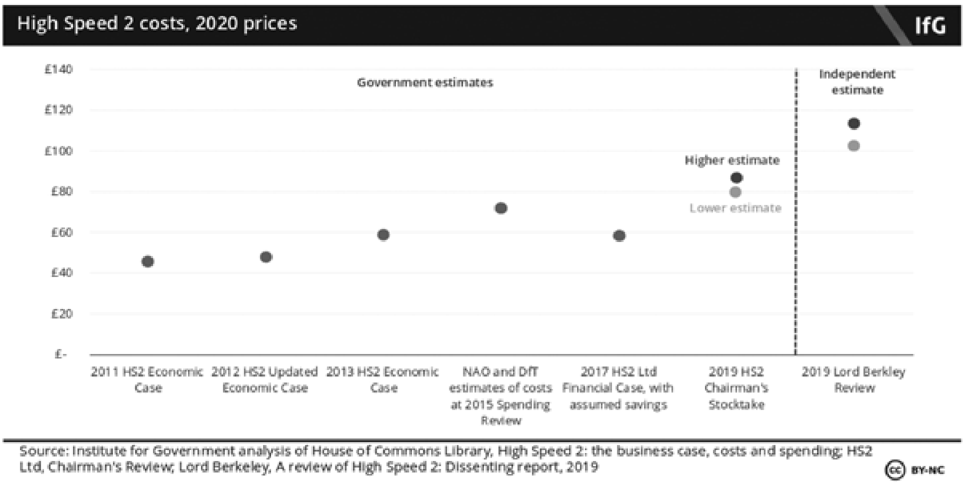
Figure 14.2 The progressive transition of levels of uncertainty

Even for forecasting future 'investment costs', which may seem at first glance an 'easy' item to forecast, the uncertainties are huge, as Figure 14.3 shows. In the earlier studies to support decision-making on HS2 (2011–17), the analysts had clearly informed decision-makers incorrectly about their assumptions about the future. Their cost estimates were far too low compared to recent insights, and their future cost estimates were just presented as point estimates, as if there was no uncertainty. The 2019 cost estimate is a 'stunning' factor two to three times higher compared to the earlier estimates and presented in a range (in 2020 prices).

In the view of the authors of this chapter, all long-term transport policy analysis problems are characterized by higher levels of uncertainty (i.e. Levels 3 and 4; see Figure 14.2). Only relatively short time 'predictions' (for example, forecasts for one day or one week ahead of congestion levels on certain road stretches) can be characterized as Level 1 and Level 2 uncertainties.

Note that with respect to Level 4 uncertainty a distinction can be made between situations in which we are still able (or assume we are still able) to bound the future around many plausible futures and situations in which we only know that we do not know. This vacuum can be due to a lack of knowledge or data about the mechanism or functional relationships being studied (bounding is possible), but this can also stem from the potential for unpredictable, surprising events (we only know we do not know).

The long-term related Level 3 and Level 4 uncertainties cannot be dealt with through the use of probabilities and cannot be reduced by gathering more information, but they are basically unknowable and unpredictable at the present time. These higher levels of uncertainty can involve uncertainties about all aspects of a transport policy analysis problem – external or internal developments, the appropriate (future) system model, the parameterization of the model, the model outcomes, and the valuation of the outcomes by (future) stakeholders. Many of the negative consequences from policy decisions in the past were due to the use of approaches that did not take into account the fact that they were facing conditions of Level 3 and 4 uncertainty (e.g. Cruz and Sarmento, 2020; Flyvbjerg et al., 2003, 2006).



Source: Institute for Government (2021).

Figure 14.3 Development in HS2 cost estimates, in billion pounds Sterling, in 2020 prices

14.3 LEVEL 3 APPROACHES: FORWARD-LOOKING SCENARIOS AND BACKCASTING

14.3.1 Forward-Looking Scenarios

When faced with Level 3 uncertainties, transport policy analysts will generally use scenarios. The core of this approach is the assumption that the future can be specified well enough to identify policies that will produce favourable outcomes in one or more specific plausible future worlds. The future worlds are called scenarios. Börjeson et al. (2006) call these ‘explorative scenarios’ to differentiate them from ‘predictive scenarios’, which some analysts think they can use to deal with Level 1 and Level 2 uncertainties (which is not the case for long-term transport planning, in our view), and ‘normative scenarios’, which use backcasting (see, for example, Quist (2007)) to determine how a specific desired target can be reached.

Scenarios are ‘stories’ of possible futures, based upon logical, consistent sets of assumptions, and fleshed out in sufficient detail to provide a useful context for engaging planners and stakeholders. A forward-looking scenario includes assumptions about developments within the system being studied and developments outside the system that affect the system, but they exclude the policy options to be examined (see also Figure 14.1). Because the only sure thing about a future scenario is that it will not be exactly what happens, different scenarios, spanning a range of developments, are constructed to span a range of futures of interest. No probabilities are attached to the futures represented by each of the scenarios. They have a qualitative function, not a quantitative function. Scenarios do not tell us what will happen in the future; rather they tell us what can (plausibly) happen. They are used to prepare for the future: to identify possible future problems, and to identify robust (static) policies for dealing with the problems.

In transport policy analysis, best-estimate models are often used (based on the most up-to-date scientific knowledge; see Chapter 16) to examine the consequences that would follow from the implementation of each of several possible policies. They do this 'impact assessment' for each of the scenarios. The 'best' policy is the one that produces the most favourable outcomes across the scenarios. Such a policy is called a robust (static) policy.

There is no general theory that allows us to assess scenario adequacy or quality. There are, however, a number of criteria that are often mentioned in literature as being important. Schwarz (1988) gives a brief summary of them. The most important of these are consistency, plausibility, credibility, and relevance.

1. **Consistency**: the assumptions made are not self-contradictory; a sequence of events could be constructed, leading from the present world to the future world.
2. **Plausibility**: the posited chain of events can happen.
3. **Credibility**: each change in the chain can be explained (causality).
4. **Relevance**: changes in the values of each of the scenario variables are likely to have a large effect on at least one outcome of interest.

A structured process for developing forward-looking scenarios, consisting of a number of explicit steps, has been used in several policy analysis studies. The steps, summarized by Thissen (1999), and based on the more detailed specifications of RAND Europe (1997), Schwartz (1996), and Van der Heijden, et al. (2002), are (see also Figure 14.1):

1. **Specify the system, its outcomes of interest, and the relevant time horizon.** A system diagram can be used to identify what is considered inside and outside the system, the system elements that affect or influence the outcomes of interest, and their interrelationships.
2. **Identify external forces (X) driving changes in the system (and thereby producing changes in the outcomes of interest (O)).** Whether or not a particular external force is potentially relevant depends on the magnitude of the change in the system and its implications for the outcomes of interest. There are many judgements involved in defining the system under consideration, the relationships among the subsystems, and the definition of what is relevant. Thus, the determination of relevant forces and changes is necessarily subjective. Potentially relevant forces and changes are often best identified by conducting a series of interactive brainstorming or focus group sessions involving experts and/or stakeholders.
3. **Categorize forces and resulting system changes as fairly certain or uncertain.** The forces/system changes from Step 2 are placed into one of two categories – fairly certain or uncertain (see Table 14.1). Those forces/system changes about which the researcher is fairly certain are placed into this category. The remaining forces/changes are placed into the uncertain category. The forces/system changes in the fairly certain category are

included in all the scenarios. The uncertain forces/system changes are used to identify the most important and relevant uncertainties that have to be taken into account.

4. **Assess the relevance of the uncertain forces/system changes.** The analyses should focus on the uncertain forces/system changes that have the largest effects on the outcomes of interest. To identify them, the impact of each uncertain force/system change is considered with respect to each of the outcomes of interest. Based on the estimated impact that the resulting system change has on the outcomes of interest, the force/system change is placed in either a high or low impact category (see Table 14.1). The uncertain forces and system changes in the low impact category are dropped from further consideration (or can be left in for 'colour'). The uncertain forces and system changes in the high impact category (those that have a high impact on at least one of the outcomes of interest), along with the fairly certain elements, form the basis for the scenarios.
5. **Design several future scenarios based on combinations of different developments in the driving forces.** These should provide strikingly different images of the future that span the space of what is plausible. A brief but imaginative description of the essential characteristics of the future depicted by each of the scenarios should then be provided. Once the specific scenarios are identified, the assumptions underlying them are converted into inputs that can be used by the system models. This forms the basis for the subsequent assessment of policy options.

Table 14.1 Selecting relevant forces for system changes for forward-looking scenarios

	Change would lead to a low impact (for all outcomes of interest)	Change would lead to a high impact (on at least one outcome of interest)
Force or change is uncertain	These forces/changes can be included (for 'colour') or left out of the scenarios	These forces/changes are candidates for scenarios
Force and change are fairly certain	These forces/changes can be included (for 'colour') or left out of the scenarios	These forces/changes are included in all the scenarios as 'autonomous developments'

After constructing scenarios using Steps 1 to 5, these are first used to specify the (magnitude of the) future problem if no additional action is undertaken. For example, these 'reference scenarios' might imply high congestion levels, a high increase in CO_2 emissions, and so forth. In other words, related to Figure 14.1, the scenario outcomes of interest may not be in accordance with the goals. The idea is that these reference scenarios assume that only the already existing and/or agreed upon policies will be implemented. As such, the need for additional policies can be identified. In practice, these reference scenarios are sometimes given other names – e.g. business-as-usual scenarios, baseline scenarios, or background scenarios.

Figure 14.4 summarizes the model-based evaluation process of policy options. In the 'validation case', the current system is used in the model to make sure that the outcomes are reasonably close to the real world outcomes. More on model validation can be found in Chapter 16. In evaluating the impacts of policy options, the researcher should always include the reference case (see Figure 14.4; see also Chapter 15), i.e. the future transport system with no policy changes. If a transportation model (see Chapter 15) was used to estimate the reference scenario outcomes, the same model should be used again with exactly the same input, except for the input parameter changes or model changes due to the policy option (or options) under study. This then results in the 'policy case', i.e. specification of the future transport system with policy changes. To be clear, the impact assessment shows the differences between the validation case (O_1 and O_2), the reference outcomes of interest (O'_1 and O'_2), and the outcomes of interest due to the policy measure (O''_1 and O''_2). These differences – the final pros and cons of the policy option – can be evaluated by the policymakers using different methods. For example, they can ask for a multi-criteria analysis (MCA), a cost-effectiveness study, or a cost–benefit analysis (see Chapter 15).

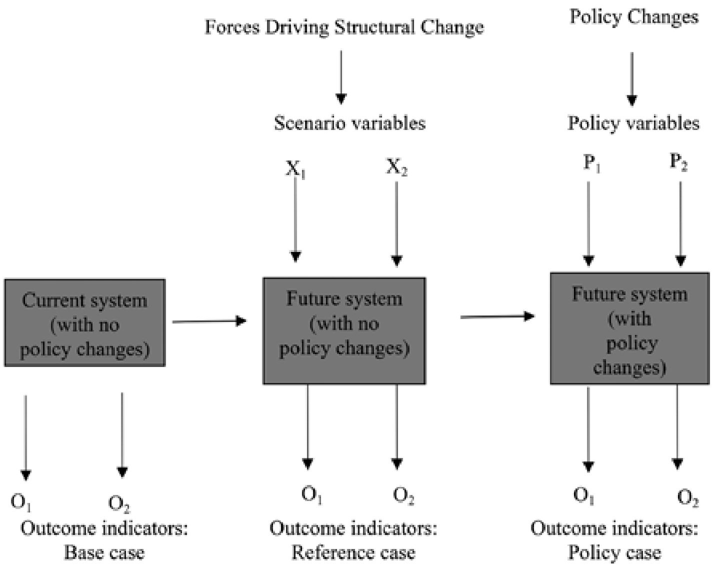
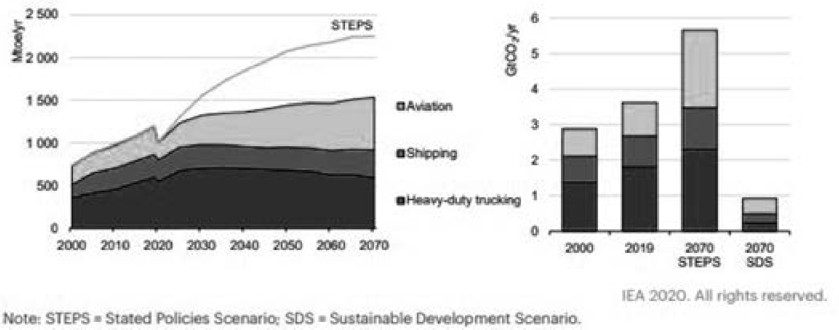


Figure 14.4 Evaluating policy options using scenarios

The policy option or options to be studied and the relevant outcomes of interest are dependent on the policy question. Impacts of new roads compared to the reference scenarios can be studied, or extra investments in public transport, or new vehicle emission standards, or kilometre charging, etc. It is also possible to evaluate the impacts of policy packages (combinations of policies) or technology packages (see also Chapter 13). Figure 14.5 gives an example of an evaluation of the impact of a future technology package (which requires strict policies to be adopted by the market) on worldwide greenhouse gas emissions (CO_2 emissions) for aviation, shipping, and heavy-duty trucking in the long term (2070) (IEA, 2021). The figure shows that, compared to the STEPS (Stated Policies Scenario) in the SDS (Sustainable Development Scenario), huge CO_2 emission reductions in 2070 are deemed possible, from almost 6 gigatons in STEPS to 1 gigaton in SDS. STEPS represents a business-as-usual scenario in which only the stated policies at the time of developing the scenarios are taken into account. In SDS, alternative fuel technologies such as electricity, hydrogen, biofuels, and synthetic aviation fuels are assumed to have been adopted on a large scale in aviation, shipping, and heavy-duty trucking, showing the huge decarbonizing potential of these technologies to politicians and the market. In Chapter 8 these technologies will be explained in more detail.



Note: The left graph is energy with STEPS presented in a bandwidth: between 2300 and 1500 Mtoe in 2070; the right graph is the CO_2 emissions with STEPS (the high range) near 6Gt and SDS about 1 Gt in 2070.
Source: IEA (2021).

Figure 14.5 Global energy consumption (Mtoe/yr) and CO_2 emissions (Gtons/yr) in aviation, shipping, and heavy-duty trucking by sub-sector in two scenarios: the Sustainable Development (SDS) and Stated Policies (STEPS) Scenarios

14.3.2 Pros and Cons of the Forward-Looking Scenario Approach

The benefits from using scenarios in policy analysis are threefold. First, scenarios help analysts and policymakers deal with situations in which there are many sources of uncertainty. Second, scenarios allow analysts to examine the 'what ifs' related to external uncertainties. They suggest ways in which the system could change in the future, and facilitate the examination of the implications of these changes. Finally, scenarios provide a way to explore the implications of Level 3 uncertainties for policymaking (prepare for the future) by identifying possible future problems and identifying (static) robust policies for dealing with the problems. These advantages have also been recognized by transport policymakers, and scenarios are becoming more and more used in strategic transport planning (Lyons et al., 2021).

However, from an analytic perspective the scenario approach has some problems. The first problem is deciding which assumptions about future external developments to include in the scenarios. Typically, these assumptions are decided upon by experts (collectively and individually). However, in the face of uncertainty, none is in a position to make this judgement. A second problem is that the researcher has little idea about whether the range of futures provided by the scenarios covers all, 95%, or some other percentage of the possible futures. A third problem with the scenario approach has to do with the large number of performance estimates generated by the scenarios. If the range is large, policymakers often tend to fall back on a single, 'most likely' scenario (implicitly assuming Level 2 uncertainty) or the do-nothing approach, arguing that 'we do not have sufficient information to make a decision at this time'. The latter is probably the worst possible outcome – when the level of uncertainty is high and the potential consequences are large, it would probably be better if policymakers acted rather than waited.

14.3.3 Backcasting Approach

Backcasting is quite different from the forward-looking scenario approach described above. Here, a normative target in the future – a desired outcome – is chosen as the starting point of the future analysis; then appropriate paths towards this desired outcome are searched for. In general, in backcasting, first an image is found that might be a future solution for the societal problem at hand. If such an image can be made explicit, the next step is to identify and assess a path between today and that future image. If no path can be found, the image will be redeveloped and adjusted (Hojer, 1998).

Within transport, several studies on sustainable development, or specifically on reducing CO_2 emissions in future transport, have used the backcasting approach – e.g. the OECD project 'Environmentally Sustainable Transport', the EU project POSSUM, and the UK project VIBAT (Geurs and van Wee, 2000; Banister et al., 2000; Hickman and Banister, 2014). Soria-Lara and Banister (2018) have developed and applied a more collaborative backcasting approach using a desired transport future for Andalusia, Spain.

Four different steps in the backcasting process related to policymaking can be distinguished:

1. **The definition of a future target or targets**, which can (for example) be zero CO_2 emissions in year 2050 for international aviation.
2. **The construction of a reference (forward-looking) scenario.** By comparing this reference case to the defined target(s) the required scale of change is specified. For example, STEPS is an example of reference scenarios (see Figure 14.5) that shows that without additional technologies and policies, CO_2 emissions in the long-distance transportation sector in Europe will increase instead of decreasing to zero in 2050. The reference scenario points to a huge gap that has to be bridged by implementing additional policies.
3. **The design of 'images of the future'.** Images are descriptions of the future that (from today's point of view) seem to meet the targets. Banister et al. (2008) have suggested criteria for future images. Schippl and Leisner (2009) summarize these: (1) the images should meet the targets; (2) each image should be plausible, but can be relatively extreme; (3) the images should be clearly different from each other, in order to give an idea of the huge variety of possible futures; and (4) the images should cover a sufficiently wide range of possibilities. However, to keep the research manageable, a small number of images should be selected. Soria-Lara and Banister (2018) also experiment with involving policymakers or other stakeholders in creating images.
4. **The specification of potential policies.** Policies that might help meet the images are specified. They are then analyzed and assessed by identifying the trajectories leading from the future images back to the present state and vice versa. Note that in some backcasting studies, the trajectories proposed are also called scenarios, which can be confusing.

Related to the uncertainty framework used in this chapter (Figure 14.2), we can identify two potential weak points in state-of-the-art backcasting methods. First, it seems highly risky to assume the future to be as forecast by the reference scenario (Step 2), as in STEPS (EIA, 2021), for example. By doing so, the future is treated as a Level 1 uncertainty, which is, of course, untrue. Here, the risk is that the policymakers are given a false feeling about the predictability of future development without additional policies, which may result in wrong policy actions (too many or too few changes to the system; or changes made too early or too late). Second, in Step 4 it is (implicitly) assumed that the specified policies will actually lead to the desired future, which is an incorrect assumption.

14.4 LEVEL 4 APPROACHES: FLEXIBLE AND ADAPTIVE APPROACHES

The previous sections focused on approaches to handle Level 3 uncertainties. However, transport policy problems increasingly emerge in which the uncertainty can be characterized as Level 4. In this case, what is known is only that the researcher does not know the future situation (or only knows the boundaries). Level 4 uncertainty is also called 'deep uncertainty'; it is defined as a condition in which analysts do not know (and/or the parties to a decision cannot agree upon) (1) the appropriate models to describe interactions among a system's variables; (2) the probability distributions to represent uncertainty about key parameters in the models; and/or (3) how to value the desirability of alternative outcomes (Lempert et al., 2003).

In most policy analysis studies involving lower levels of uncertainty, the study ends with the researcher presenting the impacts of alternative policies, leaving the choice and implementation of a preferred policy to the policymaker(s) (although the analyst and policymaker(s) should be working closely during the course of the study, as stated in Section 14.2). In the case of deep uncertainty, the implementation step of a policy analysis is explicitly addressed by the researcher. This 'implementation research' focuses on how the chosen policy could fail, and ways to protect it from failing.

In general, the literature offers three (overlapping, not mutually exclusive) ways for dealing with deep uncertainty in making policies, although there are differences in definitions, and ambiguities in terminology (see, for example, Leusink and Zanting, 2009):

1. **Resistance**: plan for the worst conceivable case or future situation (e.g. over dimensioning of infrastructure).
2. **Resilience**: whatever happens in the future, make sure to have a policy that will result in the system recovering quickly (e.g. floating roads, traffic incident management).
3. **Adaptive robustness**: prepare a policy that is flexible and adaptable, which will perform well across the full range of plausible futures (including surprises).

The first way is likely to be very costly and might not produce a policy that works well, because of Black Swans. The Black Swans metaphor is used by Taleb (2007) to explain that many events in the world are a surprise (to the observer) and can have major unforeseen impacts on world development. The second way accepts short-term pain (negative system performance) but focuses on recovery. The third way appears to be the most robust and efficacious way of dealing with deep uncertainties (Kwakkel et al., 2010b).

A variety of analytical approaches and tools have been developed to design robust and adaptive policies. Their underlying paradigm is the need for actions to reduce the vulnerability of a policy or strategy to uncertain future developments. Dewar et al. (1993) called this 'Assumption-Based Planning' (ABP). Within this paradigm, analysts use 'Exploratory Modeling' (EM) and 'Scenario Discovery' (SD). EM is a tool to explore a wide variety of scenarios, alternative model structures, and alternative value systems based on computational experiments (Bankes, 1993). A computational experiment is a single run with a given model structure and a given parameterization of that structure. It reveals how the real world would behave if the various hypotheses presented by the structure and the parameterization were correct. By exploring a large number of these hypotheses, one can get insights into how the system would behave under a large variety of assumptions (Bankes et al., 2013). SD is a tool to identify futures in which proposed strategies meet or miss their goals. It begins with a large database of model runs (e.g. from EM) in which each model run represents the performance of a strategy in one future. The SD algorithms identify those combinations of future conditions that best distinguish the cases in which the policy or strategy does or does not meet its goals.

A potential problem in EM is that, since the number of uncertainties is large, the number of model runs will be large. The set of resulting scorecards will, therefore, comprise a very large database. It is very difficult for anyone to scan this large database and interpret the results in order to identify a preferred policy for each of the plausible scenarios. Therefore, software that offers graphical tools to summarize the results of an exploratory analysis is required. Given complete sets of external forces, policies, system models, outcomes, and their weights, software is now available that is able to determine the values of the (uncertain) parameters that would lead to preferences for the different policy options (i.e. it is able to map the decision space). Agusdinata (2008), Kwakkel et al. (2010b), Van der Pas et al. (2010), and Milkovits et al. (2019) supply examples of how EM can be applied to transport policy analysis problems involving Level 4 uncertainty.

ABP was a first step towards an evolving set of analytical approaches for supporting Decision Making under Deep Uncertainty (DMDU). Four of the most commonly used approaches are:

1. **Robust Decision Making (RDM)**: RDM begins with one or more alternatives under consideration (often a current or best-estimate plan) and uses EM to make many runs of a system model to identify the futures most relevant to the plan's success. RDM uses Scenario Discovery (SD) to analyze data across the model runs to help decision-makers address such questions as: what are the key characteristics that differentiate those futures in which a plan succeeds from those in which it fails?; and what steps can be taken to help the plan to succeed over a wider range of futures? (Lempert, 2019).
2. **Dynamic Adaptive Policymaking (DAP)**: DAP focuses on implementation of an initial policy prior to the resolution of all major uncertainties, with the policy being adapted over time based on new knowledge. DAP specifies the development of a monitoring programme and responses when specific trigger values are reached. Hence, DAP makes adaptation over time explicit at the outset of plan formulation. DAP occurs in two phases: (1) the design phase, in which the basic policy, monitoring programme, and various pre- and post-implementation actions are designed; and (2) the implementation phase, in which the basic policy and the monitoring programmes are implemented, and contingent actions are taken, if necessary (Walker et al., 2019).

3. **Dynamic Adaptive Policy Pathways (DAPP)**: DAPP considers the timing of actions explicitly in its approach. It produces an overview of alternative routes into the future. The alternative routes are based on Adaptation Tipping Points (ATP). An Adaptation Tipping Point focuses on 'under what conditions will a given plan fail', which is analogous to the question that is asked in ABP or in SD (Haasnoot et al., 2019).
4. **Engineering Options Analysis (EOA)**: EOA refers to the process of assigning economic value to technical flexibility. It consists of a set of procedures for calculating the value of an option (i.e. the value of having a right (not an obligation) to take some action (e.g. expand a road because you have the space) at some cost (e.g. for road construction) over some time period), and is based on Real Options Analysis (de Neufville and Smet, 2019).

With respect to the transport domain, several DAP studies have been undertaken (a first example of DAP is presented by Hadjidemetriou et al. (2022)). As such, we will elaborate below on DAP. The basic concept of a dynamic adaptive policy is easy to explain (Walker, 2000b). It is analogous to the approach used in guiding a ship through a long ocean voyage. The goal – the end point – is set at the beginning of the journey. But, along the way, unpredictable storms and other traffic may interfere with the original trajectory. So, the policy – the specific route – is changed along the way. It is understood before the ship leaves port that some changes are likely to take place – and contingency plans may have already been formulated for some of the unpredictable events. The important thing is that the ultimate goal remains unchanged, and the policy actions implemented over time remain directed toward that goal. If the goal is changed, an entirely new plan must be developed. However, this does not mean completely starting over, as the knowledge of outcomes, objectives, measures, etc. learned during the initial DAP process would accelerate and simplify the new planning process.

An adaptive policy would include a systematic method for monitoring the environment, gathering information, implementing pieces of the policy over time, and adjusting and re-adjusting to new circumstances. The policies themselves would be designed to be incremental, adaptive, and conditional.

We now illustrate the steps to operationalize DAP using an example. The example concerns strategic planning for a large airport close to a built-up area (Kwakkel et al., 2010c). The design of the adaptive policy consists of four steps (from Marchau et al., 2010).

- **Step 1 Specification of problem, objectives, the definition of success, and constraints**

  In the past decennia, the rate of growth in air traffic was twice as large as the growth of the world economy. It is expected that, due to the increase of the world population, economic growth, and globalization, air traffic will continue to grow. Hence, an objective of an airport operator might be to improve the airport's capacity to handle increased demand. The related definition of success is that future capacity will meet future demand. Success means having a good match between supply and demand – not too much capacity, which would mean a lot of unused capacity, but not too little capacity, which would lead to delays in take-offs and landings. The constraints on policy options include costs, safety, life quality, spatial restrictions, and public acceptance.

- **Step 2 Specification of a basic policy and its conditions for success**
  A basic policy might be to expand the physical capacity of the airport (add a runway). Conditions for success of this basic policy include that demand continues to grow and that the extra aircraft noise generated does not bring strong protests. Traditional policy analysis tools are available for identifying a basic policy (Findeisen and Quade, 1985).
- **Step 3 Identifying the vulnerabilities of the basic policy and anticipatory actions to protect it**
  In Step 3 of the DAP process, the actions to be taken immediately to enhance the chances of success of the basic policy are specified. This step is based on identifying, in advance, the vulnerabilities associated with the basic policy, and specifying actions to be taken in anticipation. *Vulnerabilities* are external developments that could degrade the performance of the policy so that it is no longer successful. In short, the question is asked 'how can the basic policy fail?', and then actions are designed to prevent it from failing.

  Scenarios are used in this step and in Step 4; but they are used in a different way from the way they are used in dealing with Level 3 uncertainty. They are used to identify the ways in which the basic policy could go wrong (i.e. not lead to success), using EM (i.e. exploring a wide variety of scenarios, models, and value systems) and SD (i.e. identifying futures in which proposed strategies meet or miss their goals). In DAP, since the researcher is looking for changes in the world that can make the basic policy fail, the scenarios should differ from the present in major ways. For example, there should be some very negative scenarios. People tend to view very negative scenarios as implausible and reject them out of hand. Nevertheless, they are crucial to an adaptive policy; having thought about a situation (no matter how implausible) in advance allows contingency plans to be formulated so that they are ready to be implemented in the (however unlikely) event they are needed. So, as many Black Swans as possible should be identified in order to 'be prepared' in case one of them actually occurs. In the airport case, demand for air transport is one of the key scenario variables. There could be a sharp decrease in demand, for example due to a financial crisis. This would make the policy fail. But, there could be a sharp increase in demand, which could lead to unacceptable delays in take-offs and landings, which would also make the policy fail. We deal with this vulnerability in Step 4.

  Another vulnerability of the basic policy is resistance from people living around the airport because of the noise from the anticipated additional flights. This vulnerability is fairly certain. So, at the same time as the new runway is agreed upon, it would be wise to offer financial compensation to residents in the high noise zone to enhance the chances of success of the basic policy.
- **Step 4 Setting up a monitoring system and preparing to adapt the policy**
  After the basic policy and anticipatory actions are implemented, there is still a need to monitor changes in the world and the performance of the policy, and to take actions, if needed, to guarantee the policy's progress and success. Similar to the approach in Step 3, scenarios (or even EM and SD) can be used to identify what to monitor and when to trigger responsive actions, and the specific actions to take. In this step, actions that might be taken to guarantee the basic policy's progress and success are prepared. Also, *signposts* are identified that specify information that should be tracked, and critical values of sign-

post variables (called *triggers*) are specified beyond which actions to change the policy should be implemented to ensure that the resulting policy keeps moving the system in the right direction and at a proper speed. The starting point for the identification of signposts is the set of vulnerabilities specified in Step 3.

In the airport case, it is possible that the increases in demand are much greater than expected. This would lead to unacceptable delays, and airlines might decide to shift flights (or even their hubs) to other airports, which would lead to failure of the plan. In preparation, plans could be made to shift specific types of flights to surrounding airports (e.g. all-cargo flights or flights by low-cost carriers). Making these plans would not be expensive and they may never be needed. But, if the conditions warranted them, the plans would be there and could be implemented quickly at the appropriate time (specified by the trigger), thus saving the basic policy.

Although they are promising, adaptive policies have not yet become commonplace in public policymaking. More research is required before this will happen. First, their validity and efficacy needs to be established. Evidence is being gathered through a variety of methods, including gaming and computational experiments. Also, the costs and benefits of dynamic adaptation measures compared to traditional policymaking approaches need to be studied. Finally, the implementation of dynamic adaptation will require significant institutional and governance changes, since some aspects of these policies are currently not supported by laws and regulations (e.g. the implementation of a policy triggered by an external event).

14.5 CONCLUSIONS

The most important conclusions of this chapter are:

1. Futures research often plays an important role in transport policymaking. However, it is very important to note that the future is unknown, which makes future research outcomes (highly) uncertain, by definition. Uncertainty in this chapter is defined as being any departure from the (unachievable) ideal of complete determinism.
2. That uncertainties exist in practically all long-term transport policymaking situations is generally understood by most policymakers, as well as by most policy analysts. But there is little appreciation for the fact that there are many different dimensions of uncertainty, and there is a lack of understanding about their different characteristics, their relative magnitudes, and the available approaches and tools for dealing with them.
3. A much used approach in transport policy planning is the scenario approach. An important advantage of using scenarios in futures research is that scenarios provide a way to explore the implications of deep uncertainty for policymaking (prepare for the future) by identifying possible future problems and identifying potential policies for dealing with the problems.
4. An important disadvantage of the use of scenarios is that the scenario results are often used as 'certain' predictions, while they should be interpreted as 'what if' estimates for some plausible futures, and it is unknown (and unknowable) whether the actual future is covered by them.

5. In the backcasting method, a normative target in the future – a desired outcome – is chosen as a starting point for the futures analysis. Images of the future have to be designed that meet the specified targets. They should be clearly different from each other, in order to give an idea of the huge variety of possible futures, all of which meet the specified targets. Also in the backcasting method (1) it is important to avoid using forecasted futures as certainties, and (2) it is incorrect to assume that specified policies will actually lead to the desired future.
6. Some scientists are now thinking about policies that take uncertainty into account. The key idea is not to specify an 'optimal' policy for a single best estimate future, but rather to design a policy that is flexible and adaptable.

NOTE

1. High Speed 2 (HS2) was a British proposal to build a high-speed rail line in two parts – 'Phase 1' between London and Birmingham, and then 'Phase 2' between Birmingham and Crewe, and Birmingham and Manchester and Leeds (High Speed 2 costs | The Institute for Government, accessed December 2021). In November 2021, the UK government cancelled part of HS2 from East Midlands Parkway to Sheffield and Leeds – it is now only the route to Manchester that is going to be built. This has implications for future studies (political uncertainty) and the construction costs, etc. (www.theguardian.com/uk-news/2021/nov/18/hs2-rail-leg-to-leeds-scrapped-grant-shapps-confirms).

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