Chapter 19
A Transportation Planning Decision Support System

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Abstract In this chapter, the CapSEM toolbox is explored, applied, and evaluated in the context of transportation planning and policy-making. Transportation system elements are analyzed across all four CapSEM levels to identify relevant tools to utilize in decision support systems to address sustainability in the sector. The toolbox is applied to a strategic transportation planning case study. The application demonstrates how the framework may be used to structure and stack models across system and performance levels to handle transportation modeling and stakeholder complexity.

19.1 Introduction

The transportation sector provides critical mobility services to society, ensuring the movement of goods and people. However, the sector also significantly impacts the global and local environment. The sector accounts for 24% of global direct CO_2 emissions from fuel combustion (IEA 2020) and has increased its annual greenhouse gas emissions faster than any other societal sector since 2010 (IPCC 2022). Transportation also contributes significantly to NO_x emissions that may have adverse health effects. In Europe, the sector accounted for 55% of all NO_x emissions in 2017 (EEA 2019). Appraising sustainability performance and improvement pathways requires tools that handle the scale and complexity of transportation systems. This entails addressing sustainability across multiple systems and domains in providing holistic appraisals to support planners and policy-makers. The Capacity Building in Environmental and Sustainability Management (CapSEM) toolbox offers structure and methods for addressing sustainability across variable system and performance levels. In this chapter, the CapSEM toolbox is explored, applied,

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and evaluated in the context of transportation planning decision support systems (DSS). A case study is provided to determine its value and contribution to analyzing and solving complex sustainability challenges in the sector.

19.2 Exploring the Toolbox in the Transportation Sector

The CapSEM toolbox organizes approaches to appraise sustainability across process, product, organizational and system levels (Fet and Knudsen 2021). Each level has its distinct system and performance scope: Ascending across the four levels of the framework implies moving from low to high system complexity and narrow to broad scope of sustainability performance (Fet and Knudsen 2021). In transportation planning, multiple levels often need to be addressed simultaneously as technical, operational, and system-wide conditions need to be viewed in concert to understand the implications of transportation policies.

Table 19.1 lists elements to address improving the performance of transportation systems and associated tools for assessing them. Process change (Level 1) concerns production processes in the studied system (Fet and Knudsen 2021). Critical processes in transportation systems concern energy conversion to produce transport work. The inputs and outputs from these processes significantly impact the environment, particularly through resource depletion and air emissions. In order to assess the consequences of alternative energy carriers, conversion and abatement technologies, input-output based models are necessary.

At the product and value chain level (Level 2), the scope increases beyond operational impacts to include upstream and downstream impacts. At this level, additional input factors beyond energy carriers to produce transportation services such as materials, chemicals, and other consumables are also important. Life cycle assessment methods may be used to evaluate alternative transport options to avoid temporal or spatial problem-shifting of environmental and other sustainability impacts.

At the organizational level (Level 3), managerial and operational concerns are addressed, extending from processes and product systems to also encompass human behavior. Therefore, aspects related to economic and human factors must also be

Table 19.1 The CapSEM toolbox for transportation system sustainability appraisal

CapSEM level	Unit of study	Tool
Process	Energy conversion, e.g., engine combustion	Input – Output analysis
Product	Fuels, materials and chemicals	Life cycle assessment
Operational	Route choice, speed and technology deployment	KPIs, OPIs, preference modeling
System	Regulation and policies at regional level	SE, system analysis

considered at this level (Fet and Knudsen 2021). This may be translated to the operational features of the transportation system. The decisions and actions of multiple actors combine to produce the total system behavior and, ultimately, performance. Actors' preferences and behavioral logics strongly influence their operation of transport technologies, such as choice of transportation modes, routes, and speed (Díez-Gutiérrez and Babri 2020). To assess improvement measures at this level, preference modeling, key performance indicators (KPIs), and operational performance indicators (OPIs) may be deployed along with models on lower levels to understand the effects operational measures.

Lastly, at the system level (Level 4), holistic transportation planning, policies and regulation are of key interest. This is critical as optimizing subsets of the transportation system may provide effects that counteract overall system performance improvement. Tools for systems modeling, design, and assessment are required to provide a holistic perspective in planning and policy making.

In addition to providing a useful system breakdown structure of units of study and associated tools, there is also a cumulative aspect of the value of the CapSEM Model when applied to develop decision support systems in transportation planning. Information and knowledge retrieved at any level is relevant to inform higher levels. For instance, a life cycle assessment (Level 2) of alternative fuels also requires considering their combustion process characteristics (Level 1). A transportation system assessment (Level 4) requires a model that captures the system dynamics in a defined area where information from all previous levels (Levels 1–3) is included.

19.3 Application to a Transportation Planning Case Study

To illustrate the application of CapSEM, a case study from the Geirangerfjord World Heritage Site area is used, where authorities and transportation system actors need to balance the economic, social and environmental impacts related to tourism in the area. In 2018, the Norwegian parliament adopted a zero-emission regulation for ship traffic in the Norwegian fjords designated as world heritage sites by 2026 (Stortinget 2022). The resolution posed a complex problem to stakeholders in the Geirangerfjord area as it entailed technological, economic and logistical challenges. This required multiple actors to jointly assess alternative strategic responses to meeting the zero-emission requirements. As the transportation system includes land and sea traffic related to regular and tourist-based activities, the assessment rapidly increased in complexity. In order to provide a system-level assessment, tools from all levels in the CapSEM toolbox were utilized to build a holistic decision support system. Figure 19.1 shows the DSS resulting from this application, which is further elaborated in subsequent sections.

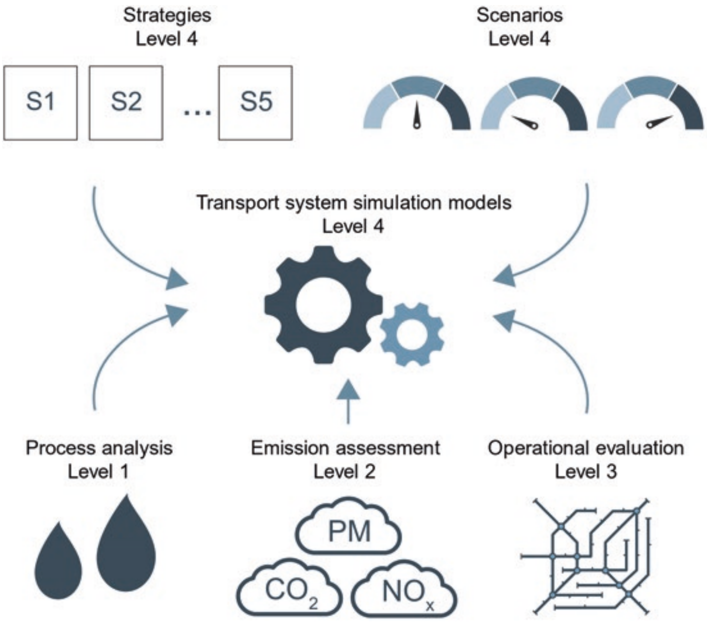

Fig. 19.1 Models and tools in the transportation planning decision support system across CapSEM Levels

19.3.1 Using CapSEM Tools to Develop DSS for Transportation Planning

The system-level responses to the regulation require structuring and modeling decisions and scenarios involving multiple actors. To establish a joint problem statement, the SPADE methodology was used. SPADE is a soft systems engineering approach valuable in handling complex problems in multi-actor environments (Aspen, Haskins, and Fet 2018; Haskins 2008). The methodology was applied to identify stakeholders (S), problems (P), and alternative strategies (A) to synthesize a decision analytical structure (D) for further modeling and evaluation (E). The stakeholder analysis helped classify key actors to include in the subsequent problem formulation. These included cruise companies, port authorities, transport companies, tourist operators and politicians. The problem formulation helped structure strategic responses to the regulation and identify uncertainties, scenarios, and key performance indicators to use in the subsequent modeling and analysis.

Next, a transportation system simulation model was established. As both road and sea traffic would be affected by the zero-emission resolution and respond interactively to alternative strategic actions taken, two separate models were developed and connected to assess the overall dynamic system response. The land traffic model handled all transport on road links in the area and included a module to specify cruise characteristics. The sea traffic model handled cruise ship activity and local ferry transport. The combined model made it possible to estimate sustainability performance metrics such as air emissions and traffic congestion. More elaborate information about transport models and parameters may be found in Díez-Gutiérrez and Babri (2020, 2022), Johansen (2021) and Johansen, et al. (2021).

In order to estimate air emissions in a holistic simulation model, several components were developed using tools across levels 1–3 in the CapSEM toolbox. Firstly, models were developed to predict operational responses (level 3) to various perturbations in the transportation system. This entailed addressing traveler preferences and impacts on e.g. route choice (Díez-Gutiérrez and Babri 2022). On this level, models to derive energy consumption for various operational patterns in road and sea traffic were also established (Aspen, Johansen and Babri 2020). Life cycle inventory data was used to establish emission factors (Level 2) from alternative fuels in sea traffic (Winnes and Fridell, 2010). Lastly, process models (Level 1) to derive emissions for various operational profiles, fuels, and abatement technologies were created (Aspen et al., 2020, Johansen 2021, Johansen et al. 2021).

The four-level approach enabled holistic and comprehensive analyses and evaluation of strategic policy responses for key transportation actors. The comprehensive study included assessment criteria across all sustainability dimensions, but for simplicity, a truncated illustration of the decision support system and associated tools deployed is shown in Fig. 19.1.

19.3.2 Insights Gained from Model Deployment

The application of systems engineering (Level 4) provided several problem structuring elements, such as definition of system boundaries, key stakeholders, a specified set of strategies, scenarios, and performance evaluation criteria. Figure 19.2 shows the study area with the strategic transport responses to the new regulation from the multi-stakeholder group consulted. Through their engagement, five main strategies were defined to explore transportation patterns for visitors to Geiranger based on alternative cruise traffic routing. For all strategies, cruise ship emissions were calculated based on a configuration of marine gas oil with exhaust gas cleaning technology installed (SCR). Strategy 1 (S1) was to work toward business as usual (BAU) which represents the current situation where cruise ships call to port in Geiranger. This would require delayed enforcement or reversal of the parliament regulation. Strategy 2 (S2) was to work towards a dispensation for zero-emission sailing in a “blue corridor” within the world heritage area. Strategy 3 (S3) was to develop a new cruise port outside the world heritage area in the Stranda village. Strategy 4 (S4) was to take no action and make cruise ships call to nearby ports outside the world heritage area, while strategy 5 (S5) was to route cruise ships outside the entire area, visiting other sites than the ports within the study area. Within all scenarios, various combinations of land traffic (bus) and zero-emission

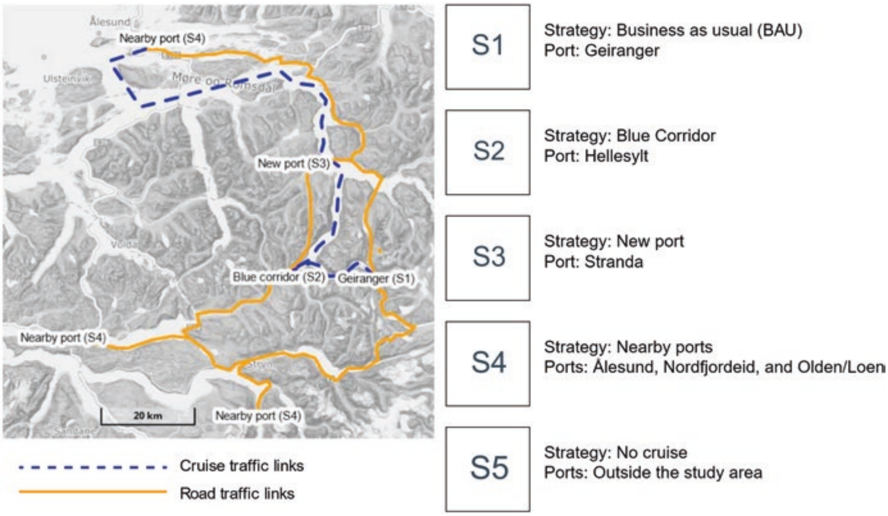

Fig. 19.2 Summary of boundaries and strategies defined in the problem structuring process. The map is created in the Norgeskart portal by ©Kartverket

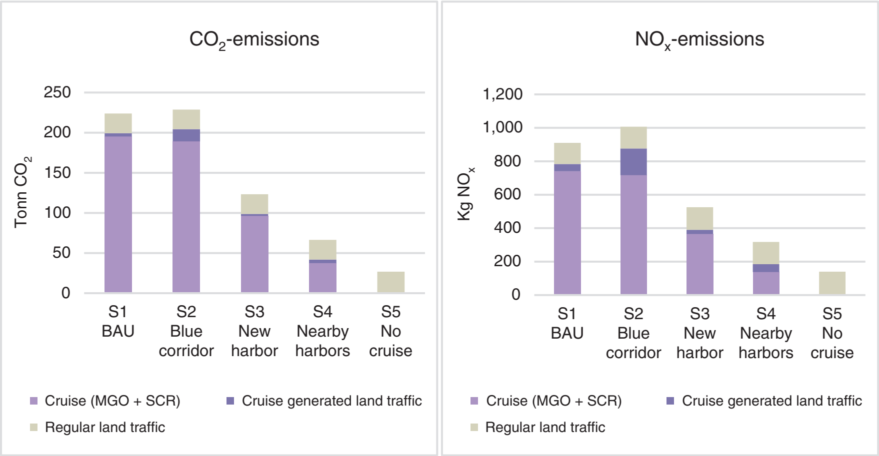

Fig. 19.3 Total CO_2 and NO_x emissions in the study area under a medium scenario

vessels to bring visitors to various sites in the Geiranger village were also computed. To account for uncertainties, scenarios for high, medium and low visitor volumes were also used when assessing strategies.

By deploying models at all CapSEM Levels, it was possible to assess the total transportation system performance across all strategies and scenarios. Figure 19.3 shows selected results from the broader sustainability impact assessment, displaying the CO_2 and NO_x emissions for a medium scenario where a bus roundtrip is assumed for visitors traveling between alternative ports and the Geiranger village. The figure illustrates that potential cruise-generated bus traffic would only contribute to a small portion of the total transport-related air emissions in the study area. This insight was critical as several stakeholders were concerned about problem shifting through the transferal of emissions from sea to land traffic. The analysis showed that emissions from road traffic were negligible compared to emissions from cruise ships and that cruise port location was of a greater importance.

Another critical parameter of concern was the potential for traffic congestion on road links in the study area due to cruise traffic rerouting. As cruise-generated bus traffic would increase significantly following strategies 1–4, an estimation of reduced speed compared to the respective speed limit was performed for each road segment under a maximum traffic scenario. The results in Fig. 19.4 show that the Blue Corridor strategy generated the highest level of congestion on road links in the

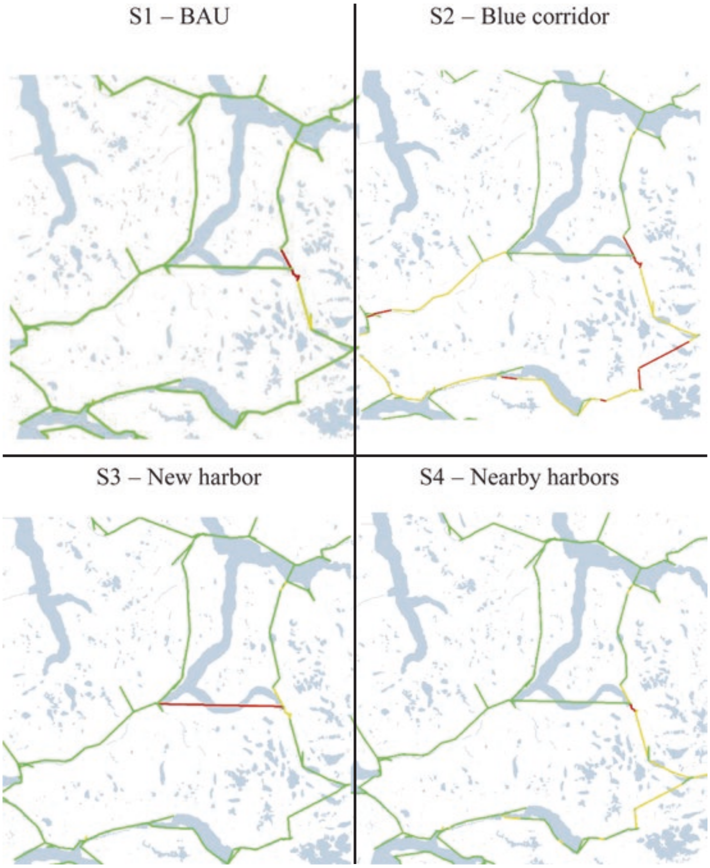

Fig. 19.4 Congestion on road links with cruise generated bus transport across strategies 1–4 under a maximum scenario. (*Green link*: no congestion, *yellow link:* medium congestion level, *red link:* high congestion level)

study area. For this strategy, it was evident that local transport between cruise port and the village had to be accommodated partially or wholly by sea transport compliant with the regulatory zero-emission requirement.

19.3.3 Concluding Remarks

In this chapter, the CapSEM toolbox has been explored and applied for developing a decision support system in the transport sector. The explicit formulation and combination of models within the four-level CapSEM structure proved useful in addressing transportation system sustainability issues in the case study.

From a modeling and analysis perspective, the CapSEM Levels helped organize a model breakdown structure in the DSS. The sustainability performance of the total transportation system depends on elements at all CapSEM levels: Physical input-output processes in energy conversion, techno-economic processes in product systems, the operational behavior of transport system actors and material, and strategic policy and planning processes at the system level. At the same time, models were designed to let information propagate through the layers facilitating increasingly complex inferences about the sustainability performance of transportation measures. This was convenient as it helped manage and exploit multiple domains and logics necessary to support transportation planning. It also made it easier to compartmentalize critical factors and assumptions in the model structure and keep track of key parameters and their sensitivities.

From the viewpoint of stakeholder engagement and interaction, the approach also facilitated a clear and transparent dialogue between analysts and various decision-makers on the data, assumptions, and reasoning at each system level. This is important to ensure stakeholder comprehension, judgment, and utilization of information and knowledge in transportation planning processes.

This case provides a simple illustration of how the CapSEM Model may be applied in the transport sector. While the chapter only focused on assessing air emissions from various responses to environmental regulation, several other sustainability aspects could and should be explored utilizing the CapSEM Model and associated tools. This includes other environmental impacts, such as land use and ecological impacts, as well as social and economic aspects influenced by various transportation system planning strategies.

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