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A common ground? Constructing and exploring scenarios for infrastructure network-of-networks

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ABSTRACT

Contemporary infrastructure networks require large investments especially due to aging. Investment opportunities of network-of-networks are often obscured because current scenarios often concern single infrastructure networks. Major barriers to the construction and use of network-of-networks scenarios are institutional fragmentation and the disconnection of scenario-development phases. This paper aims to construct and enhance the use of network-of-networks scenarios through a participatory scenario process. We employed a hybrid-method approach comprising document analysis, Disaggregative Policy Delphi, and futures-oriented workshop for five large national infrastructure administrations in the Netherlands. This approach yielded twelve key infrastructure developments for which 28 infrastructure experts provided future estimates. We constructed seven scenarios through cluster analysis of experts' quantitative estimates, qualitative direct content analysis of the qualitative data, and a futures table. The scenarios are: Infraconomy; Techno-Pessimism; Safety; Technological; Missed Boat; Hyperloop; and Green. Our results stress the importance of collaboration: desired scenarios are improbable when infrastructure administrations maintain their current sectoral perspective, whereas an intersectoral perspective may generate more investment opportunities. However, these network-of-networks investment opportunities do not simply emerge from network-of-networks scenarios; reasons include administrators' prevailing conception that sufficient optimization capacity remains within their own networks, and that no common ground exists that helps to overcome institutional fragmentation.

1. Introduction

Infrastructure planners in many western countries are increasingly confronted with new challenges. On the one hand, these relate to aging infrastructures and to increased quantity and quality demands of infrastructures¹ such as roads, railways, and sea- and airports

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¹ More precisely, with infrastructure we broadly refer to “the physical network that channels a flux (...) through conduits (...) or a medium (...) with the purpose of supporting a human population” (Neuman, 2006, p. 6). In our study, infrastructure concerns the physical conduits, i.e., the nodes and links of the network, demarcated to utilities (e.g., gas and electricity), public works (also when they are not publicly administered, e.g., highways and bridges), and individual physical facilities (e.g., ports and airports) at a national scale (as opposed to component or asset scale). We focus on transport and energy distribution infrastructures. We do *not* refer to social infrastructure (e.g., parks, sport facilities, hospitals, etc.) and knowledge networks (e.g., schools, universities).

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(EIB, 2015; Herder & Wijnia, 2012; Womack, 2008). On the other hand, these relate to increasing interdependencies between systems generally (Biggs et al., 2015; De Roo & Silva, 2010; Loorbach, 2010) and different infrastructure networks specifically that can cause malperformance and cascade from one infrastructure network to another (D'Agostino & Scala, 2014; Lee et al., 2007; Rinaldi et al., 2001; Zimmerman, 2001). Because of the increasing demand for infrastructure services due to, inter alia, economic growth, and societal requirements such as sustainability and climate adaptation (Anand et al., 2018; Hansman et al., 2006; Schuckmann et al., 2012; Schwab et al., 2017), aging and interdependent infrastructures increasingly threaten the uninterrupted flows of services – such as energy provision, transportation of goods and persons, and even human life in the case of, e.g., fatal breakdowns, gas explosions, or floods (De Bruijne, 2006; Verbong & van der Vleuten, 2004).

Considerable investments are needed to prevent infrastructure failures (EIB, 2015; OECD, 2017). These investments should address the long lifespan of infrastructures, because infrastructures are characterized by high sunk costs and therefore invoke path dependencies and lock-in; once constructed, infrastructures are not easily abandoned and they become sources of inertia (De Bruijne, 2006; Geels, 2004; Wegener & Fürst, 1999). Additionally, future developments and societal needs are characterized by uncertainty (Maier et al., 2016; Pot et al., 2018; Rauws, 2017; Rittel and Webber, 1973; Walker et al., 2013), and different developments and needs may require different infrastructures. Therefore, infrastructure planners should *anticipate multiple possible futures* (cf. Börjeson et al., 2006) collectively, given network interdependency effects (cf. Rinaldi et al., 2001).

Usually, however, infrastructure administrators only moderately collaborate in strategic infrastructure planning processes (Van der Duin & Ligtvoet, 2019a, 2019b). A major barrier for collaboration in infrastructure planning is institutional fragmentation due to sectoral optimization (Busscher et al., 2015; De Bruijne & Van Eeten, 2007; Heeres et al., 2016; Loorbach et al., 2010). Sectoral optimization results in sectoral isolation instead of sectoral integration (De Bruijne, 2006; Geels, 2004), making strategic infrastructure planning processes vulnerable to myopia (Pot et al., 2018). Fragmentation also applies to infrastructure administrators' strategic policy and innovation agendas, which are largely determined by government and politics. In turn, “this means that major decisions may be made on a political spur, while more incremental or maintenance-related decisions require careful readjustment of increasingly rationalized budgets” (Van der Duin & Ligtvoet, 2019a, p. 72). Whilst sectoral isolation may decrease the perceived complexity of decision-making processes with the promise of increased efficiency (Teisman et al., 2009), it hampers the collective anticipation of multiple possible futures. Furthermore, institutional fragmentation may hamper strategic planning processes that address the interdependencies between infrastructure networks, thence obscuring investment opportunities on a *network-of-networks level*. A network-of-networks is the combination of multiple networks, where the functionality of one infrastructure network may (positively or negatively) affect another network, through geographic co-location or functional interdependence of goods or information (Rinaldi et al., 2001). Importantly, an infrastructure network in a network-of-networks may malfunction – despite having no investment need of itself – because of disruptions and interconnections of (tightly) coupled networks with direct interconnections. For example, the disruption of an energy network may inhibit the operation of an airport, which may cause departure halls to overcrowd, for which the access to the airport may be restricted to prevent panic by closing parts of the highway and railroad networks connecting to the airport. Therefore, despite institutional fragmentation, infrastructure administrations involved in making investments in infrastructure networks *should* address both this network-of-networks level and multiple possible futures to explore investment opportunities and improve network functioning.

In this paper, we address the challenges of anticipating multiple possible futures of network-of-networks. We argue that strategic infrastructure (investment) planning processes require insight in a set of possible futures – i.e., scenarios – that a network-of-networks is required to accommodate, and that those scenarios should be collectively enacted upon between infrastructure administrators (cf. Hertogh & Bakker, 2017; Moloney et al., 2017). Whereas recent scenario studies focused on single networks (e.g. Liimatainen et al., 2014; Linz, 2012; Tapio et al., 2017), scenarios on a network-of-networks level are largely absent (Hall et al., 2013). Furthermore, this paper provides insight into how the phases of scenario construction and use can be bridged. This is pivotal because the disconnection of these scenario phases hampers effective anticipation (O'Brien & Meadows, 2013) and because little is known about how to effectively connect these phases, despite contemporary developments in participatory scenario studies (e.g. Heger and Rohrbeck, 2012; Nygrén, 2019; van der Duin et al., 2014).

The aim of this paper is to investigate possible future developments surrounding infrastructure networks by constructing scenarios for the network-of-networks, and to explore the use of those scenarios for the planning of individual infrastructure networks and the network-of-networks by infrastructure administrators. The research questions are: (1) what are possible scenarios on a network-of-networks level and (2) what are the consequences of the constructed scenarios for infrastructure planning? We focused our study on the Netherlands, because Dutch infrastructure planning is often characterized as institutionally fragmented, and because the country's high spatial density of inhabitants and infrastructure networks gives rise to many interdependencies and possibly network-of-networks investment opportunities.

2. Scenarios as products and processes

Acknowledging the versatility of the concept of scenarios and the discussion about definitions and approaches in the literature (Bradfield et al., 2005; Spaniol & Rowland, 2018; Vecchiato & Roveda, 2010), scenarios can generally be defined as fundamentally different futures that are analytically coherent and internally consistent, encompassing concrete and plausible end states, their surroundings, and the wider environments in a concrete and focused narrative (Bishop et al., 2007; Hirschhorn, 1980; Nowack et al., 2011; Ramirez et al., 2008; Schoemaker, 1993; Wright & Goodwin, 2009). Scenarios are a purposeful *basis* for further inquiry of, and for imaginatively engaging with, the future: they intend to capture and bound the mental mode of decision-makers, highlight predictability and uncertainty, and reduce the risk of being surprised or unprepared. Scenarios thus aid in changing decision-makers'

Table 1
Overview of Data Collection and Analysis.

Round	Method	Data Analysis	# Collected	Time Period
1	Document analysis (3.1.)	Coded strategic foresight documents for critical forces to determine scenario content	33 documents	June 2018 – September 2018
2	Disaggregative Policy Delphi Survey 1: seminars (3.2.1;3.2.2)	Employ Expertise matrix to maximize participant variety and expertise coverage	36 surveys	December 2018 – April 2019
3	Disaggregative Policy Delphi Interviews: 1–1 (3.2.3; 3.2.5)	Execute Qualitative Direct Content Analysis to construct scenario storylines	34 interviews	April 2019 – May 2019
4	Disaggregative Policy Delphi Survey 2: seminars (3.2.2; 3.2.4)	Run Multivariate Cluster Analysis of 45 variables in 11 themes; 1 expert = 2 future estimates; employ Futures Table to construct scenarios	28 surveys, minimum 4 per infrastructure administration	May 2019 – June 2019
5	Futures-oriented Workshop (3.2.6; 3.3)	Assess probability, desirability, and sectoral orientation to analyze scenario use	29 attendees, incl. six plus-one invitees	October 2019

minds, without yet describing a course of action (Bishop et al., 2007; Bradfield et al., 2005; Chermack, 2017; O'Brien & Meadows, 2013; Schoemaker, 1993; Van der Heijden, 2005). Moreover, scenarios are both products and (social) processes: the product focusses on the development of the scenario content; the process on organizational learning and consensus building (Hulme & Dessai, 2008; O'Neill et al., 2008). Both perspectives are required to enhance the quality of decision-making (Hulme and Dessai, 2008).

Scenarios-as-products capture the mental modes and *future images* of decision-makers, i.e., the informally constructed, individually, and sometimes implicitly and inconsistently held knowledge, values, and beliefs – in particular envisioned futures – that consciously and subconsciously assist the holder in anticipating the future (Bell, 2003; Kaboli & Tapio, 2018; Polak, 1973; Rubin, 2013; Van Asselt et al., 2010). Transforming future images into *clear* and *rich* scenarios is crucial to inform decision-making, because when not done well, scenarios “are insufficiently precise and can mean many things to different people. No wonder that scenarios sometimes disappoint” (Van der Heijden, 2005, p. 18). Scenarios are not *predictions*, but *depictions* of possible futures (cf. Börjeson et al., 2006). Scenarios-as-products can help decision-makers “to improve the probability of desirable ones [futures], decrease the probability of the undesirable ones, and gear up to coping with the inconceivable sure to come” (Dror, 2006, p. 90).

Scenarios-as-processes are valued mostly (or only) for the consequent *decision-making and learning* (Durance & Godet, 2010; Hulme & Dessai, 2008; O'Neill et al., 2008; Wilson, 2000) and are aimed at performative effects, varying from acquaintance (knowing possible futures) to consideration (having frames of reference for decision-making) and consent (actually being influenced by the scenarios) (van Doren et al., 2013). In order to have *performative* effects, the scenario construction and scenario use phases need to be bridged (Daheim & Uerz, 2008; Godet, 2000; O'Brien & Meadows, 2013; Schoemaker et al., 1998; Wright et al., 2013), especially in multi-organizational contexts (Wright et al., 2017, p. 2). Limited phase bridging may result in limited scenario implementation and appropriation, thence limiting learning success and reducing anticipatory and decision-making power (Lehr et al., 2017).

To bridge scenario construction to scenario use, *participation* is important. Participating throughout the scenario process may enhance actors' consideration of the plausibility of the scenarios. This, in turn, may incentivize these actors to employ the scenarios in strategy formulation or to compare their strategies to the scenarios, thus enhancing stress-testing capacity² (Durance & Godet, 2010; Godet, 2000; Lehr et al., 2017; O'Brien & Meadows, 2013). Additionally, participation may contribute to broader variety of thought and unlock the capability of participants to engage in strategic decision-making processes instead of just their operational or tactical time-scale knowledge (Chermack & Nimon, 2008). Moreover, participation “can avoid the risk of being limited to existing mental models, becoming one-dimensional and narrow-sighted [sic] or being influenced by the power structures within the company” (Gattringer et al., 2017, p. 299). However, participation is not broadly adopted because it introduces social influences and biases such as groupthink, halo effects, status, and strong personalities (Hallowell, 2009; Landeta, 2006; Tersine & Riggs, 1976), thus negatively influencing the *clearness* and *richness* of the scenarios. In practice, construction-participants are therefore not necessarily use-participants, despite the potential to enhance scenario use by involving participants throughout the scenario process (Schwartz, 1991).

3. Materials and methods

Table 1 summarizes our data collection and analysis, a hybrid of three methods: document analysis, Disaggregative Policy Delphi (DPD), and a futures-oriented workshop. This hybrid approach addresses biases the methods alone cannot. First, the document analysis enhances transparent and systematic selection of the actual scenario documentation (by expert-practitioners) and subsequent content (by the researcher) rather than having biases such as implicit presuppositions and personal expertise of the researchers guide this selection (Kulshrestha et al., 2018). Second, the Delphi's anonymous and round-based structure limits social influences and biases such as groupthink, halo effects, status, and strong personalities (Hallowell, 2009; Landeta, 2006; Mullen, 2003; Okoli & Pawlowski, 2004; Tersine & Riggs, 1976) for scenario construction. Thirdly, the futures-oriented workshop *connects scenario construction to scenario use*

² “Stress-testing emphasizes optimizing simultaneously against a number of different futures which are all considered equally plausible decisions, instead of one scenario being more likely than another” (Van der Heijden, 2005, p. 4).

and enhances stress-test capacity (Chermack & Nimon, 2008; Godet, 2000; Street, 1997). Together, the combination of these methods enabled a participatory scenario process, where experts of the infrastructure administrations participated in all rounds, which incentivized scenario use; at the same time, the participation of the experts does not inhibit the reproducibility of the scenario construction because the analysis was done by the researchers utilizing qualitative directed content analysis, cluster analysis, and a futures table. Finally, the sampling strategies of these combined methods intended to be representative of current infrastructure administrations in order to reveal futures images and futures estimates that prevail in contemporary infrastructure administrations. By doing so, the employed methods are equipped to strike the mental modes of decision-makers (Van Asselt et al., 2010), and they allow for comparing multiple possible futures from a departure point that is grounded in contemporary planning practice.

3.1. Document analysis for identifying scenario themes

In the first round, we identified the thematic content of the scenarios (in other scenario construction methods often called scenario drivers), i.e., key infrastructure developments, by systematically sampling (Bowen, 2009; Matthies & Coners, 2017) strategic foresight documents (cf. Kuusi et al., 2015) of five major infrastructure administrators in the Netherlands: Rijkswaterstaat, ProRail, Port of Rotterdam, Schiphol, Alliander³. We requested documents that, according to the administrators, had an actual influence on decision-making processes and classify as official data and records (cf. O'Leary, 2004, p. 219). Examples included strategic visions, roadmaps, and strategic asset management plans. We coded for critical forces of futures studies, comprising trends, driving forces, events, weak signals, discontinuities, and wild cards (Boeije, 2010; Saritas & Smith, 2011). This yielded the twelve most prevalent developments, which for the purpose of consistency of the methodological jargon are now called themes: infrastructure length, infrastructure cost, mobility, safety, reliability, cybersecurity and digitalization and innovation, economy, national and international freight and infrastructure interdependency, energy, environmental pollution, and governance. We operationalized and quantified these codes as natural variables, unless that was impossible or data were unavailable (cf. Varho and Tapio, 2013) to serve as input for the DPD.

3.2. Disaggregative Policy Delphi for constructing scenarios

In the second round, we collected data for the scenarios' thematic content through a Disaggregative Policy Delphi (DPD) (Tapio, 2003; Varho & Tapio, 2013). A DPD integrates quantitative (through questionnaires) and qualitative (through interviews) perspectives of an expert panel about probable and preferable futures, which are translated into multiple, alternative scenarios through a futures table (Rikkonen & Tapio, 2009).

3.2.1. Establishing the panel

Since only very generic expert selection criteria can be found in literature (Baker et al., 2006; Collins & Evans, 2002; Goodman, 1987; Williams & Webb, 1994), we selected experts employing an expertise matrix to ensure sufficient coverage and variety of expertise, excluding laypersons (see Appendix A) (Hussler et al., 2011; Kuusi, 1999; Skinner et al., 2015; Varho & Tapio, 2013). In line with literature on expert selection (Clayton, 1997; Møldrup & Morgall, 2001; Mullen, 2003; Skulmoski et al., 2007; Tersine & Riggs, 1976; Varho, 2015), our criteria comprised specialist-field specific and technical know-how, and tacit and experiential knowledge. We operationalized these in categories of: thematic knowledge, infrastructure knowledgeability, background organizations (both employed within and outside of infrastructure administrations (cf. Okoli and Pawlowski, 2004)), level of education, and management level. Persons of first contact at the infrastructure administrations assisted in the selection process of experts (cf. Landeta, 2006).

3.2.2. Questionnaires

The first survey visually displays quantitative time-series indicators (see Appendix B), and the second survey displays all experts' round-one answers (Appendix C). Following Varho & Tapio (2013), we created the questionnaire in Microsoft Excel to visually aid experts by directly plotting their estimates⁴ in graphs that show trend continuation or alteration. We set the time horizon at 2030 and 2050, because 2050 is an estimated peak for infrastructure renewal (Walta, 2015) and because 2030 can aid in connecting the present to that long time-period. We collected the quantitative data in multiple face-to-face seminars – instead of the common individual Delphi approach – because high attrition resulted from experts having to provide estimates about infrastructures and themes outside of their primary expertise. Each seminar started with a short presentation by the researcher outlining the structure of the study, the need

³ We selected these infrastructure networks because they (1) face significant aging-related investment needs (Ruitenburg & Braaksma, 2017), (2) have at least a national orientation and “infrastructure has always been and still is planned, debated, evaluated, decided, and financed mainly at national level” (Short & Kopp, 2005, p. 363), which is especially the case for these infrastructure networks, and (3) each individual network is a part of a network-of-networks (e.g. D'Agostino & Scala, 2014; Hall et al., 2013; Herder et al., 2008). Knowledge on long-term developments and consequences for infrastructure administrations in network-of-networks may be extended by other studies by varying infrastructure network selection regarding these criteria.

⁴ Quantitative exactness should not be confused with objective facts, because there are no statistics on the future (Durance and Godet, 2010) and (2) the quantitative estimates of future states are inter-subjectively determined by the experts (Tapio et al., 2011). Nor should it be confused with statistical representativeness, since Delphi studies do not represent a random sample selection, but a purposively selected sample based on specific expertise (ibid.).

Table 2
4R framework for adapting (transport) infrastructure (adapted from Givoni & Perl, 2017).

Option	Definition			Sectoral Orientation
Renew	Refurbishment of existing infrastructure to continue its current transport function. Often includes an upgrade that expands capacity.			Sectoral
Redesign	Converting infrastructure capacity to support different transport modes in the future from what it was originally built for (can be “and/or”).			Inter-sectoral
Repurpose	Allocating infrastructure and its surrounding space to a purpose other than transport function(s).			Inter-sectoral
Remove	Completely extract the infrastructure from the space it had occupied.			Sectoral
Round	Method	Data Analysis	# Collected	Time Period
1	Document analysis (3.1.)	Coded strategic foresight documents for critical forces to determine scenario content	33 documents	June 2018 – September 2018
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4	Disaggregative Policy Delphi Survey 2: seminars (3.2.2; 3.2.4)	Run Multivariate Cluster Analysis of 45 variables in 11 themes; 1 expert = 2 future estimates; Futures Table to construct scenarios	28 surveys, minimum 4 per infrastructure administration	May 2019 – June 2019
5	Futures-oriented Workshop (3.2.6; 3.3)	Assess probability, desirability, and sectoral orientation, to analyze scenario use	29 attendees, incl. six plus-one invitees	October 2019

to develop network-of-networks scenarios, and an explanation of the advantages of quantitative data despite experts’ difficulties of making quasi-exact estimates. Subsequently, experts were asked to complete the Excel-based questionnaire in the shared room using their own computer. Informative questions were allowed; content-laden discussions were not. Each seminar included 4–8 experts and lasted approximately 90 min. We repeated the seminar approach in the fourth round (see Table 1), where we also provided participants with a summary report of the interview data to inform their second-survey mutations.

3.2.3. Interviews

In the third round, we conducted 34 semi-structured face-to-face interviews. These lasted between one and two hours, were tape-recorded, and transcribed. In the interviews, we asked: how interviewees interpreted each indicator per infrastructure; how each indicator was perceived to relate to other indicators and infrastructures; how interviewees related probable and preferable future estimates to each other; whether interviewees were coherent in their future estimates throughout various themes (see Section 3.1); and whether interviewees had an overarching narrative for plausible futures. We prepared the interviews by checking whether the respondents’ future estimates seemed unlikely to co-exist (e.g., large mobility and reliability increase, but limited innovation and cost increase).

3.2.4. Cluster analysis

Using the second-survey data, we analyzed the quantitative future estimates by using multivariate cluster analysis on each variable theme.⁵ Clustered elements were future estimates. Since each respondent provided both a probable and preferable future estimate, the total amount of future estimates is equal to the number of respondents multiplied by two. All variables were standardized linearly on a scale of 0–1. No weighing of variables was applied. We selected standardized Euclidean distance as dissimilarity measure, and agglomerative hierarchical clustering furthest neighbor (complete linkage) as clustering algorithm. We calculated the arithmetic means of the resulting clusters as cluster center. We limited the number of clusters to minimally four or maximally seven (Varho & Tapio, 2013). Final cluster selection was based on the mutual combination of quantitative and qualitative data (Tapio et al., 2011): we compared whether arithmetic means of all thematic variables between cluster options varied sufficiently for the available qualitative data to explain that variation, and used the hierarchical trees (dendrograms) to visually check for the structure of the responses – i.e., sub-clusters and outliers – and formed our cluster judgement.

3.2.5. Qualitative directed content analysis

The 34 interviews resulted in over 700 pages of transcripts. We grouped the qualitative arguments per theme and employed qualitative directed content analysis to target specifically determined categories of experts’ transcripts (Hsieh & Shannon, 2005) as informed by the cluster analysis (cf. Varho & Tapio, 2013).

⁵ Multivariate cluster analysis groups similar units of analysis together ensuring “that the scenario set is based on the views of the expert panel instead that of the researcher’s own prejudices” (Tapio & Heinonen, 2018, p. 118).

Table 3
Futures table depicting all scenarios.

Themes and Variables	Units	Infra-economy	Techno-Pessimism	Safety	Techno-logical	Missed Boat	Hyperloop	Green
<i>Length</i>								
Roads	km	7000	6400	5291	5720	5685	6750	5000
Rail	km	5000	3212	3172	3274	4017	3600	4700
Ship	km	5000	4395	4337	4382	4373	4700	4370
<i>Cost</i>								
Road Construction	€ mln	3000	1143	267	1000	1017	2500	644
Road Renewal	€ mln	1400	886	1067	713	1042	700	1275
Rail Renewal	€ mln	1700	1468	867	928	1279	1000	2125
Ship Renewal	€ mln	220	297	290	250	417	500	294
<i>Mobility</i>								
Road	bln vehicle km	169	159	138	134	150	175	90
Rail	bln travelers km	26.78	23.52	19.33	23.75	31.20	40.00	40.00
Ship	quantity ships Port of Rotterdam	33,000	31,619	25,167	24,625	26,200	50,000	27,000
Aviation	quantity flights Schiphol airport	644,444	531,905	531,667	412,500	390,000	400,000	250,000
<i>Safety</i>								
Road	severe accidents	15,400	13,100	1118	7186	12,250	7186	7186
Rail	significant accidents	40	12	2	18	21	18	18
Ship	severe accidents	170	82	9	126	157	126	126
<i>Reliability</i>								
Road	mln vehicle lost hours	132.0	100.0	42.8	42.8	68.9	38.3	61.6
Rail	travelers' punctuality	80.0	93.0	95.7	95.7	93.0	97.5	91.9
Ship	Norm Time Passage Sluices	90	85	88	88	80	67	75
Aviation	On Time Performance	50.0	80.0	87.8	87.8	76.3	56.7	71.4
Electricity	Downtime (minutes)	200	200	22	22	67	47	34
Gas	Downtime (seconds)	0	150	29	29	94	3	22
<i>Innovation</i>								
ICT	€ bln invested	74.8	74.2	74.2	249.4	74.2	285.1	30.8
Innov and R&D	€ bln invested	25.5	23.1	23.1	47.5	23.1	50.0	67.5
Cybersecurity	% organizations > 250 employees	25.2	73.8	73.8	61.3	73.8	0.0	50.0
<i>Economy</i>								
GDP	€ billions	1563	893	776	1041	893	1375	983
FDI	€ billions	94	63	68	85	63	182	150
<i>Freight</i>								
Roads	mln metric ton	915	872	600	748	713	835	585
Rail	mln metric ton	106	49	43	66	52	52	111
Inland Shipping	mln metric ton	426	336	300	406	315	380	383
International Ship	mln metric ton	1154	638	400	679	612	630	650
Pipelines	mln metric ton	185	144	130	139	103	225	152
Aviation	mln metric ton	8	2	0	3	2	2	1
Terminals	quantity	59	53	32	66	54	60	49
<i>Energy</i>								
Road, fossil	Petajoule	376.4	320.0	100.0	206.7	125.0	83.3	0.0
Road, electric	Petajoule	16.5	37.6	63.0	117.5	250.0	425.0	203.0
Rail, fossil	Petajoule	0.8	0.0	0.2	0.8	0.6	0.3	0.0
Rail, electric	Petajoule	7.4	8.8	7.4	6.6	20.0	6.6	7.3
Ship, fossil	Petajoule	540.0	414.0	244.4	410.1	275.0	375.0	0.0
Aviation, fossil	Petajoule	191.8	186.0	94.4	150.0	105.0	108.3	0.0
<i>Environment</i>								
Land	mln kg CO2	2917	4687	2917	2750	2750	408	408
Sea	mln kg CO2	9667	8350	9667	5321	5321	2034	2034
Air	mln kg CO2	17,500	12,477	17,500	7571	7571	3275	3275
Energy	mln kg CO2	56,000	45,227	56,000	21,500	21,500	6208	6208
<i>Governance</i>								
Administrative Pressure	Likert scale	4.75	4.15	2.80	4.15	4.15	2.50	2.15
Regulatory Pressure	Likert scale	5.00	4.54	3.40	4.54	4.54	3.83	2.15
Spatial Pressure	Likert scale	5.00	3.92	3.10	3.92	3.92	4.83	4.58

3.2.6. Futures table

Subsequently, we constructed the scenarios by means of a futures table, in which the rows express the themes and variables, the columns represent the scenarios, and the cells comprise the cluster value of a future state (Varho & Tapio, 2013; Vinnari & Tapio, 2009). The quantitative values of the futures table result from the cluster analysis. Since we ran cluster analysis per theme, different themes can have different numbers of clusters. Initially, when any futures table is created with cluster values, the columns do not yet represent a scenario. Therefore, we reorganized the cluster themes and connected one theme to another as based on the qualitative directed content analysis so that the columns represent a coherent storyline and to maximize internal scenario consistency (Table 3 is the resultant futures table). Finally, we wrote storylines supported by the qualitative data and we named the scenarios accordingly (cf. Varho & Tapio, 2013).

3.3. Futures-oriented workshop for scenario use

In the fifth round, we organized a futures-oriented workshop, a direct-participatory mode of foresight to bridge scenario construction and scenario use. Appendix D provides an anonymized overview of the participants. We invited the scenario construction participations from round 4 as participants of the workshop (cf. Franco et al., 2013; Gattringer et al., 2017). Additionally, we offered the construction-participants the possibility to invite a colleague with expertise on infrastructure, long-term thinking, renewal, and investments (cf. Shah and Swaminathan, 2008) to further enhance scenario use beyond the scenario construction experts. We structured the workshop in four phases to maximize familiarization with and application of the scenarios (Cairns et al., 2013; Franco et al., 2013; Lauttamäki, 2016; Nygrén, 2019; Street, 1997; Wilson, 2000).

In the first phase, we started the workshop with a ten-minute introduction explaining the workshop goals and structure. The second phase served to familiarize the participants with the scenarios: we provided the participants with the futures table and qualitative storylines shaped as newspaper articles from the year 2050 (Neef et al., 2019a; Neef et al., 2019b; O'Brien, 2004). The main question of this phase was “what is the impact of the scenarios on the functioning of your own infrastructure network?” Therefore, the participants were grouped per infrastructure administration in five groups with a minimum of four experts. In the third phase, the phase-two groups were asked to explore important potential infrastructure changes to their own infrastructure under each scenario and to discuss the underlying rationale of those changes. We provided the participants with the 4R framework to spark and structure their thoughts (Table 2; see also (Givoni & Perl, 2017)). The phase concluded with the participants individually and anonymously ranking each scenario on a 7-Likert for probability and desirability (cf. Tapio et al., 2017). In the final phase, the participants were regrouped to groups containing at least one expert of each infrastructure administration. They explored the most probable and desirable scenarios⁶ for network-of-networks interactions, possible joint infrastructure adjustments, and investment opportunities. Using the 4R framework has the advantage that the 4R infrastructural adaptation options have a (pre)disposition to either sectoral or inter-sectoral orientation adaptations. These dispositions aid scrutinizing under what scenarios the infrastructure administrators primarily think and act individually or with the network-of-networks in mind.

The data were collected through flip-over sheets that were structured identically for each group, and by questionnaires that were handed out directly after the workshop. Facilitators assisted in data collection and group discussion moderation. They were researchers involved in the research project, including the authors, thus closely involved with the subject matter (Lauttamäki, 2016). They were timekeeper, data recorder, and moderator (Lauttamäki, 2014). As moderator, their role was to minimize their own influence and to maximize participants' idea sharing and development (Lauttamäki, 2016).

4. Results

4.1. Seven scenarios

The columns in the futures table (Table 3) depict the scenarios quantitatively. The values are the result of the cluster analyses (section 3.2.4.). For example, the values for theme safety for road, rail, and ship, in both the technological and hyperloop scenarios, are respectively 7186, 18, and 126 accidents. The columns represent scenarios because the theme clusters are connected by the qualitative directed content analysis (section 3.2.5). For example, the safety theme values of the technological scenario correspond with different mobility values than the safety theme values of the hyperloop. Next, we describe the seven scenarios qualitatively by emphasizing their main themes and how they cohere. Table 3

4.1.1. The Infraconomy Revolution

The first scenario is called *The Infraconomy Revolution*. It envisions a thriving economy, a strong growth in mobility and freight, and major expansion of the infrastructures. It consists for 5.2 % of all probable and 4.2 % of all preferable estimates.⁷ According to the qualitative data, infrastructure facilitates knowledge-intensive and product-based economic developments. Experts envisioned industry innovators meeting face-to-face and thus high mobility levels. Economic interests are paramount in shaping infrastructural demands. A respondent (ID11) illustrates this: “*Shrimp are caught in the Netherlands, shipped to Morocco for peeling, and returned to the Netherlands on the same day simply because it is cheaper.*” They envisioned this ‘the market knows best’ paradigm to co-exist with major

⁶ Due to time constraints (cf. Lauttamäki, 2014).

⁷ The total of the scenario estimates exceeds 100% because theme cluster analysis intrinsically results in double counting.

infrastructure expansion to facilitate such economic interests. Their arguments indicate that transport-related energy demands may therefore rise, requiring fossil energy increase resulting in environmental pollution. Respondent (ID25) highlights the crucial role of market parties herein: *“The industry determines innovation: if Boeing says we go green, then the rest will too.”*

4.1.2. The Techno-Pessimism Revolution

The second scenario is characterized by skepticism whether innovation truly alters mobility use and is thus called the *Techno-Pessimism Revolution*. The scenario is based on 16.4 % of all probable and 8.8 % of preferable estimates. Qualitative data specific to this scenario underscore that, although technology has changed society over the last centuries, it has been incapable of reducing mobility – *“In the past, technology has created more rather than less traffic: why would that change now?”* (Respondent ID32). Moreover, despite many efforts to change habitual mobility behavior, people simply prefer to travel alone rather than carpooling. As a respondent (ID33) stated: *“The self-driving car won’t solve congestion if everybody uses the car individually (...). If driving becomes more convenient, people might cover larger distances.”* Additionally, the modal split car-to-train has been firmly constant over the past decades: why would this change now? Experts stress that skepticism also applies to fake news, which for example relates to the effectiveness of new road infrastructure or mobility pricing policies for solving congestion, or to the necessity of climate mitigation measures. Therefore, experts indicate that extensive infrastructure expansion to increase reliability and low environmental scores are likely.

4.1.3. The Safety Revolution

Wellbeing is the central theme in the *Safety Revolution*. This scenario consists of 8.3 % of all probable and 10.4 % of all preferable estimates. Here, experts emphasize that spending quality time with friends, family or oneself is paramount: *“The Dutch live in large luxury already. It is not a given that people want to work 4–5 days in the week anymore: we don’t want to see our colleagues more often than our children”* (Respondent ID10). Experts provided examples of working less hours and being less in traffic. Their motivation for these developments comprises lower societal acceptance of transport externalities, such as environmental pollution and foremost safety: *“Society simply stops accepting that so many severe traffic injuries occur with something as mundane as transport: the more welfare and wellbeing one attains, the more weight is put on safety”* (Respondent ID2). Experts envision automatic driving in rural areas and Mobility as a Service (MaaS) concepts in urban areas to stimulate citizens to live rurally and enhance livability in crowded urban areas. Experts indicate that, because value of time is high in train-based transport, allocated road infrastructure budgets will shift to developing the rail network. The resulting reduced car movements and innovation may increase reliability. However, since economic development is reduced, achieving environmental goals may not quite be feasible because of a shortage of energy transition budgets.

4.1.4. The Technological Revolution

The fourth scenario is called the *Technological Revolution* because this scenario includes the highest innovation and ICT budgets. It contains 11.9 % of all probable and 11.2 % of all preferable estimates. Technological innovations are envisioned in all infrastructures, for example intelligent asset management, predictive maintenance, automatic train operation, smart shipping, hydrogen fuel, and 3D printing. The qualitative data emphasize that technological innovation will *only* be successful if it is accompanied by cooperation, i.e., collaborative governance or social innovation: *“We must break the ‘passing the buck’ culture. Innovation is more than ICT, it is especially cooperation between parties”* (Respondent ID20). For example, cross-sector intelligent asset management may provide data to limit costs, but this must also be enacted upon: cross-sector collaboration resulting in lower total costs may not occur if higher within-sector costs are not adjusted for. Finally, experts suggest that infrastructural network reliability may increase due to flexible working hours of knowledge workers, which may enhance peak shaving especially when aforementioned innovations work: a reliability shift can only occur through combining self-driving, peak-shaving, employer-oriented and employee-oriented approaches, working at home, and more efficient system use, for example MaaS to align supply and demand between users (Respondent ID34).

4.1.5. The Missed Boat Revolution

The fifth scenario is characterized by *attempts* to make society more sustainable. Yet, climate goals are just not met due to multiple environmental, societal, and governance-related challenges. We thus named this scenario the *Missed Boat Revolution*. It represents 13.3 % of all probable and 9.1 % of all preferable estimates. Experts indicated that periods of political turbulence (e.g., *mouvement des gilets jaunes*; growth of climate-sceptic political parties) occur and delay environmental advancements. For example: *“Simultaneously an anti-movement exists, like the yellow vests and Forum for Democracy, which may lead to an entirely different government (...); Yellow-vest movements may disrupt achieving environmental targets through resisting oil prices, parking budgets, and driving price policy”* (Respondent ID8); *“Climate is a strongly politicized matter. Political parties such as CDA and VVD, who until recently were climate sceptics, are now implementing pro-climate policies. But now there is a party that completely wipes its butt with those policies. There is disinformation from Russia, American thinktanks”* (Respondent ID11). Additionally, they indicate that, although environmental-innovation advancements such as biofuels and electric driving are funded broadly, their adoption is lacking. This is seen in various infrastructure networks. For example, for the waterway network, inland shipping on environment-friendly fuels, which could make a large environmental contribution through transporting massive amounts of goods on biofuel, may be inhibited by droughts. Related to aviation, societal habituation of wealth concurring with luxury and loss aversion: international vacation trips and luxury goods are highly valued but environmentally polluting, yet society may not accept radical curtailments. Finally, for highway infrastructure, MaaS may be slowly adopted because car use remains high as people do not want to carpool. This necessitates more cars, making fossil-car fleet replacement a time-consuming development. Experts indicate that such challenges, despite vast investments in rail (both transport of freight and persons), probably result in an over consumption of fossil fuels causing pollution levels just above Parisian Accord levels.

4.1.6. The Hyperloop Revolution

Multiple experts stated that especially a hyperloop could revolutionize transport of goods and people, as well as significantly push back energy demand and therefore environmental pollution. Information policy (cf. Kuusi et al., 2015) caused that the *Hyperloop Revolution* was envisioned quantitatively in for example high length values for road and shipping, because respondents felt that a hyperloop did not fit in any given category. This scenario contains 4.4 % of all probable and 6.0 % of all preferable estimates. This scenario can be considered a special case of the Technological Revolution. A hyperloop is a transport system that moves people and cargo through low-pressure or vacuum tubes in wheel-less pods, which may achieve a top speed of approximately 1000 km/h. Hyperloops promise to be very energy efficient due to extremely low aerodynamic drag and partially powered track parts, and to be very safe because no interaction exists with transport or wildlife, and reliable because no human-driver related error happens. However, high uncertainty exists about customer affordability.⁸ If realized, the hyperloop therefore reduces traffic incidents, long-distance mobility and freight, energy use and therefore benefits the environment: “*Environmental interests may necessitate new types of infrastructures such as the hyperloop. Traffic on short and middle distance is flexible and fast, yet polluting. Shipping is good for long distance, yet polluting as well. For exchange between Asia and Europe, pipelines or hyperloops are required*” (Respondent ID4). Although infrastructure costs of contemporary infrastructures may not rise, total societal costs increase since experts envision that the development of the hyperloop will need to be at least partly publicly financed: “*Is the mostly private ownership of pipelines desirable for the speed of the energy transition? (...). The Port of Rotterdam may co-invest or think along for pipeline freight from a business perspective, but the Port is no grid operator. This reactive approach delays the subsurface energy transition development*” (Respondent ID15).

4.1.7. The Green Revolution

In this final scenario, experts envision a world as environmentally friendly as possible, where fossil fuel use and CO₂ levels are maximally reduced. We therefore called this scenario the *Green Revolution*, consisting of 5.2 % of all probable and 9.6 % of all preferable estimates. Experts envision a specific mix of policy instruments and societal acceptance. For example, innovations reducing fossil fuels, such as MaaS, hydrogen and full electric driving, may be complemented with policy measures such as pricing policy for freight in rush hours and incentives to stimulate first movers to invest in subsurface hydrogen infrastructure. Combined with societal acceptance, this may result in a second-hand green-car-only market: “*Regardless of political fusses, people will get used to using fossil fuels only as last resort*” (Respondent ID31). Moreover, experts emphasize that achieving less pollution may occur when governance addresses the *invisible* characteristics of pollution: since both international and inland shipping are more polluting than landside mobility (e.g. fuel oils and dredgers), innovations in the landside mobility sector may be applied to the shipping sector (e.g. smart shipping, cleaner fuels, and fleet replacement). Contrasting, experts also envision spatial solutions that concern invisibility: cities as circular warehouses, 3D-printing, and logistic hubs at edges of cities that limit and hide freight. International governance addresses invisibility further: especially aviation, shipping, and rail freight are of concern, where governance stimulates plane-to-train substitution above the 500 km range and international rail freight networks are standardized. Finally, the qualitative data emphasizes a societal and governmental mind shift: *vliegschaamte* (aviation shame) and *treintrots* (train pride) feelings can invigorate policies limiting polluting modes of transport and stimulate the use of green alternatives: “*Climate-perverted developments such as a shopping-weekend in Barcelona or New York will automatically disappear*” (Respondent ID3); “*Flying to Australia emits as much CO₂ as a household in one year, and households are even becoming more economical*” (Respondent ID11).

4.2. Enhancing scenario use: the workshop

Since the goal of the workshop was to connect the phases of scenario construction and scenario use, workshop data are of interest when it informs about infrastructure administrators’ mental mode resonance with the scenarios, and how the administrators experienced scenario usefulness. Moreover, data highlighting similarities and differences between different administrations and their strategic decision-making within each scenario may indicate particular scenario usefulness for the network-of-networks level.

The second phase of the workshop (see Section 3.3) demonstrated reoccurring considerations in specific scenarios across the groups (Appendix E). Reoccurrence may indicate associations that best reflect the mental modes of decision-makers that were struck. Phase three demonstrated that participants felt largely positive about the scenarios’ contributions to explore various sectoral infrastructure adaptations and underlying strategies. Positive attitudes towards adaptations and strategies may indicate scenario usefulness in this phase.

Next, infrastructural adaptations – see Table 2 for the description of the four types: renew, redesign, repurpose, and remove – were found for each scenario (for a more detailed description, see Appendix F). Comparing the infrastructural adaptations in each scenario, what stands out in the *Technological Revolution* is that the required infrastructural adaptations depend on specific technologies (see Section 4.1.4) that, in turn, structure future infrastructural requirements. Consequently, recommended adaptations are diminishing the removal and maximizing the conservation of existing infrastructure. In the *Green Revolution*, administrators experience more certainty about infrastructural requirements; inter-sectoral adaptations such as infrastructure redesign and repurpose prevail over sectoral adaptations. In the *Infraconomy Revolution*, administrators also experienced more certainty about infrastructural requirements, yet dominant adaptations comprise construction of new infrastructure and renewing aged infrastructure. In the *Safety Revolution*, primarily redesign adaptations are employed to adapt to changing societal demands. In the *Techno-Pessimism Revolution*, no clear

⁸ (<https://hyperloop-one.com/facts-frequently-asked-questions>).

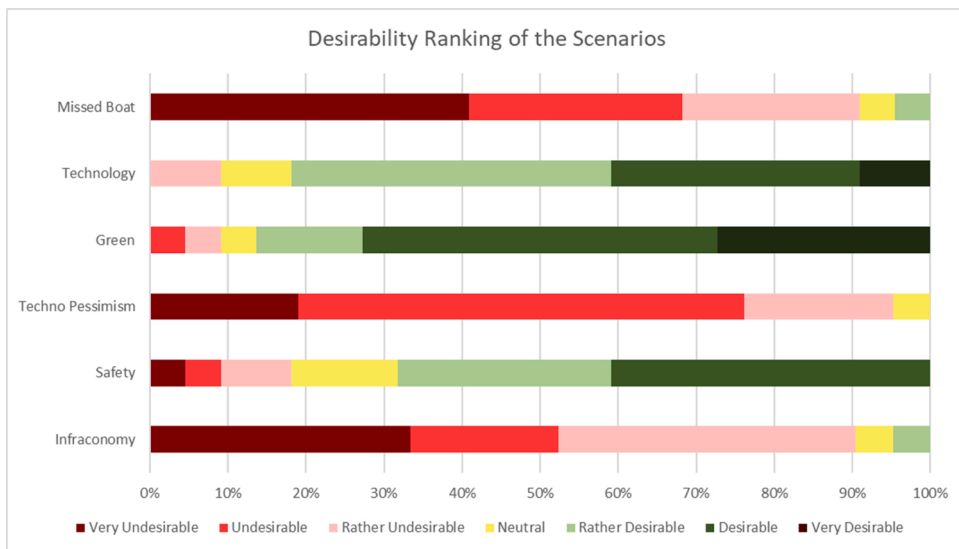


Fig. 1. Scenario desirability ranking.

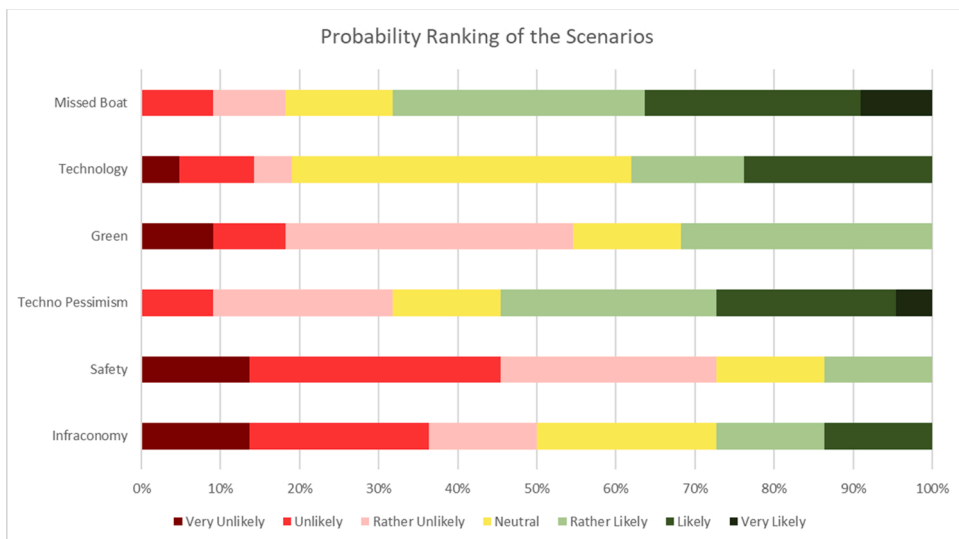


Fig. 2. Scenario probability ranking.

Table 4
Different sectoral orientations of probable vs. desirable scenarios.

Scenario	Dominant Sectoral Orientation	Dominantly ranked in workshop as
Infraconomy	Sectoral	Probable
Techno-Pessimism	Sectoral	Probable
Safety	Inter-sectoral	Desirable
Technology	Inter-sectoral	Desirable
Missed Boat	Sectoral	Probable
Green	Inter-sectoral	Desirable

adaptation focus emerges, resulting in renewal of already existing infrastructures. In the *Missed Boat Revolution*, no clear adaptation focus emerges because infrastructural adaptations result from compromises between green or social-conservative strategies.

Comparing these types of adaptations (Table 2), ranked according to desirability and probability, it stands out that of the three least desired scenarios – Infraconomy, Techno-Pessimism, and Missed Boat (Fig. 1) – the latter two were considered the most likely (Fig. 2).

These three scenarios have in common that they, in contrast to the others, emphasize sectoral renewal adaptations as dominant. Conversely, the three more desired scenarios pursue inter-sectoral redesign and repurpose adaptations (Table 4). Potentially, these findings indicate that desirable yet unlikely futures are characterized by inter-sectoral infrastructural adaptations, and probable yet less desired futures are characterized by sectoral adaptations.

The fourth phase of the workshop demonstrated that participants were more positive about the scenarios' contribution to scenario use for the network-of-networks than for sectoral networks. Furthermore, participants are generally positive about the workshops' contribution in terms of informing strategy (Appendix G). Together, scenario use seems especially informative for insight in network-of-networks, and less so for concrete investment opportunities or sectoral applicability because participants are more aware of their sectoral than network-of-network status quo.

Scenario use in the fourth phase comprises formulating infrastructure adaptations, exploring interdependencies, and examining administrator role changes. However, significant unequivocalness exists regarding the exploration of concrete investment opportunities (Appendix G, Fig. G2). Few adaptations were found in the Missed Boat scenario. Participants stated that both interdependency adaptations and network-of-networks investment opportunities were sparsely found because this characterizes that scenario. However, interdependent adaptations were also challenging to formulate for the Green scenario. Examples of these adaptations could be Schiphol providing international train travel thus also tending to ProRail, or Rijkswaterstaat providing electric vehicle charging or electricity generation on their area, thus investing in energy infrastructure. Moreover, specific role changes for the infrastructure administrators were suggested in the Green scenario: since ProRail has been shifting from a mostly technical-mechanical to a mostly software-driven organization, ProRail could serve as software coordinator of the network-of-networks; Alliander could function as broker, shifting from an energy infrastructure provider to a manager of decentral flows; the Port of Rotterdam could make a market-role shift from merely supporting the market towards initiating or being the market regarding, for example, H₂-infrastructure. Finally, Rijkswaterstaat could prioritize tunneled infrastructures to better capture emissions, increase living quality, and make other administrators' subsurface infrastructures better accessible.

What these depicted adaptations have in common is that, firstly, interdependencies are challenging to find and to translate into joint investment opportunities. Secondly, interdependent adaptations are characterized by an organization-outward orientation. Thirdly, the adaptations shift from a sectoral character in the Missed Boat to an inter-sectoral character in the Green scenario. The implication of these findings may be that, to realize these changes and adaptations, administrators require a more proactive role, i.e., a shift from renew and remove to repurpose and redesign.

At the end of the workshop, every group independently concluded that the collective exploration or utilization of network interdependencies (e.g. aligning time windows of construction) is hampered by insufficient vision, direction, or coordination on the network-of-networks level. Participants stated that sub-utilization and sub-exploration (e.g. not considering potential positive externalities for other administrations) may be explained by a prevailing conception that sufficient remaining capacity can be exploited within their own network. Simultaneously, they acknowledged the need to accept sub-optimal performance of their own network if that enables the network-of-networks to perform better, because they expect that overall their own network will perform better on the long-term when other administrators also sometimes accept sub-performance. Moreover, they also expressed that interdependency underutilization is more resource intensive (e.g. space, materials) and thus less sustainable in environmental and societal terms. Consequently, they expressed a need for a common network-of-networks vision to prevent less desirable scenarios from becoming more probable.

5. Discussion

5.1. Scrutinizing network-of-networks scenarios

The network-of-networks scenarios intended to further explore how growing interconnectedness between infrastructure networks may be exploited in light of aging infrastructures and rising quality and quantity demands of infrastructure services. In other words, what network-of-networks interdependencies may inform the strategic planning of multiple infrastructure networks? Where specific sectoral infrastructural adaptations were found, transforming those to interdependent infrastructural adaptations is difficult, despite employing participatory foresight methods. In order to further that transformation, administrators can invest in scenario use by including all sectoral adaptations in a cross-table to investigate whether different administrator's adaptations are compatible. For example, is extension of *electricity* stations possible along with creating amenities along *highways* (cf. Platform Green Infrastructures, 2020)? Is *truck* platooning possible within the *Port* of Rotterdam in such a way that it becomes an innovation that can substitute environmental unfriendly practices? Can light-rail development prevent the *plane-to-train* substitution from overloading the train network in a tunneled system where access to *electricity* cables is convenient?

Next, our workshop data suggest that the less desirable though more probable scenarios (e.g. Missed Boat) offer the least opportunities for interdependent infrastructure investments. Those scenarios emphasize sectoral infrastructural adaptations, such as renewal, over inter-sectoral adaptations such as redesign and repurpose. Alternatively, more desirable futures (e.g. Green Revolution) emphasize redesign and repurpose adaptations. Possibly, such adaptations create more interdependencies and therefore more joint investment opportunities. After all, the number of investment-involved infrastructure administrators may increase from one in renewal adaptations to multiple in redesigning or repurposing adaptations.

The workshop results also suggest that redesigning and repurposing adaptations coincide with a more proactive and collaborative role of infrastructure administrators; it requires creation of a *common vision, language, approach, or (financial) assessment framework* for the planning of collective, long-term, infrastructure investments. Examples are, jargon, protocol, and a renewal database that is inter-

administrationally operated. On the one hand, our study enabled infrastructure administrators to communicate about possible futures of both their own infrastructure networks and of other administrators' networks. On the other hand, progressing from gazing over the boundaries of their sectoral networks to a *common (institutional) ground* that enables them to identify and act on network-of-networks investment opportunities proved more challenging. This common ground either does not exist or the common ground constitutes the absence of sectoral collaboration and proliferation of acting with an intersectoral orientation (for the planning of collective, long-term, infrastructure investments). Put more clearly: a basic *language* that allows infrastructure administrators to communicate across sectors exists, a common *ground* to act upon does *not*. The workshop results suggest that this lacking common ground may be explained by administrators their prevailing conception that sufficient remaining capacity can be exploited within the individual networks. Moreover, the data suggest that administrators think that sector-specific institutional frameworks suffice to further develop their networks. Hence, while interdependencies between networks may be scrutinized in earlier phases of the workshop, they do not make their way in administrators' minds to act upon those interdependencies in later phases of the workshop. The lack of attention for the interdependencies between networks may especially inhibit identifying network-of-networks investment opportunities when there is no incentive or awareness that another administration could benefit from an administration's infrastructural adaptation. Here, developing a common ground requires addressing institutional fragmentation. A proactive and collaborative role of administrators should then be a prominent feature in developing and enacting a common ground as a way of thinking and acting in the planning of collective, long-term, infrastructure investments.

5.2. Scrutinizing scenario use

The futures-oriented workshop intended to connect scenario construction to scenario use. Scenario use occurred both within and outside the study. Within the workshop, the positively evaluated effects on familiarizing the scenarios and applying the scenarios to the infrastructure networks and network-of-networks serve as evidence. Outside the study, all participants of Rijkswaterstaat wrote an official letter to their management about the necessity of developing a network-of-networks vision to prevent sub-optimal futures regarding major challenges (e.g., energy transition and renewal) from becoming reality. Together, scenario use may thus amount to establishing sense of urgency.

Whether scenario use could be augmented beyond establishing sense of urgency towards a more concrete exploration of joint investment opportunities – by means of the joint formulation of ex-ante interdependencies between the respective infrastructure networks – remains to be answered. Because clear interdependencies did not emerge from the construction process, the formulation of them by the research team may not resonate with the administrators' mental modes. Additionally, the performative dimension of a single workshop is limited: whether similar processes have been instigated at other infrastructure administrations than Rijkswaterstaat is unclear; moreover, whether actual decision-making is affected by the scenarios cannot yet be said. In our study, we consider scenarios as 'a purposeful basis for further inquiry' and as such the scenarios aid in transparently and systematically scrutinizing network-of-networks and creating sense of urgency to further decision-making. Moreover, the workshop itself and networking afterwards provided a basis for a social network-of-networks, which was informally mentioned to the researchers as a valuable result in itself. Overall, the results suggest that the futures-oriented workshop is well equipped for discussing various future images of involved actors, about themselves and about others (Cairns et al., 2013; cf. Street, 1997), as well as collaborative learning (Nygrén, 2019). However, a single workshop may limit scenario use regarding strategy formulation (cf. Nowack et al., 2011) in a multi-actor setting.

Finally, the workshop may enhance the use of network-of-networks scenario through enhancing mutual understanding between administrators. During the workshop, the administrators indicated a willingness to accept a sub-optimal operation of their own network for the benefit of the network-of-networks, despite the lack of institutional mechanisms to incentivize such inter-sectoral thought. Thus, by connecting scenario construction to use, this participatory mode of foresight may have contributed to the idea that keeping to individual infrastructure decision-making processes does decrease the perceived complexity of the decision-making (cf. Teisman et al., 2009), but doesn't show interdependent network-of-networks effects. We thus underscore that participatory foresight may have a potential to emphasize participants' interrelations in situations of institutional fragmentation, because it created awareness at infrastructure administrators that their foresight processes should be more intertwined (cf. Van der Duin & Ligtoet, 2019a).

5.3. Methodological considerations

Whereas in the first Delphi survey many experts stated that providing future estimates was challenging⁹ because they had to give estimates about infrastructures and developments outside of their primary expertise, the second round demonstrated few adaptations indicating limited transdisciplinary learning. Multiple respondents explained, at the end of the second seminar, that they had thought thoroughly about their estimates in the first survey, and therefore would not adapt their answer as long as they were no extreme outlier. Possibly, respondents were affected by a commitment mechanism (Cialdini, 2013). Moreover, some experts indicated that the summary report portrayed arguments for both raising and lowering their estimates thence reducing their inclination to adapt their

⁹ Experts experienced difficulty providing a specific number for estimates, arguing that they do not *know* that number precisely leading to feelings of 'guessing'. However, quantitative estimates differ from objective quantitative exactness and objective facts: there are no statistics on the future (Durance and Godet, 2010) and the quantitative estimates are inter-subjectively determined by the entire expert panel (Tapio et al., 2011). Especially experts with a quantitative background, i.e. civil engineers and asset managers, found this concept hard to grasp.

estimates. However, the results demonstrated that workshop participants were clearly satisfied with learning about other networks. Consequently, the combination of the Delphi *and* a futures-oriented workshop seems to contribute to transdisciplinary learning.

Whilst our methodological approach has the advantage of being representative of the demographics of infrastructure administrators and reveals that current infrastructure administrators likely portray a certain intersectoral blindness, simultaneously our approach may imply a certain institutional bias, speaking to the prevailing administrators-in-power. Indeed, the document analysis involved documents that the current experts of infrastructure planning indicated as influential, and the Delphi consisted of experts who, while representative of contemporary infrastructure planning, mostly represent a rather narrow demographic. An approach counteracting our sampling strategy – for example primarily seeking critical forces outside of infrastructure planning and selecting experts not based on technical know-how, and tacit and experiential knowledge, as well as explicitly targeting a different demographic (e.g., under 35 and female) – might have led to different scenarios, a different interpretation of probability and desirability, a different understanding of collaboration, and more common ground for long-term strategizing in network-of-networks. For example, would such scenario construction and use be better able to identify more possibilities for (institutional) collaboration and co-investment across infrastructure silos, and would the more desirable scenarios be assumed more probable? The resulting scenarios might have been more out-of-the-box and transformative, though this would have been at the expense of representativeness of contemporary infrastructure planning and potentially resonating less with the mental modes of infrastructure administrators. Such an alternative approach is complementary to this study and is an interesting avenue for future research.

Finally, preferable future estimates may indicate a relative degree of importance. For instance, the value “zero” frequently occurred for safety desirability, i.e. the amount of serious injuries on various infrastructures. Experts explained that anyone would enter the preferable value “zero” for such an indicator. However, following that same rationale, a zero-value answer should also apply to fossil fuel use (energy use), environmental pollution (CO₂ emissions), cybersecurity (ICT incidents), and reliability (no transport or distribution jams). This was far less often the case (Appendix H). Arguments for scoring a non-zero value on safety mostly relate to feasibility; for example, the costs would be too high to achieve full safety. Since respondents that scored zero on safety offer this argument for other themes, zero values may capture the relative importance of variables as traded off against feasibility, indicating a relative value hierarchy. Alternatively, any zero-value option may be considered a limitation of the method, because it provides insight in value prioritization rather than a realistic estimate of plausible future values.

6. Conclusion

Infrastructure planners are confronted with considerable investment needs because of aging infrastructures and societal and climate challenges such as the energy transition. Tackling those challenges with an explicit *long-term* focus is vital because of the major sunk costs, long infrastructure lifetimes and consequent path dependencies, lock-ins, and inertia involved (De Bruijne, 2006; Geels, 2004; Wegener & Fürst, 1999). Also, an explicit collective focus is needed due to increasing interdependencies between infrastructures in a network-of-networks. Both are challenging due to institutional fragmentation in general and fragmentation of foresight processes in particular. To enhance anticipation of aforementioned challenges, we constructed seven scenarios with an explicit focus on practitioner participation to help bridging scenario construction and scenario use. This enabled the scenarios to become performative across fragmented institutional boundaries of the studied infrastructure administrations.

Our study produced, through a hybrid-method approach, seven explorative scenarios: the Infraconomy Revolution, the Safety Revolution, Techno-Pessimism Revolution, the Technological Revolution, The Green Revolution, The Missed Boat, and the Hyperloop Revolution. The analysis of the scenarios generated three main conclusions. First, interdependencies do not simply emerge from scenario processes with multiple infrastructure administrators, i.e. network-of-networks actors, arguably because each scenarios’ depicted infrastructural adaptations have a strong sectoral character. Potentially, this is due to a prevailing conception of infrastructure administrators that sufficient optimization capacity remains within the own infrastructure network. Second, there is a need to collaborate: the less desirable scenarios appear more probable when a sectoral optimization (i.e. non-collaborative) perspective is maintained (e.g. like-for-like renewal), whereas the more desirable scenarios appear to build on inter-sectoral infrastructural adaptations (e.g. redesign and repurpose adaptations). Third, to draft and implement inter-sectoral adaptations, infrastructure administrators need to employ a proactive role in seeking such adaptations. To conduct an infrastructural adaptation with a sectoral orientation may seem logical from one administrators’ perspective, but it may miss out on joint investment opportunities from another administrators’ perspective. Infrastructure administrators require a *common ground*, for instance in the form of a common database or vision, to identify these opportunities. The lack of such a ground, in terms of being non-existent or constituting one without inter-sectoral collaboration, is reflective of institutional fragmentation. One of the barriers of putting more effort in creating a common ground may be aforementioned optimization conception.

Finally, this study also provides insight in methodological developments of participatory foresight. A major benefit of participatory foresight is its incentivizing power to connect scenario construction to use, and especially to do so in an institutionally fragmented situation such as infrastructure network-of-networks. However, bridging scenario construction and scenario use does not equate complete strategy development. Scenario use in this study yielded establishing a sense of urgency, i.e., growth of interest in collaboration in the foresight phase: “For cases that require radical change of behavior and/or substantial investments of multiple actors, it is imperative that a joint visioning, planning and execution program is established” (Gattringer et al. 2017, cited from Rohrbeck et al., 2015 p.6). We thus add that if those joint initiatives do not arise independently, participatory foresight is an instrument to initiate those processes especially in institutionally fragmented situations such as inter-sectoral infrastructure planning.

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Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix

A Expertise matrix

See Fig. A1.

The expertise matrix reveals the coverage and variety of the expertise in the panel. The two elements that stand out are the low numbers of female participants (3/33) and participants aged under 30 years old (2/33). The percentages in this professional branch are representative of the Dutch population for females (9%), but are not for persons aged 25–35 (22 %) (CBS, 2016). The relatively low representation of young participants is attributed to the definition of ‘expert’, which may be considered rare within the young age group. We thus consider the expertise matrix to reveal sufficient coverage and variety for representational purposes.

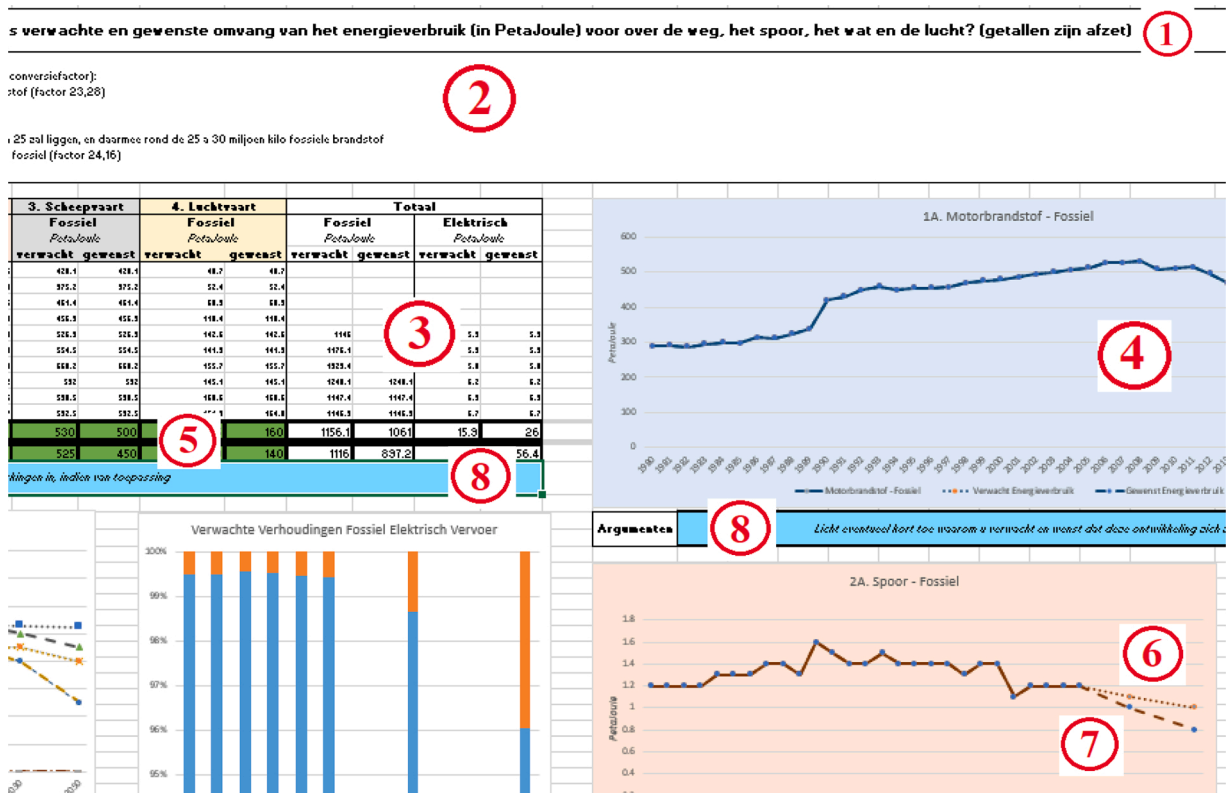


Fig. A1. Delphi survey one: excerpt of a single theme, querying multiple infrastructures visually with graphs displaying a single respondents probable and preferable futures estimates.

B Delphi survey 1 example

See Fig. B1.

The first survey displays the question (top row, numbered 1), elaborates on the indicator (below, text cropped, numbered 2), the time-series data of multiple infrastructures quantitatively (visible in grey and yellow, cropped, numbered 3), the time-series data visually (graphs with blue and orange background, numbered 4) that plots the future estimates that respondents enter in the green cells (numbered 5), where the dotted line (see orange graph) represents *probable* estimates (numbered 6), and the dashed line represents *preferable* estimates (numbered 7). Qualitative data may be entered in the light blue cells (numbered 8).

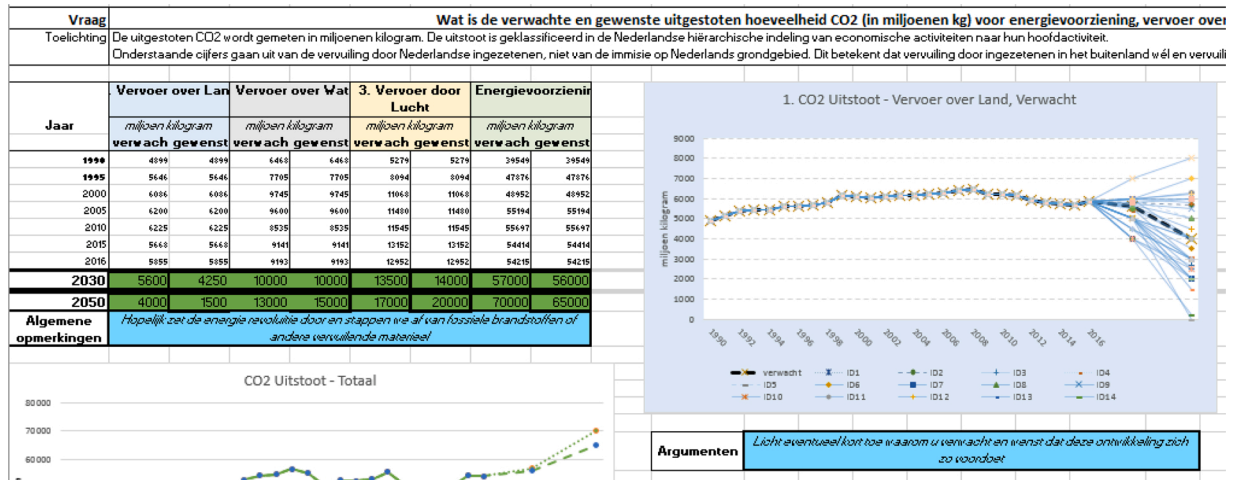


Fig. B1. Delphi survey two: excerpt of a single theme, querying multiple infrastructures visually, with graphs displaying all respondents either probable or preferable estimates.

C. Delphi survey 2 example

See Fig. C1.

The second survey differs from the first survey in two elements. Firstly, the graphs now display *either* preferable or probable future estimates instead of both. Second, the graph displays the other experts' estimates in blue-colored lines, and the survey-specific respondent's estimates in a thick black-dashed line.

Expertise Matrix - Desired Variation	Respondent code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	Actual Total		
Main category	Subcategory																																							
	<i>Specialist-field specific and Technical know-how</i>																																							
		? ?																																						
2) Thematic knowledge	Within Infra Admin																																							
	Asset Management; Renewal Strategy; Innovation	1	2	3	4	5	6	7					8					9					10	11	12	13	14	15	16	17	18						18			
	Mobility			1	2	3	4							6	7	8							9	10	11		12	13	14	15	16	17	18			9	10	11	12	12
	Energy						1																																9	
	Environment																																						1	
	Cybersecurity; ICT																																						1	
	Physical Safety																																						2	
	Economy; Freight																																						4	
	Governance	1																																					11	
	Generalist	1																																					11	
	Outside Infra Admin																																						1	
	External Field																																						2	
3) Infrastructure knowledgeability	Road	1	2	3	4	5								6	7																							12		
	Rail																																						10	
	Sea port	1																																					7	
	Air port																																						7	
	Energy																																						12	
	Other	1	2																																				1	
4) Background organisation	Administration	1	7	8	9	10	2	3	11	4	5	6	12	13	14	15	16																					29		
	Politics																																					8		
	Interest group or NGO	1																																					3	
	Media																																						0	
	Business																																					9		
	Research	1																																					5	
	Other																																						1	
5) Level of education	PhD																																						4	
	MSc / MA	1	6	7	8	2	3	9	4																														21	
	BSc / BA																																						7	
	MBO, high school and other																																						1	
	<i>Tacit and Experiential Knowledge</i>	? ? ?																																						
6) Management level / job specialization (not captured by aged?)	junior (0 - 5 years)																																							
	medior (5 - 15)	1																																				11		
	senior (15 + years)	5	6	7	8	1	9	10	2	3	4	11																											20	
	<i>Additional sample characteristics</i>	? ? ?																																						
7) Gender	Male	1	7	8	9	10	2	11	3	12	4	5	6	13																								30		
	Female																																						3	
	Other																																						0	
8) Age	< 30	? ? ?																																						
	30 - 39																																						7	
	40 - 49	1	3	4																																			14	
	50 - 59																																						6	
	60 +																																						4	

Fig. C1. Expertise matrix.

D. Futures-oriented Workshop: Survey and Participants

Table D1 shows the number of respondents per organization that were present at the futures-oriented workshop.

Table D1

Futures-oriented workshop.

Organization	Number of Participants	Cumulative
Rijkswaterstaat	5	
ProRail	4	9
Port of Rotterdam	1	10
Alliander	2	12
Schiphol	5	17
Other	6	23
Facilitators	6	29

E Futures-oriented Workshop: Phase 2

Phase two demonstrated yielded phrases and considerations that reoccurred in specific scenarios across groups (see Table E1), possibly explaining the generally positive affect regarding the familiarization with the constructed scenarios as displayed in Fig. E1.

Table E1

Workshop results: reoccurring phrases and consideration of the familiarization phase.

Scenario	Reoccurring phrases and considerations
Infraconomy	Wearing blinders; your wish is our command; Singapore vs. Shanghai?; barely environmentally aware; spatial scarcity; up-scaling, capacity increase
Safety	Will we have more (ProRail & Alliander), or less to do (PoR) or is it unclear (RWS & Schiphol); local and/or decentral
Techno-Pessimism	Muddling through, little change in current approach or current paved path. Results in the Missed Boat, but not deliberately.
Green	Decentral infrastructure streams, central direction; the intended path; less fossil; strategically and/or long term different
Technological	Difficulty of applying technology and making technology compatible
Missed Boat	Polarization; failing public support; compromising at its best; disinvestments; short-cycle perspective; keeping the pot boiling

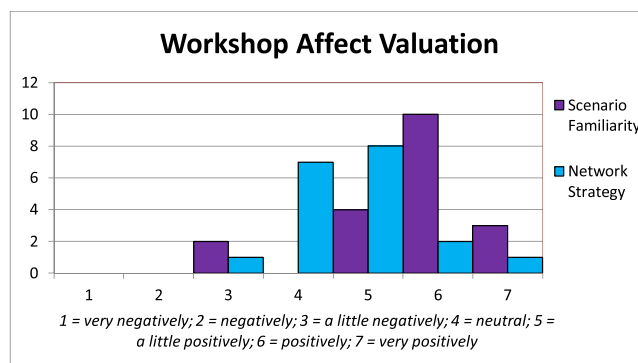


Fig. E1. Workshop results: participants' affect towards increased familiarity of the constructed scenarios (in purple) and network strategy formulation (in blue).

F Futures-oriented Workshop: Phase 3

Multiple infrastructural adaptations were found for each scenario.

See [Table F1](#).

Table F1

Workshop results: reoccurring adaptations and considerations that inform sectoral investment strategies.

Scenario	Reoccurring adaptations and considerations
Infraconomy	Emphasis on <i>renew</i> for all administrations. Adaptations all concern assets of the own administration (PoR: storage depots and Goerree Overvlakkee; RWS: connection Schiphol-Amsterdam-Almere; Alliander: new electricity stations; Schiphol: new terminal; ProRail: more general rail infra).
Safety	Emphasis on <i>redesign</i> for all administrators <i>except ProRail who emphasizes repurpose</i> (moving from a mechanical to software-logistics driven organization) (PoR: platooning hub; RWS: new amenities along the road; Alliander: redesign network structure; Schiphol: exclusive access through (light) rail).
Techno-Pessimism	Emphasis on <i>renew</i> for all administrators, stressing muddling through without specifying what that means.
Green	Emphasis on <i>repurpose and redesign</i> for all administrators, because most infrastructure administrators gain an environmental-oriented perspective (e.g. PoR Carbon Capturing and 'restwarmte' replacing current petrochemical industry; RWS tunnel construction to better capture CO2 at tunnels' edges, and using its area for energy production and distribution; Alliander shifts to a broker role instead of mere network administrator to stimulate and balance local community-based production and energy storage; Schiphol shifts towards H2 and electric fuel options, with a high business-transposition of plane-to-train; ProRail gain a challenge regarding light-rail transport and coordination of multi-level networks).
Technological	Emphasis on <i>no remove</i> for all administrators except Schiphol (parking) because of efficient infrastructural use. Emphasis on redesign and/or repurpose depending on technologies (integration of software logistics with environment; required employees at Schiphol airport due to robotization; demands for road infrastructure from truck platooning and energy infrastructure from new energy sources)
Missed Boat	Unequivocal mix of <i>renew and redesign</i> . Renew comprises life extension of assets and like-for-like replacement (Schiphol, Alliander) and thus no proper attention for the renewal challenge (RWS), where redesign comprises mild adaptations of hubs (Schiphol as new transfer methods and as train hub; Alliander obtains a role as energy bank; PoR marginal investments in new business)

G Futures-oriented Workshop: Phase 4

See Figs. G1,.

H Hierarchy Tree of Relative Variable Importance based on Zero Values

Preferable future estimates might indicate a relative degree of importance.

See Table G1.

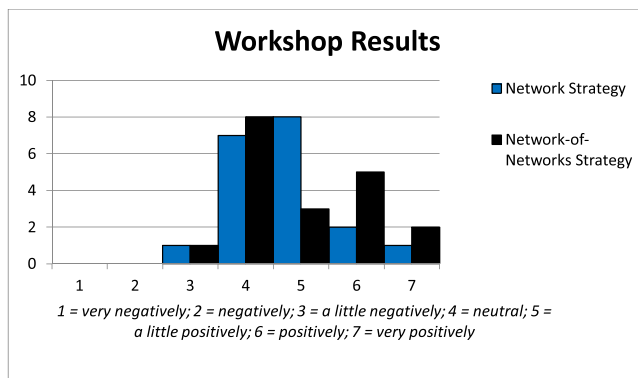


Fig. G1. Workshop results: contribution to network-of-network strategy is valued higher than to network strategy.

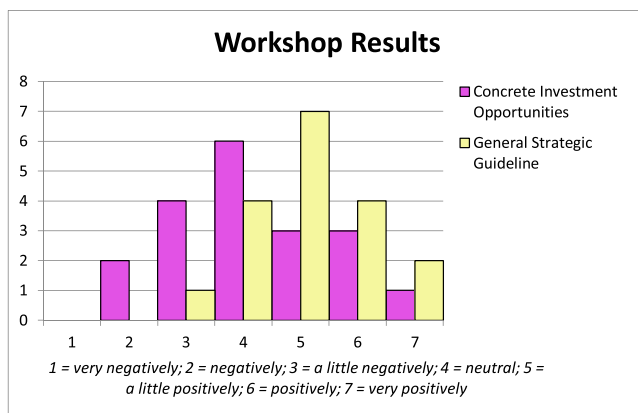


Fig. G2. Workshop results: contribution to general strategic information is valued higher than to concrete investment opportunities.

Table G1

Delphi data of zero values.

Variable	Indicator	Involved # Infra-structures in indicator	Zeros applied to # infrastructures	Total Amount of Zeros
Safety	Severe incidents	3	3	41
Energy (fossil fuels)	Petajoule	4	4	33
Environment	CO2 emissions	4 (road & rail aggregated)	4 (road & rail aggregated)	16
Cybersecurity	ICT incidents	1 (all infrastructures aggregated)	1 (all infrastructures aggregated)	4
Costs (Construction)	Million euros	3	2	3
Freight	Million tons	5	1	1
Mobility	Billion vehicle kilometers	4	1	1

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