CivilEng

MDPI

Supplement of

Identifying the input uncertainties to quantify when prioritizing railway assets for risk-reducing interventions

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1. Introduction

This file provides supplementary information for the paper "Identifying the input uncertainties to quantify when prioritizing assets for risk-reducing interventions". In this file, the input data used for the estimation of net-benefit is made available.

The structure of this file is as follows. Section 1 introduces the file. Section 2 presents the notations used in the file. Section 3 offers an overview of the input variables and values used in the file. Section 4 and 5 provide information regarding the assets and traffic restrictions, respectively. Section 6 contains the event trees and the probabilities of events. The input values related to interventions and site restorations is given in sections 7 and 8, respectively. Section 9 presents the number of fatalities and injuries considered, while section 10 lays out the input values for the estimation of the additional travel time. Finally, section 11 provides the unit costs of time, fatalities and injuries.

2. Notations

Table 1 presents the notations used in the document. The capital letters are used to notate vectors, while the small letters are used to notate point values.

Table 1. Notations.

Notation	Definition	Notation	Definition
a	the asset	m	the meters
B	the bridges	nb	the net benefit
€	the euro	ne	the network use event
best	the best estimate	NH	the natural hazards
c	the cost	o	the state of the asset
cl	the closure	P	the probabilities
D	the traffic restrictions	Q	the restorations
DD	the duration of traffic restrictions	QI	the restoration interventions
DT	the additional travel time	QS	the site restorations
c_e	the environmental cost	r	the risk
P[F]	the probabilities related to failures	S	the switches
g	the asset type	sc	the scenarios
H	the hazards	se	the societal events
high	the high estimate	spr	the maximum speed restrictions
i	the intervention	T	the track sections
ie	the infrastructure event	TR	the traffic on the asset
k	the risk-reducing intervention	u_t	the unit cost of time
l	the asset extent	U_Z	the unit cost of fatalities and injuries
l_e	the asset length	v	the network location
le	the load event	X	the input values
low	the low estimate	Z	the fatalities and injuries

3. Overview of input variables and values

The term "input data" refers to the values of the variables provided by the railway manager. Figure 1 offers an overview of the variables required to estimate the net-benefit and how they are related. An example of how Figure 1 should be read is as follows: The probability of load events is estimated as a function of the state of the asset before and after a risk-reducing intervention is executed, $o\backslash k$ and $o|k$ respectively, on the amount of traffic *TR* and natural hazard *NH* considered, and the type of asset g. It affects the estimation of the probability of failure due to traffic $P[F^{TR}]$, and natural hazard $P[F^{NH}]$. These, in turn, affect the estimation of risks with $r_{o\backslash k}$ and without a risk-reducing intervention $r_{o|k}$, and consequently, the net benefit nb_k.

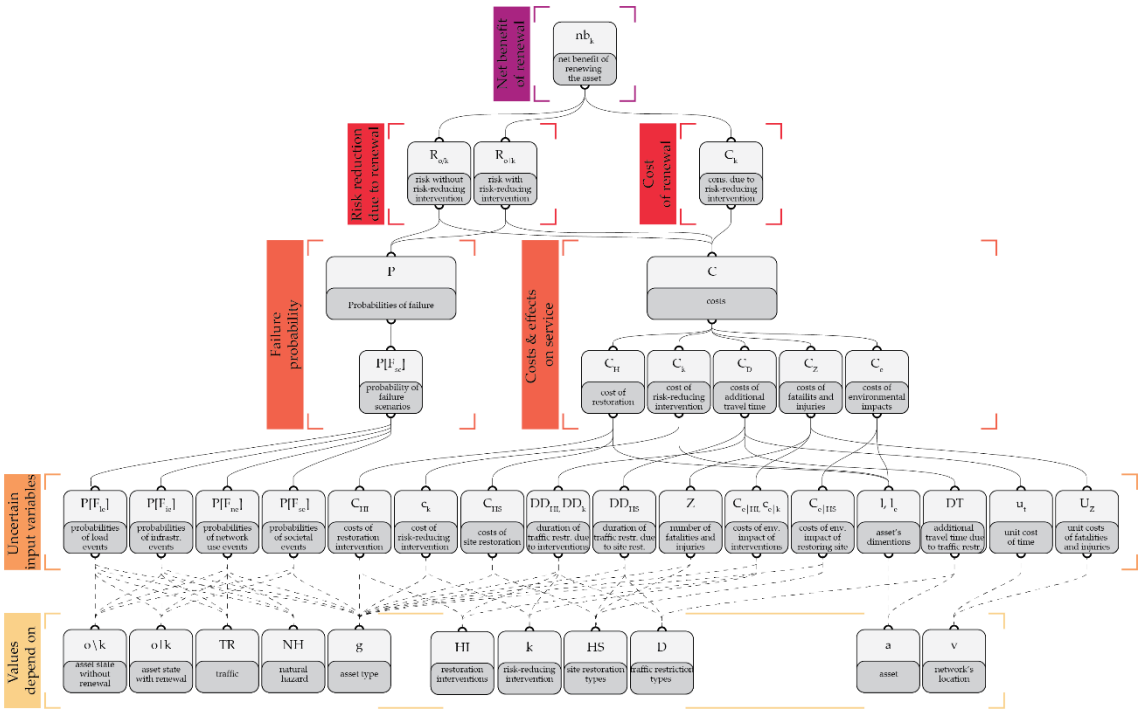


Figure 1. Overview of the variables required to estimate the net-benefit.

For each variable, three types of estimates were determined:

1. the reasonable best estimate,
2. the reasonable lowest estimate, and
3. the reasonable highest estimate.

These estimates derive from the input of experts, whose judgments are based on existing models and historical data. The best, low and high estimates for each variable are provided in the following sub-sections.

Using these three estimates, a skewed normal distribution was built, assuming the high and low estimates, x_{high} and x_{low}, encompass the 95% confidence interval and the best estimate, x_{best}, is the mean value ($\bar{x} = x_{best}$).

Figure 2 shows the probability density function of a skewed normal distribution, $P(x)$, that was built using the best, x_{best},, low, x_{low}, and high, x_{high}, estimates of the input value x. This is a right-skewed distribution because it has a longer tail on the right.

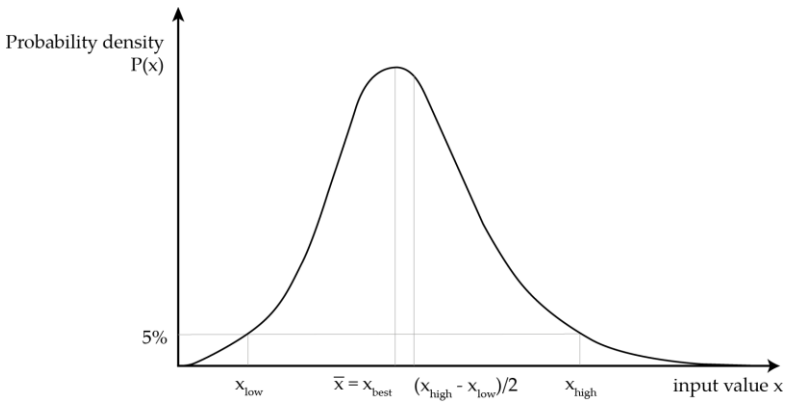


Figure 2. Illustration of the best, low and high estimates and a positively skewed normal distribution of input value x.

4. Assets

4.1. Dimensions

Tables 2-4 show the estimates of the dimensions of track sections, switches and bridges, respectively.

Table 2. Dimensions of track sections.

ID	Extent estimate, l, in m of length			Length estimate, l_e, in m		
	Best	**Low**	**High**	**Best**	**Low**	**High**
T1	255	253	257	255	253	257
T2	255	253	257	255	253	257
T3	533	531	535	533	531	535
T4	533	531	535	533	531	535
T5	543	541	545	543	541	545
T6	543	541	545	543	541	545
T7	764	762	766	764	762	766
T8	790	788	792	790	788	792
T9	521	519	523	521	519	523
T10	385	383	387	385	383	387
T11	41	39	43	41	39	43

Table 3. Dimensions of switches.

ID	Extent estimate, l, per asset			Length estimate, l_e, in m		
	Best	**Low**	**High**	**Best**	**Low**	**High**
S1	1	1	1	10	9	11
S2	1	1	1	10	9	11
S3	1	1	1	10	9	11
S4	1	1	1	10	9	11
S5	1	1	1	10	9	11
S6	1	1	1	10	9	11
S7	1	1	1	10	9	11
S8	1	1	1	10	9	11
S9	1	1	1	10	9	11
S10	1	1	1	10	9	11
S11	1	1	1	10	9	11
S12	1	1	1	10	9	11
S13	1	1	1	10	9	11
S14	1	1	1	10	9	11
S15	1	1	1	10	9	11
S16	1	1	1	10	9	11
S17	1	1	1	10	9	11
S18	1	1	1	10	9	11
S19	1	1	1	10	9	11
S20	1	1	1	10	9	11
S21	1	1	1	10	9	11
S22	1	1	1	10	9	11
S23	1	1	1	10	9	11

Table 4. Dimensions of bridges.

ID	Extent estimate, l, in m² deck surface area			Length estimate, l_e, in m		
	Best	**Low**	**High**	**Best**	**Low**	**High**
B1	720	718	718	72	69	75
B2	1'130	1'128	1'128	113	110	116
B3	470	468	468	47	44	50
B4	320	318	318	32	29	35
B5	372	370	370	38	35	41
B6	167	165	165	17	14	20
B7	167	165	165	17	14	20
B8	350	348	348	35	32	38
B9	500	498	498	50	47	53
B10	250	248	248	25	22	28
B11	350	348	348	35	32	38
B12	1'410	1'408	1'408	141	138	144
B13	500	498	498	50	47	53
B14	450	448	448	45	42	48
B15	400	398	398	40	37	43
B16	640	638	638	64	61	67
B17	230	228	228	23	20	26
B18	230	228	228	23	20	26
B19	960	958	958	96	93	99
B20	320	318	318	32	29	35
B21	600	598	598	60	57	63
B22	330	328	328	33	30	36
B23	460	458	458	46	43	49
B24	450	448	448	45	42	48
B25	650	648	648	65	62	68
B26	720	718	718	72	69	75
B27	270	268	268	27	24	30
B28	765	763	763	45	42	48
B29	192	190	190	12	9	15
B30	110	108	108	11	8	14
B31	160	158	158	10	7	13
B32	240	238	238	15	12	18
B33	345	343	343	15	12	18
B34	345	343	343	15	12	18
B35	136	134	134	8	5	11
B36	425	423	423	25	22	28
B37	187	185	185	11	8	14
B38	187	185	185	11	8	14
B39	255	253	253	15	12	18

4.2. State

Each asset is in one of four possible states, i.e. 1 – like new, 2 – slightly deteriorated, 3 – significantly deteriorated, 4 – severely deteriorated. The state of the assets is shown in Figure 3. All these states are functional, i.e. operating an asset in any of these states ensures acceptable service levels. The execution of risk-reducing intervention, i.e. renewal, was considered to restore the asset to state 1, and, thus, for all the assets:

$$o_{a|k} = 1 \tag{1}$$

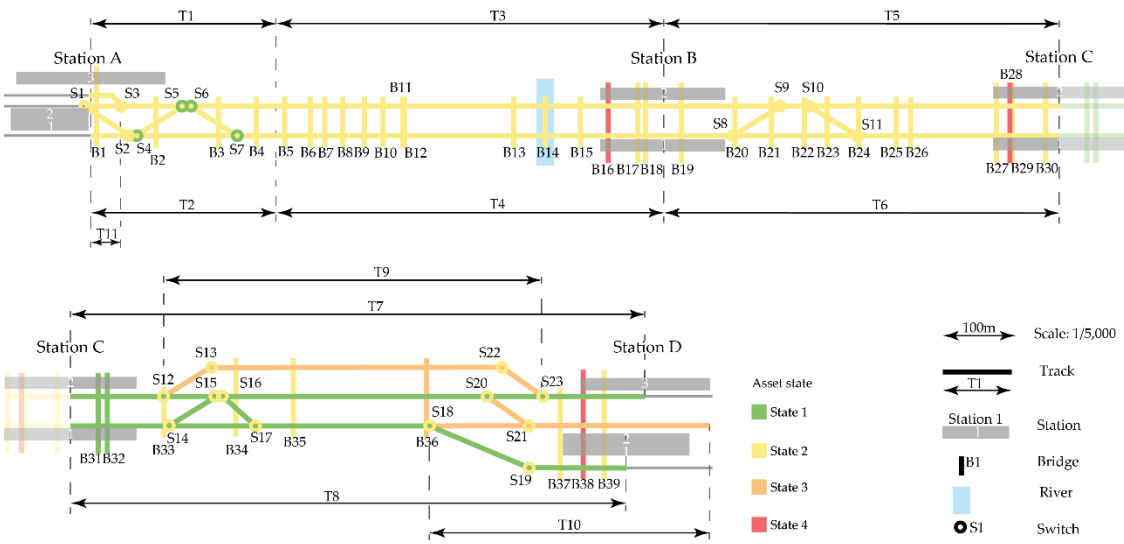


Figure 3. State of assets without the execution of the risk-reducing intervention, $o_{a\backslash k}$.

4.3. Type

The asset type is shown in Figure 4 The track sections are classified into two subcategories, i.e. those with a maximum allowable speed greater than 40km/h, and those with a maximum allowable speed lower than or equal to 40km/h. The bridges are classified into three subcategories, i.e. concrete, masonry and metal bridges.

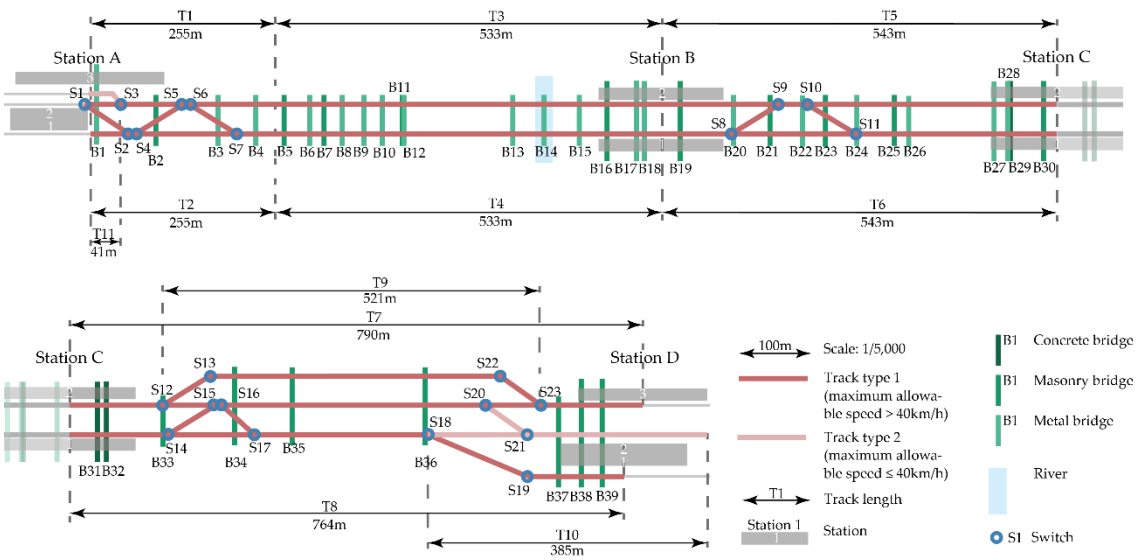


Figure 4. Track sections, switches and bridges of the case study.

5. Traffic restrictions

The types of traffic restrictions due to the unavailability of the assets are presented in Table 5.

Table 5. Traffic restrictions, *D*.

Notation	Description	Notation	Description
spr1	Maximum speed restriction at 40 km/h for an hour during an average day	*cl1*	Closure for an hour during an average day
spr1	Maximum speed restriction at 40 km/h for an hour during a weekend	*cl2*	Closure for an hour during a weekend

6. Probabilities of events

6.1. Events

Table 6 - Table **8** present the load, infrastructure, and network use events, respectively, per asset type. The societal events for track sections are given in Table 9 - Table **10**, while Table 11 and Table 12 present the societal events for switches and bridges, respectively.

Table 6. Load events, *LE*, per asset type.

Load event type	Notation	Description		
		Track	**Switches**	**Bridges**
Traffic load	***le|TR***	Annual tonnage on the track section based on the timetable	Annual wheel load on the switches due to train movements based on the timetable	Normalized annual traffic loads due to the daily traffic based on the timetable
Level 1 load due to natural hazard	***le1|NH***	Thermal stresses on the track section caused by 17°C ambient temperature	Neglectable thermal stresses on the switch elements	Neglectable increase in river flow speed
Level 2 load due to natural hazard	***le2|NH***	Thermal stresses on the track section caused by 25°C ambient temperature	Moderate thermal stresses on the switch elements	River flow speed that corresponds to a 25-year flood event
Level 3 load due to natural hazard	***le3|NH***	Thermal stresses on the track section caused by 40°C ambient temperature	High thermal stresses on the switch elements	River flow speed that corresponds to a 50-year flood event
Level 4 load due to natural hazard	***le4|NH***	Thermal stresses on the track section caused by 43°C ambient temperature	Thermal stresses beyond the designed level on switch elements	River flow speed that corresponds to a 100-year flood event
Level 4 load due to natural hazard	***le5|NH***	Thermal stresses on the track section caused by 60°C ambient temperature	-	-

Table 7. Infrastructure events, *IE* per asset type.

Infrastructure event type	Notation	Description		
		Track	**Switches**	**Bridges**
No damage	***ie1***	No noticeable damages on the track section due to the load event	No noticeable damages on the switch due to the load event	No noticeable damages on the bridge due to the load event
Minor damage	***ie2***	Damages that partially affect the track geometry or the rail condition	Damages that partially affect either the condition of the elements or the operation of the switch	Damages that partially affect the structural stability
Severe damage	***ie3***	Potential lack of stability of the track section to support the dynamic wheel load according to the required speed	Damages that significantly affect either the condition of the elements or the operation of the switch	Potential lack of structural stability

Table 8. Network use events, *NE*, per asset type.

Network use event type	Notation	Description		
		Track	**Switches**	**Bridges**
Normal use	***ne1***	Fully operational track section	Fully operational block	Fully operational block
Maximum speed restriction	***ne2***	The operation of the track section is possible only when the speed is less than 40km/h	The operation of all affected blocks is possible only with speed below 40km/h	The operation of the block where the bridge is located is possible only with speed below 40km/h
Closure	***ne3***	Closure of track section and all the blocks located in this track section	Closure of switch and all the affected blocks	Closure of the bridge and all the affected blocks

Table 9. Societal events, *SE*, used for the estimation of risk related to track sections (first part *se1-se14*).

Notation	Description	Notation	Description
se1	No accident; no restoration at the site and no intervention; no traffic restriction	***se8***	Accident; minor restoration at the site, rail replacement and tamping of the track section; traffic restrictions due to restoration, rail replacement, and tamping
se2	No accident; no restoration at the site and no intervention; maximum speed restriction for 24 hours	***se9***	Accident; minor restoration at the site and renewal of the track section; traffic restrictions due to restoration and track section replacement, and maximum speed restriction for a week after renewal
se3	No accident; no restoration at the site and track section renewal after a month; maximum speed for a month until track section replacement and for a week after the renewal	***se10***	No accident; minor restoration at the site and tamping of the track section; maximum speed restriction until the restoration of the site is complete, and the track section is tamped
se4	No accident; minor restoration at the site and tamping of the track section; traffic restrictions due to restoration and tamping	***se11***	No accident; minor restoration at the site, and rail replacement and tamping of the track section; maximum speed restriction until the restoration of the site is complete, and the rail is replaced, and the track section is tamped
se5	No accident; minor restoration at the site and rail replacement and tamping of the track section; traffic restrictions due to restoration and rail replacement	***se12***	No accident; minor restoration at the site and track section renewal; maximum speed restriction until the restoration of the site is complete, the track is renewed and for a week after renewal
se6	No accident; minor restoration at the site and renewal of the track section; traffic restrictions due to restoration and track section replacement and maximum speed restriction for a week after renewal	***se13***	Accident; minor restoration at the site and tamping of the track section; maximum speed restriction until the restoration of the site is complete, and the track section is tamped
se7	Accident; minor restoration at the site and tamping of the track section; traffic restrictions due to restoration and tamping	***se14***	Accident; minor restoration at the site and rail replacement and tamping of the track section; maximum speed restriction until the restoration of the site is complete, the rail is replaced, and the track section is tamped

Table 10. Societal events, *SE*, used for the estimation of risk related to track sections (second part *se15-se21*).

Notation	Description	Notation	Description
se15	Accident; minor restoration at the site and track section renewal; maximum speed restriction until the restoration of the site is complete, the track section is renewed, and for a week after renewal	***se19***	No accident; major restoration at the site and track section renewal; traffic restrictions until the restoration of the site is complete, and the track section is renewed; maximum speed restriction for a week after renewal
se16	No accident; minor restoration at the site and tamping of the track section; closure of the section until the restoration of the site is complete, and the track section is tamped	***se20***	Accident; major restoration at the site and track section renewal; traffic restrictions until the restoration of the site is complete, and the track section is renewed; maximum speed restriction for a week after renewal
se17	No accident; minor restoration at the site, and rail replacement and tamping of the track section; closure of the section until the restoration of the site is complete, the rail is replaced and the track is tamped	***se21***	No accident; major restoration at the site and track section renewal; closure of the section until the restoration of the site is complete, and the track section is renewed; maximum speed restriction for a week after renewal
se18	No accident; minor restoration at the site and track section renewal; closure of the section until the restoration of the site is complete, and the track section is renewed; maximum speed restriction for a week after renewal		

Table 11. Societal events, *SE*, used for the estimation of risk related to switches.

Notation	Description	Notation	Description
se1	No accident; no restoration at the site and no intervention; no traffic restriction	***se9***	No accident; minor restoration at the site and switch renewal; maximum speed restriction until the restoration of the site is complete, and the switch is renewed
se2	No accident; no restoration at the site and no intervention; maximum speed restriction for 24 hours	***se10***	Accident; minor restoration at the site and welding or grinding of the switch; maximum speed restriction until the restoration of the site is complete, and welding or grinding is performed on the switch
se3	No accident; no restoration at the site and switch renewal after a month; maximum speed for a month until switch renewal	***se11***	Accident; minor restoration at the site and switch renewal; maximum speed restriction until the restoration of the site is complete, and the switch is renewed
se4	No accident; minor restoration at the site and welding or grinding of the switch; traffic restrictions due to restoration and interventions	***se12***	No accident; minor restoration at the site and welding or grinding of the switch; closure of the section until the restoration of the site is complete, and the switch is welded or ground
se5	No accident; minor restoration at the site and switch renewal; traffic restrictions due to restoration and switch renewal	***se13***	No accident; minor restoration at the site and switch renewal; closure of the section until the restoration of the site is complete, and the switch is renewed
se6	Accident; minor restoration at the site and welding or grinding of the switch; traffic restrictions due to restoration and welding or grinding	***se14***	No accident; major restoration at the site and switch renewal; traffic restrictions until the restoration of the site is complete, and the switch is renewed
se7	Accident; minor restoration at the site and switch renewal; traffic restrictions due to restoration and switch renewal	***se15***	Accident; major restoration at the site and switch renewal; traffic restrictions until the restoration of the site is complete, and the switch is renewed
se8	No accident; minor restoration at the site and welding or grinding of the switch; maximum speed restriction until the restoration of the site is complete, and the switch is welded or ground	***se16***	No accident; major restoration at the site and switch renewal; closure of the section until the restoration of the site is complete, and the switch is renewed

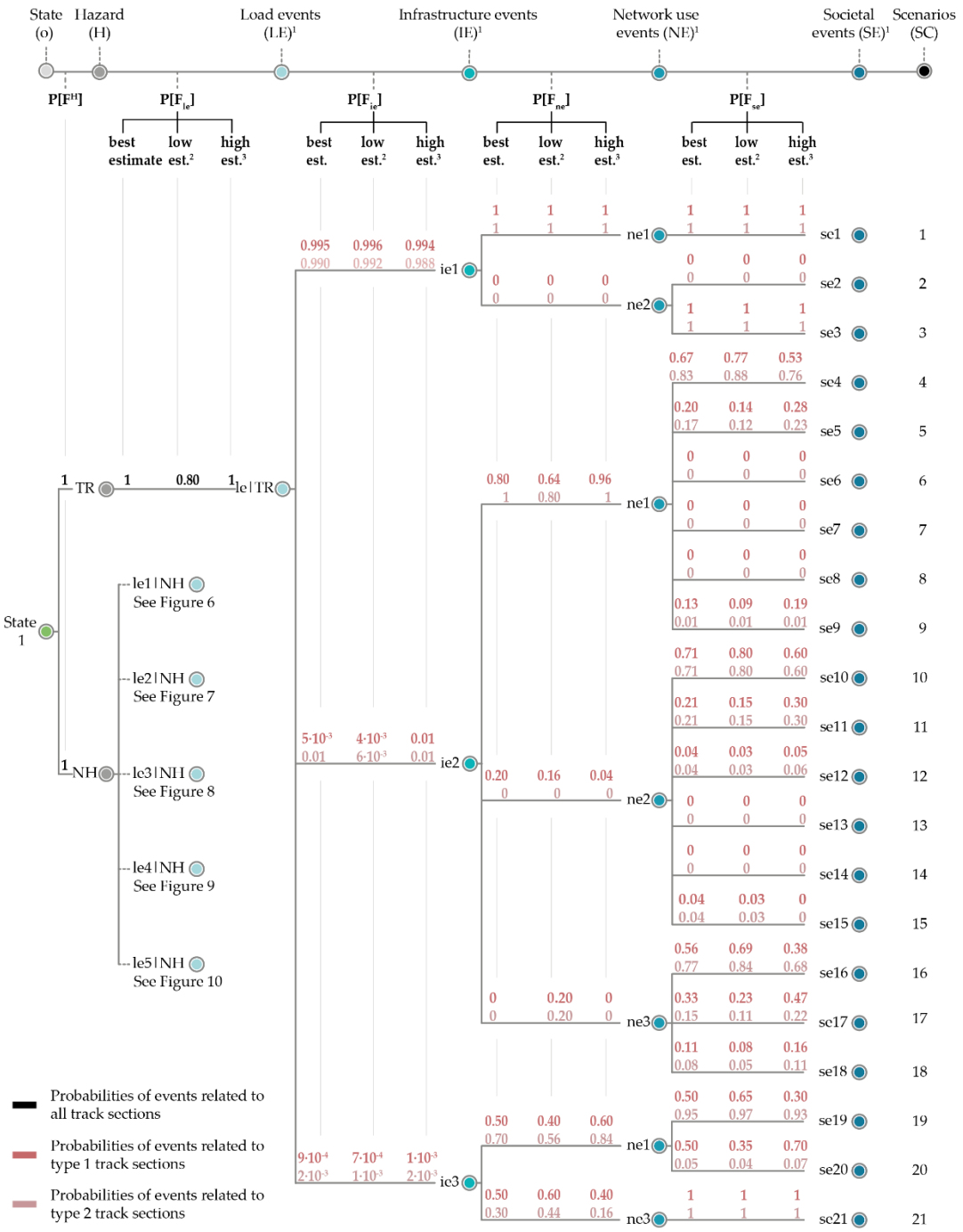
Table 12. Societal events, *SE*, used for the estimation of risk related to bridges

Notation	Description	Notation	Description
se1	No accident; no restoration at the site and no intervention; no traffic restriction	***se9***	No accident; minor restoration at the site and bridge renewal; maximum speed restriction until the restoration of the site is complete, and the bridge is renewed
se2	No accident; no restoration at the site and no intervention; maximum speed restriction for 24 hours	***se10***	Accident; minor restoration at the site and strengthening of the bridge; maximum speed restriction until the restoration of the site is complete, and the bridge is strengthened
se3	No accident; no restoration at the site and bridge renewal after a month; maximum speed for a month until bridge renewal	***se11***	Accident; minor restoration at the site and bridge renewal; maximum speed restriction until the restoration of the site is complete, and the bridge is renewed
se4	No accident; minor restoration at the site and strengthening of the bridge; traffic restrictions due to restoration and interventions	***se12***	No accident; minor restoration at the site and strengthening of the bridge; closure of the section until the restoration of the site is complete, and the bridge is strengthened
se5	No accident; minor restoration at the site and renewal of the bridge; traffic restrictions due to restoration and bridge renewal	***se13***	No accident; minor restoration at the site and bridge renewal; closure of the section until the restoration of the site is complete, and the bridge is renewed
se6	Accident; minor restoration at the site and strengthening of the bridge; traffic restrictions due to restoration and intervention on the bridge	***se14***	No accident; major restoration at the site and bridge renewal; traffic restrictions until the restoration of the site is complete, and the bridge is renewed
se7	Accident; minor restoration at the site and renewal of the bridge; traffic restrictions due to restoration and bridge renewal	***se15***	Accident; major restoration at the site and bridge renewal; traffic restrictions until the restoration of the site is complete, and the bridge is renewed
se8	No accident; minor restoration at the site and strengthening of the bridge; maximum speed restriction until the restoration of the site is complete, and the bridge is strengthened	***se16***	No accident; major restoration at the site and bridge renewal; closure of the section until the restoration of the site is complete, and the bridge is renewed

6.2. Events trees

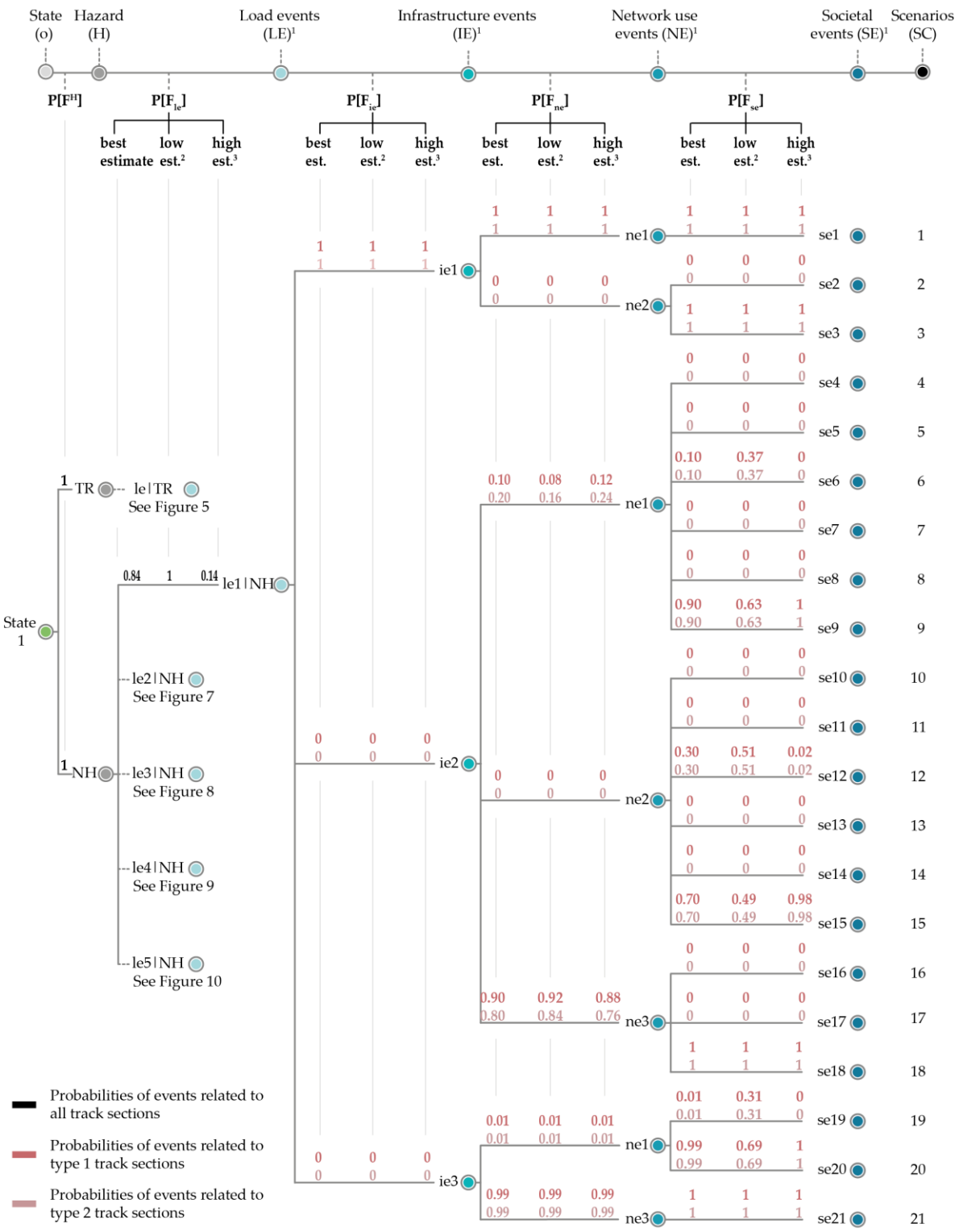
6.2.1. Track sections

Figures 5-28 depict the event trees and the estimates of event probabilities used for the calculation of risk related to track sections.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 5. Event tree and probabilities used for the estimation of risk related to track sections in state 1 due to traffic.



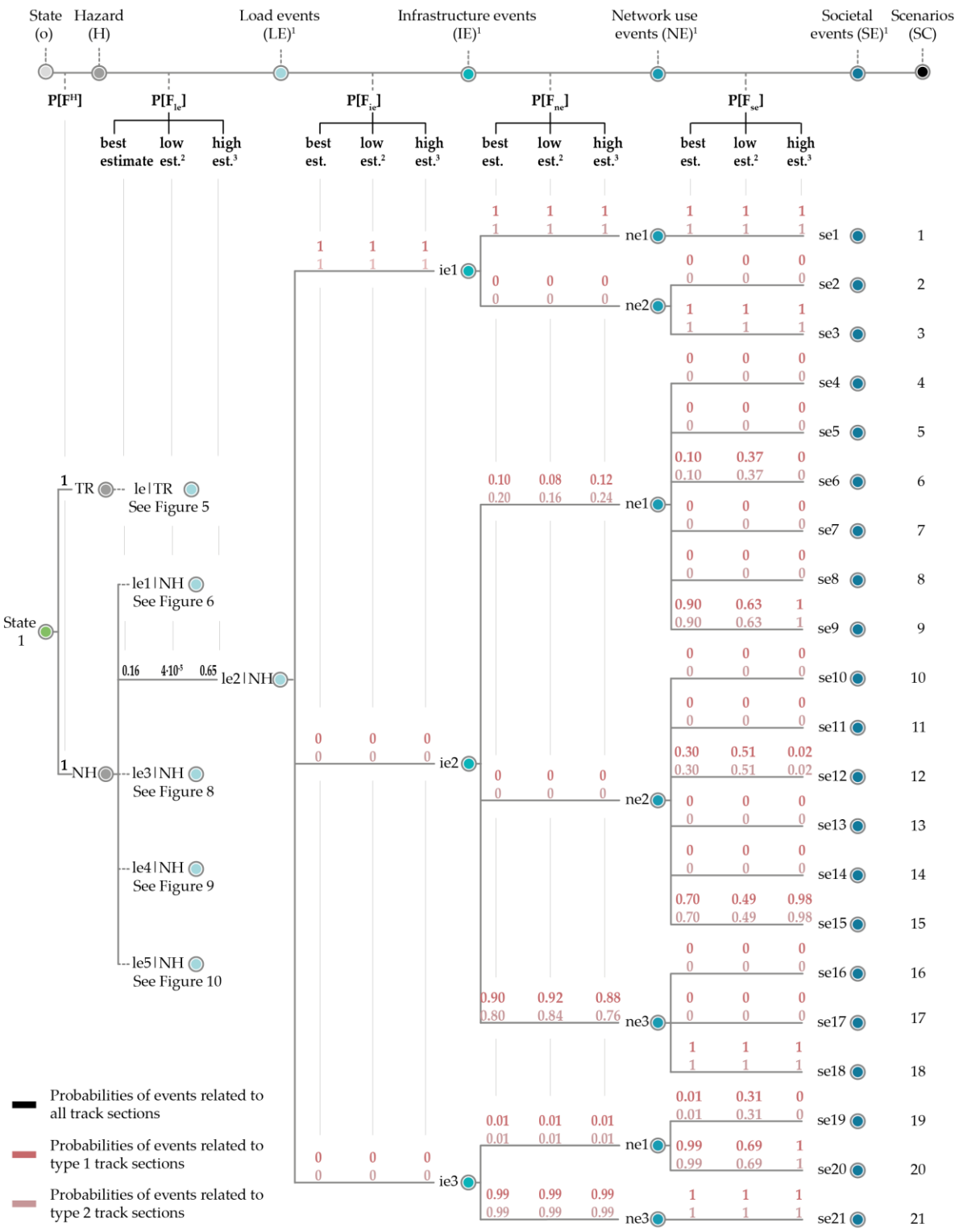
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

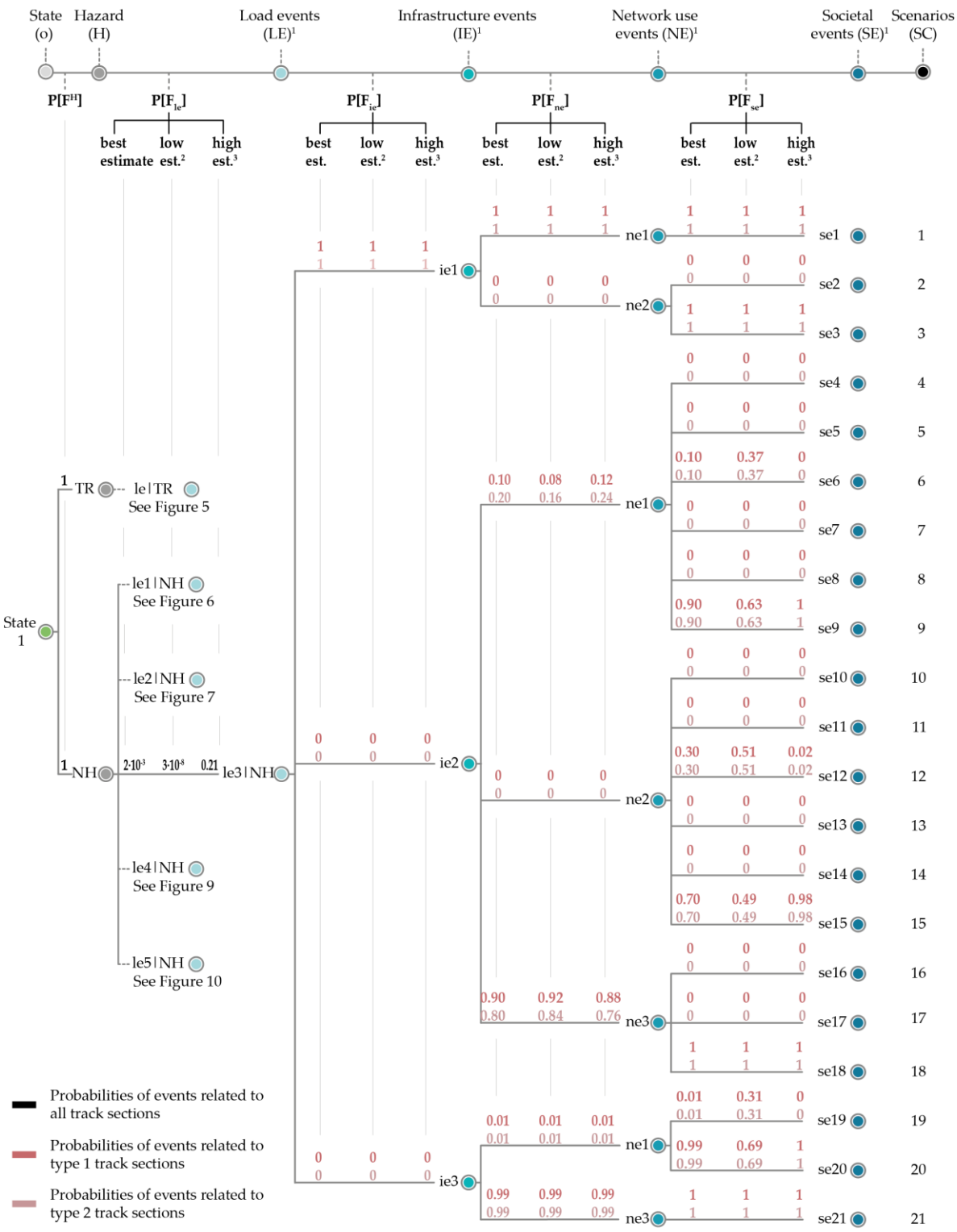
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 6. Event tree and probabilities used for the estimation of risk related to track sections in state 1 due to natural hazard and load event le1.



All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 7. Event tree and probabilities used for the estimation of risk related to track sections in state 1 due to natural hazard and load event le2.



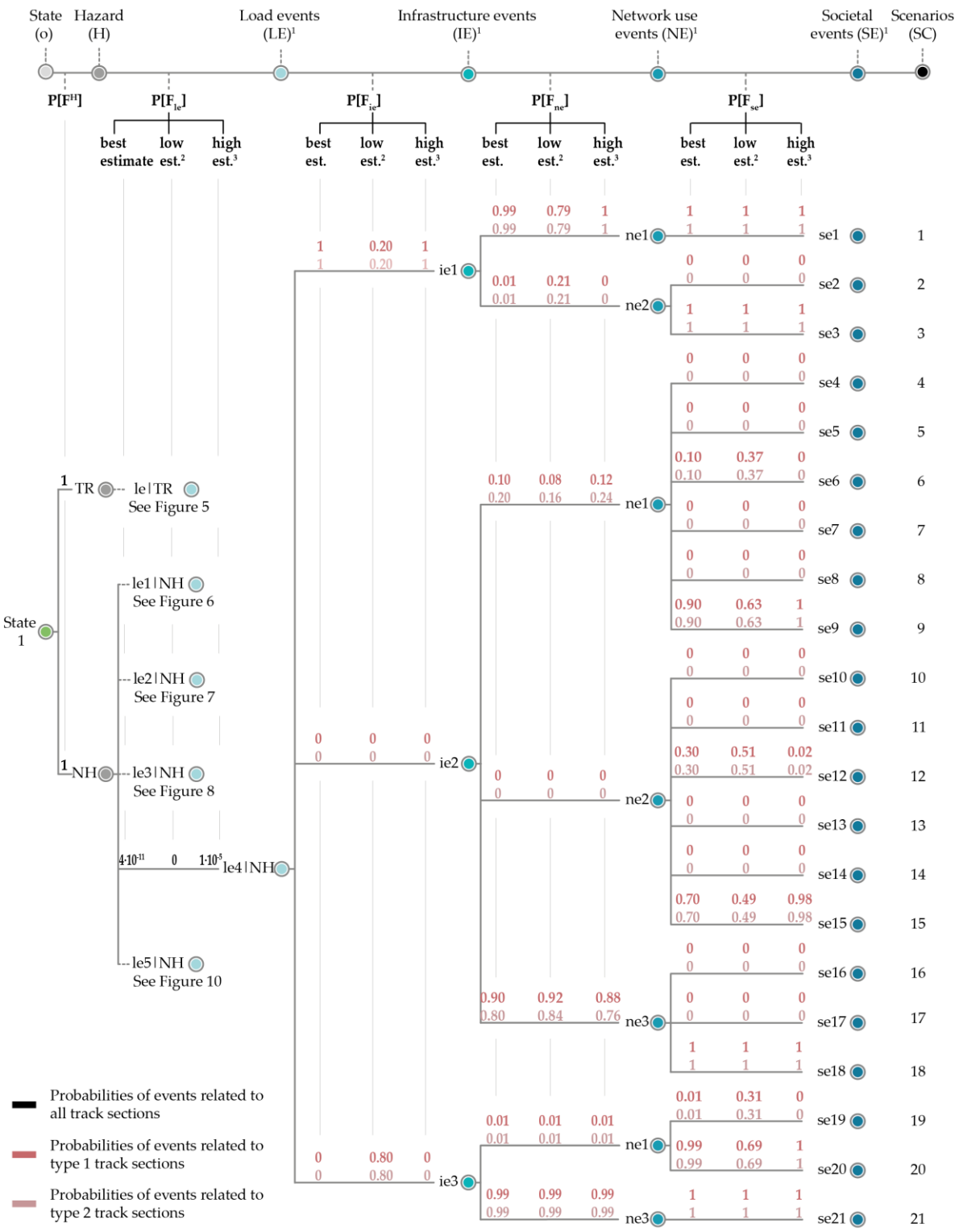
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 8. Event tree and probabilities used for the estimation of risk related to track sections in state 1 due to natural hazard and load event le3.



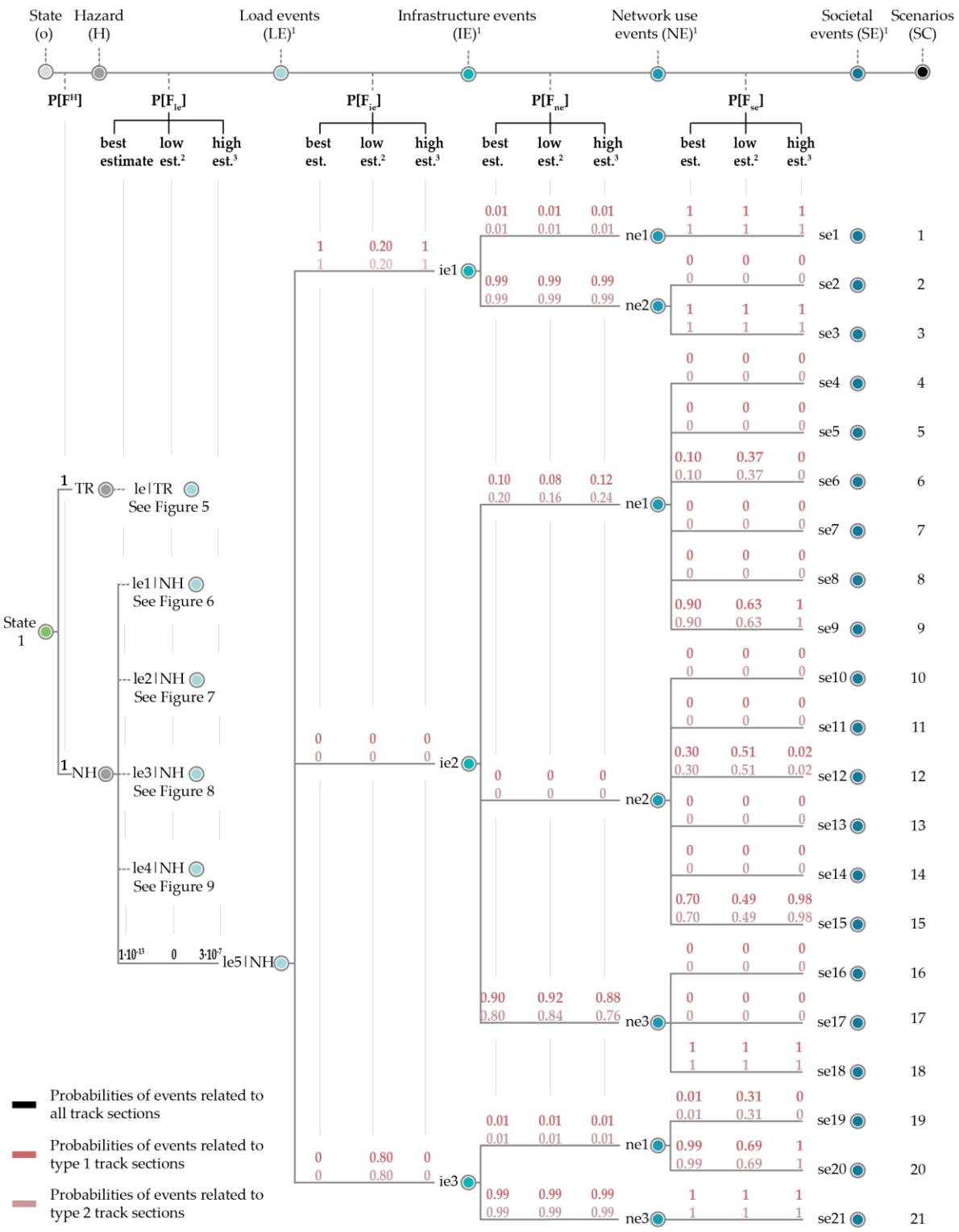
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

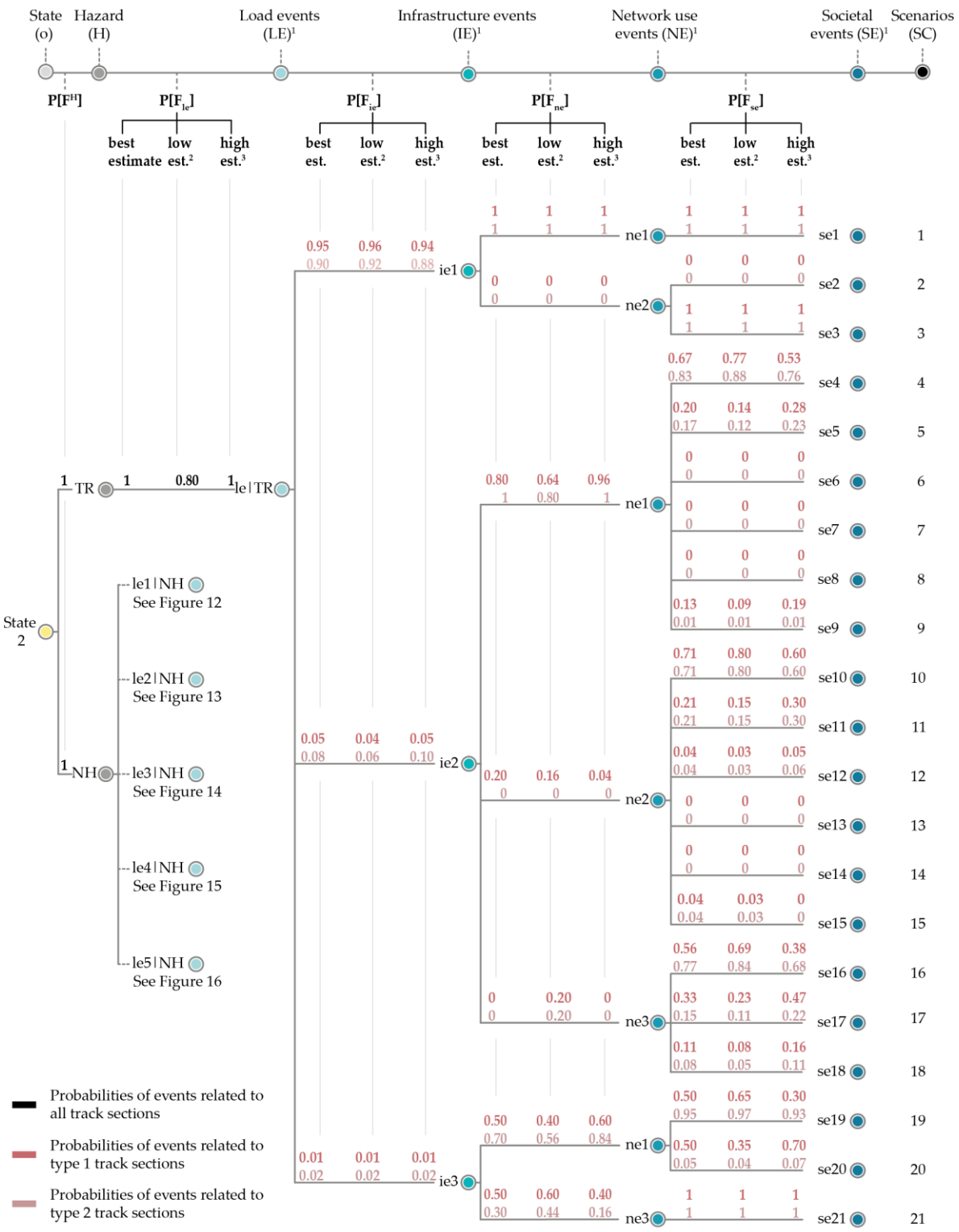
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 9. Event tree and probabilities used for the estimation of risk related to track sections in state 1 due to natural hazard and load event le4.



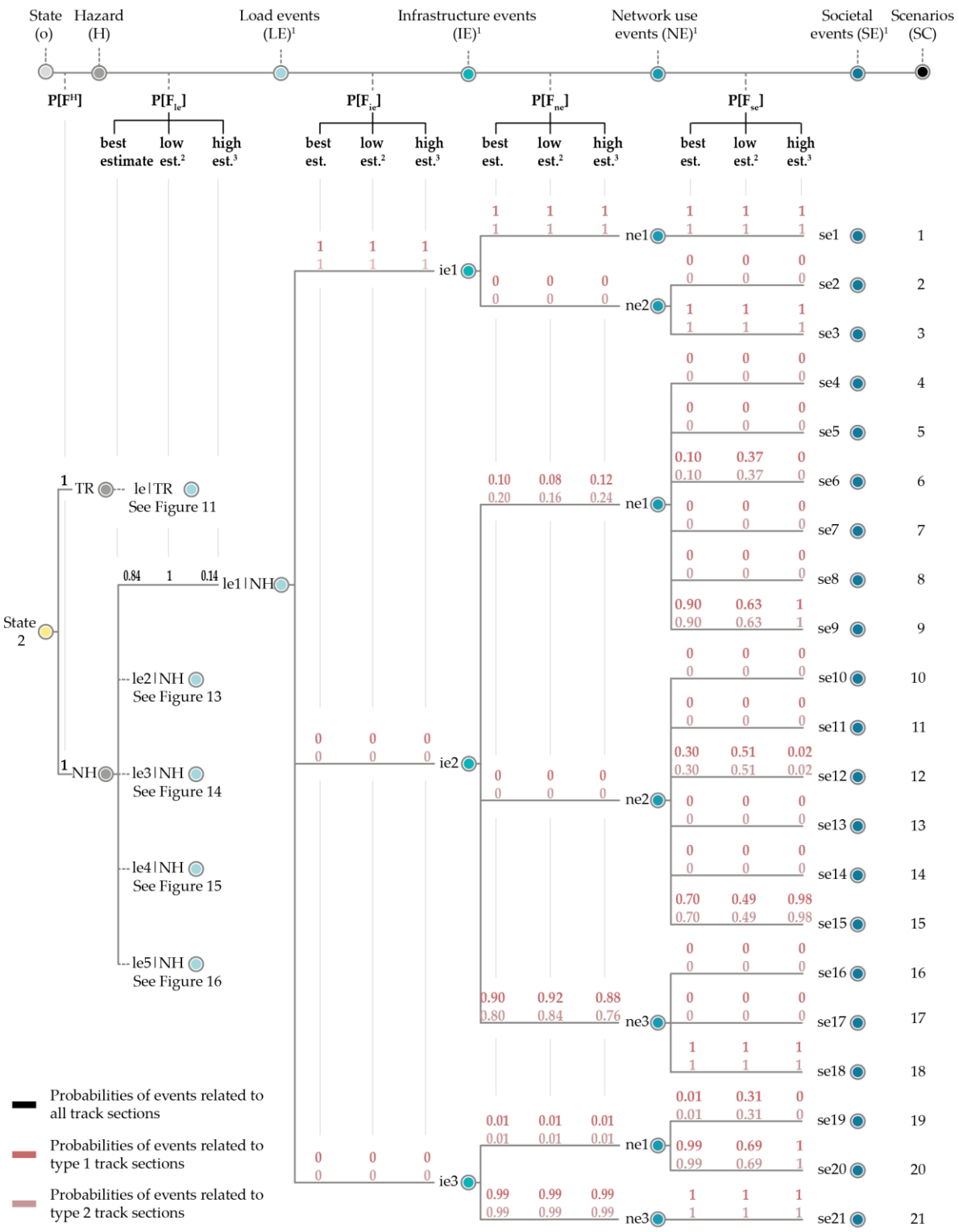
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 10. Event tree and probabilities used for the estimation of risk related to track sections in state 1 due to natural hazard and load event le5.



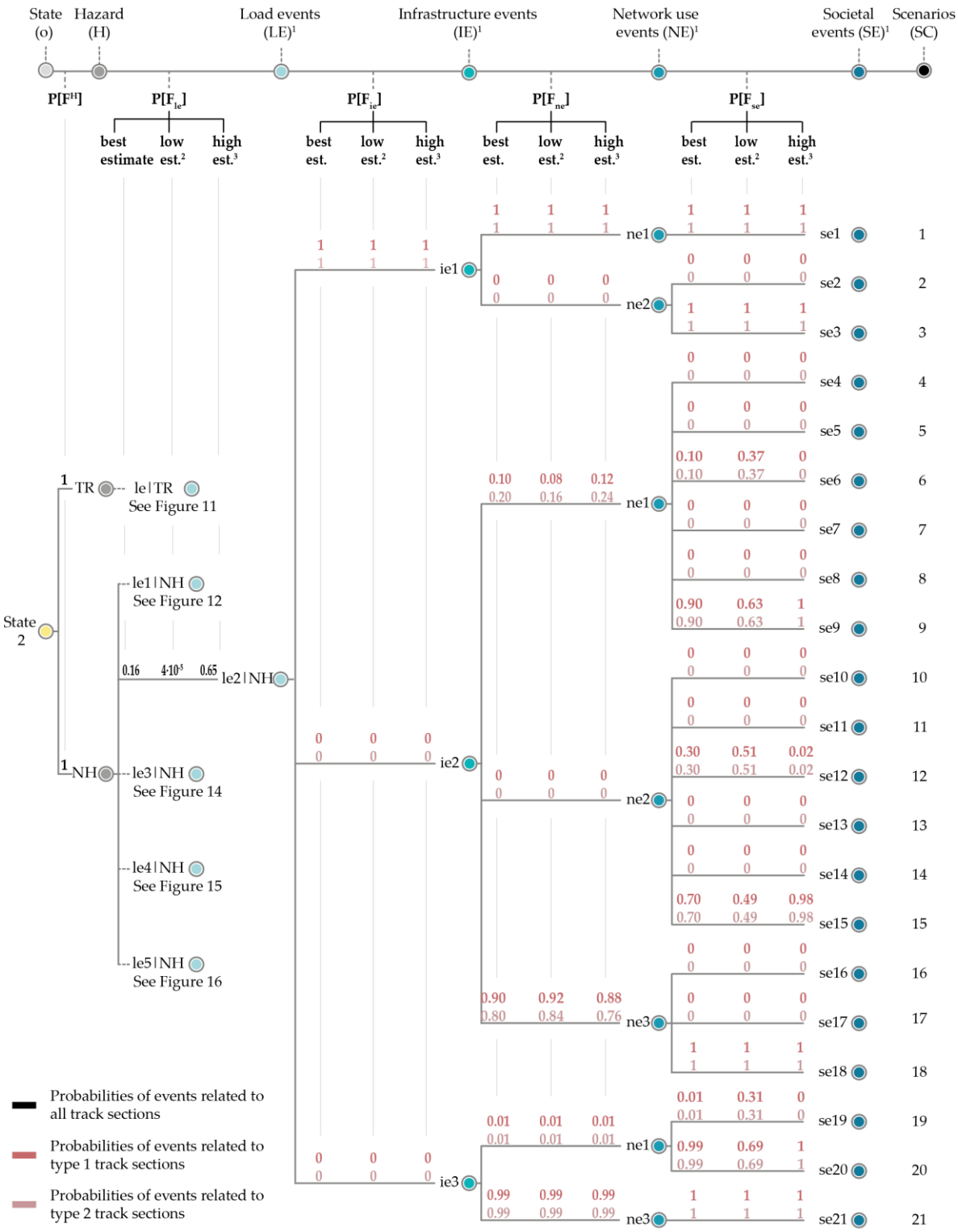
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 11. Event tree and probabilities used for the estimation of risk related to track sections in state 2 due to traffic.



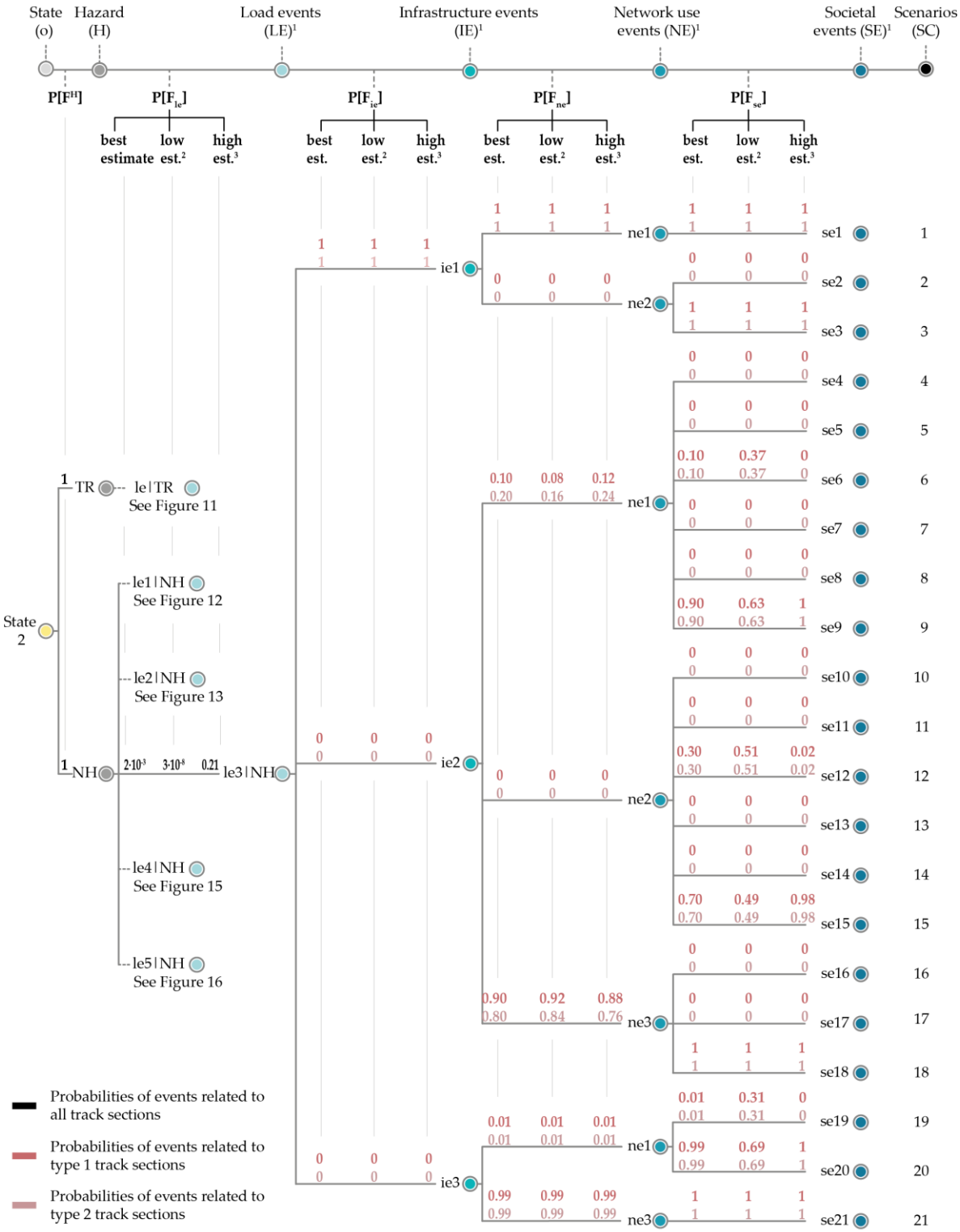
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 12. Event tree and probabilities used for the estimation of risk related to track sections in state 2 due to natural hazard and load event le1.



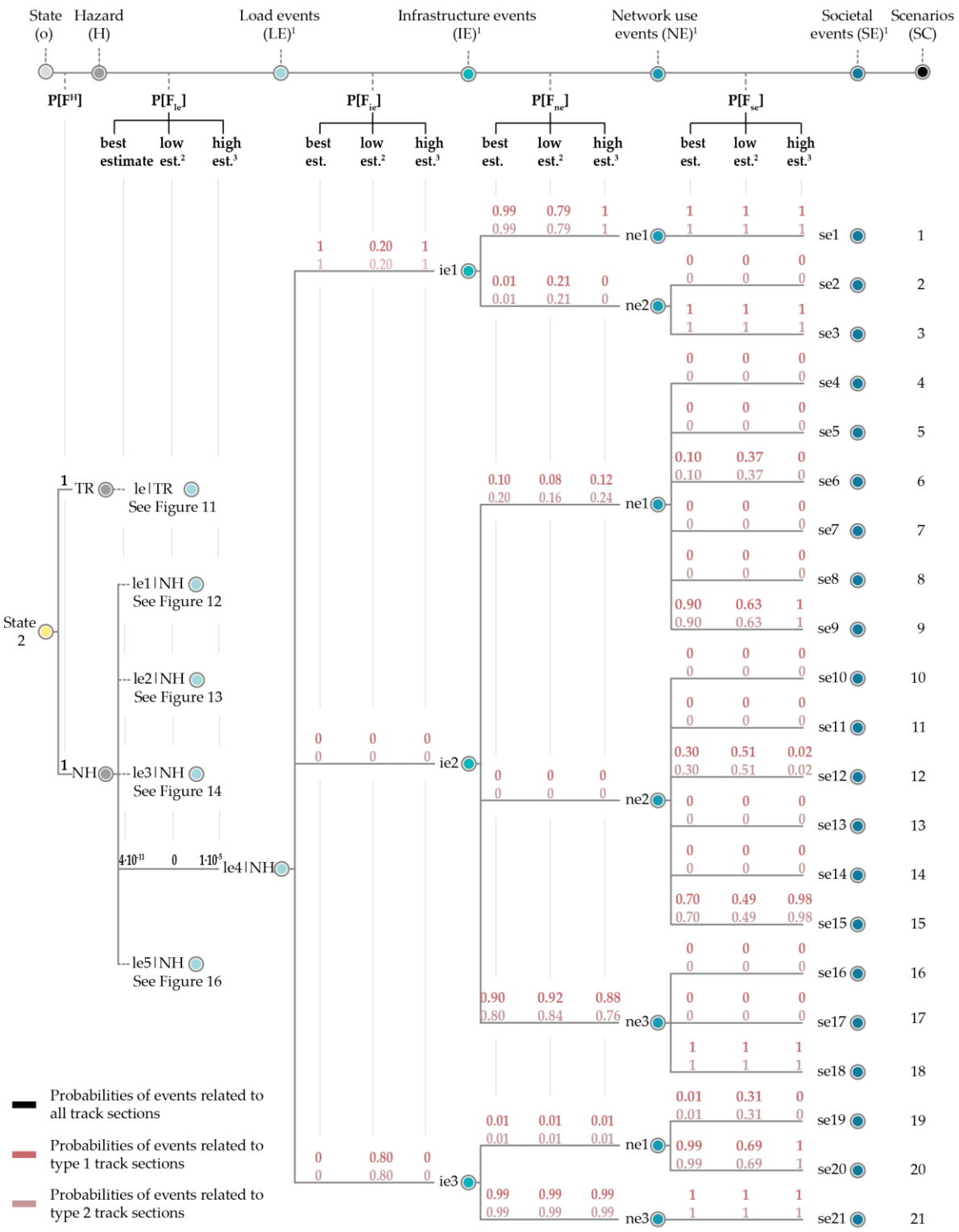
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 13. Event tree and probabilities used for the estimation of risk related to track sections in state 2 due to natural hazard and load event le2.



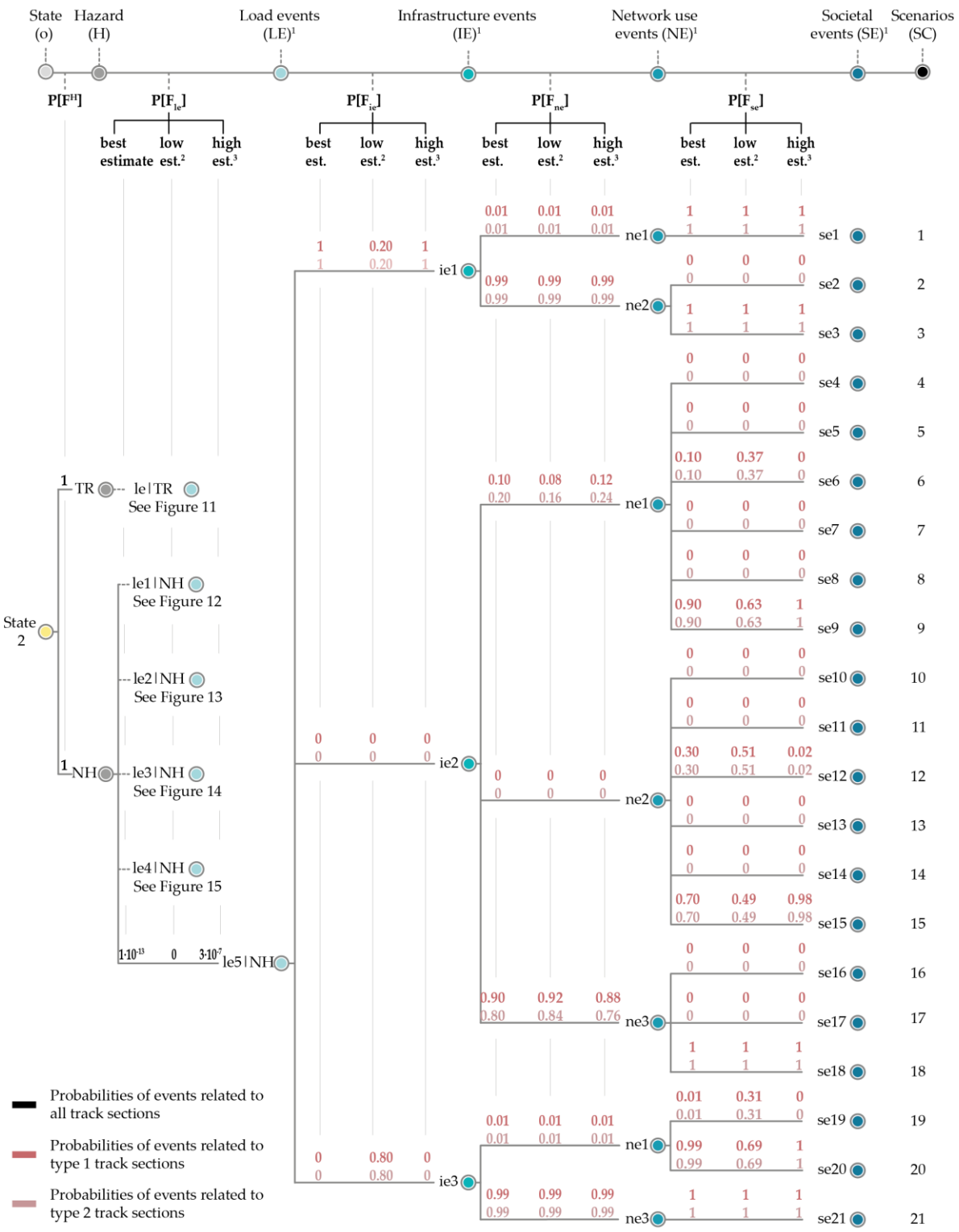
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 14. Event tree and probabilities used for the estimation of risk related to track sections in state 2 due to natural hazard and load event le3.



All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 15. Event tree and probabilities used for the estimation of risk related to track sections in state 2 due to natural hazard and load event le4.



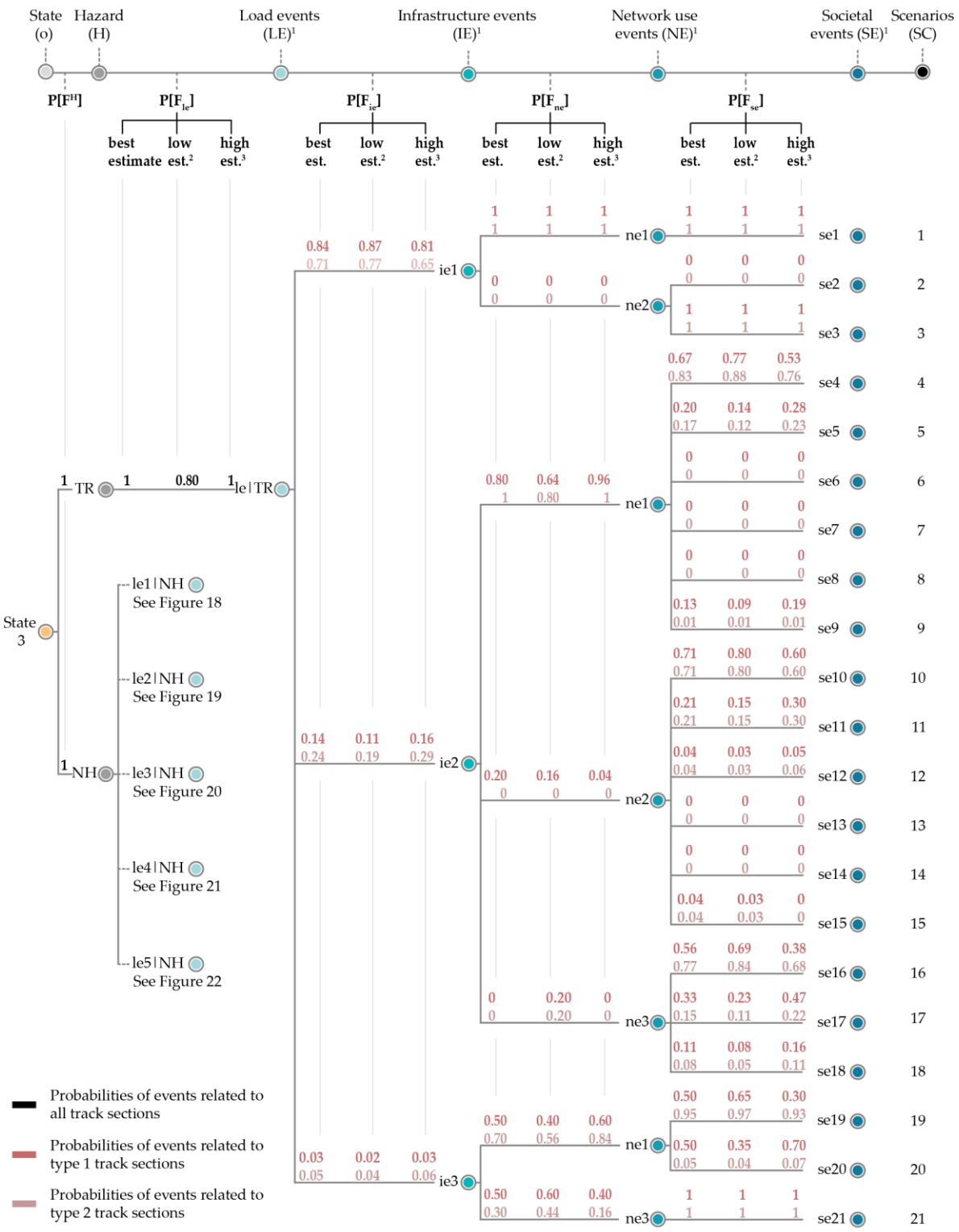
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 16. Event tree and probabilities used for the estimation of risk related to track sections in state 2 due to natural hazard and load event le5.



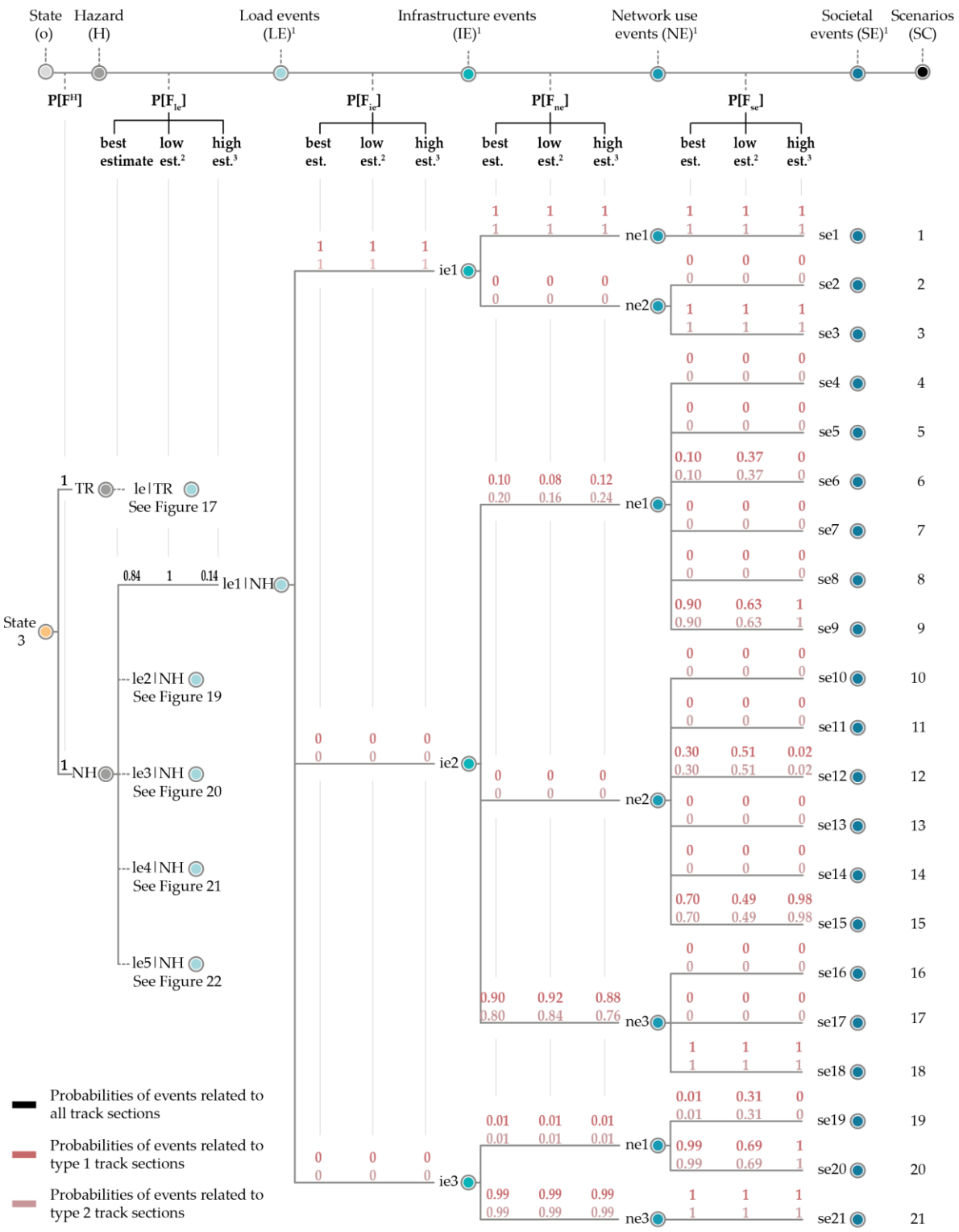
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 17. Event tree and probabilities used for the estimation of risk related to track sections in state 3 due to traffic.



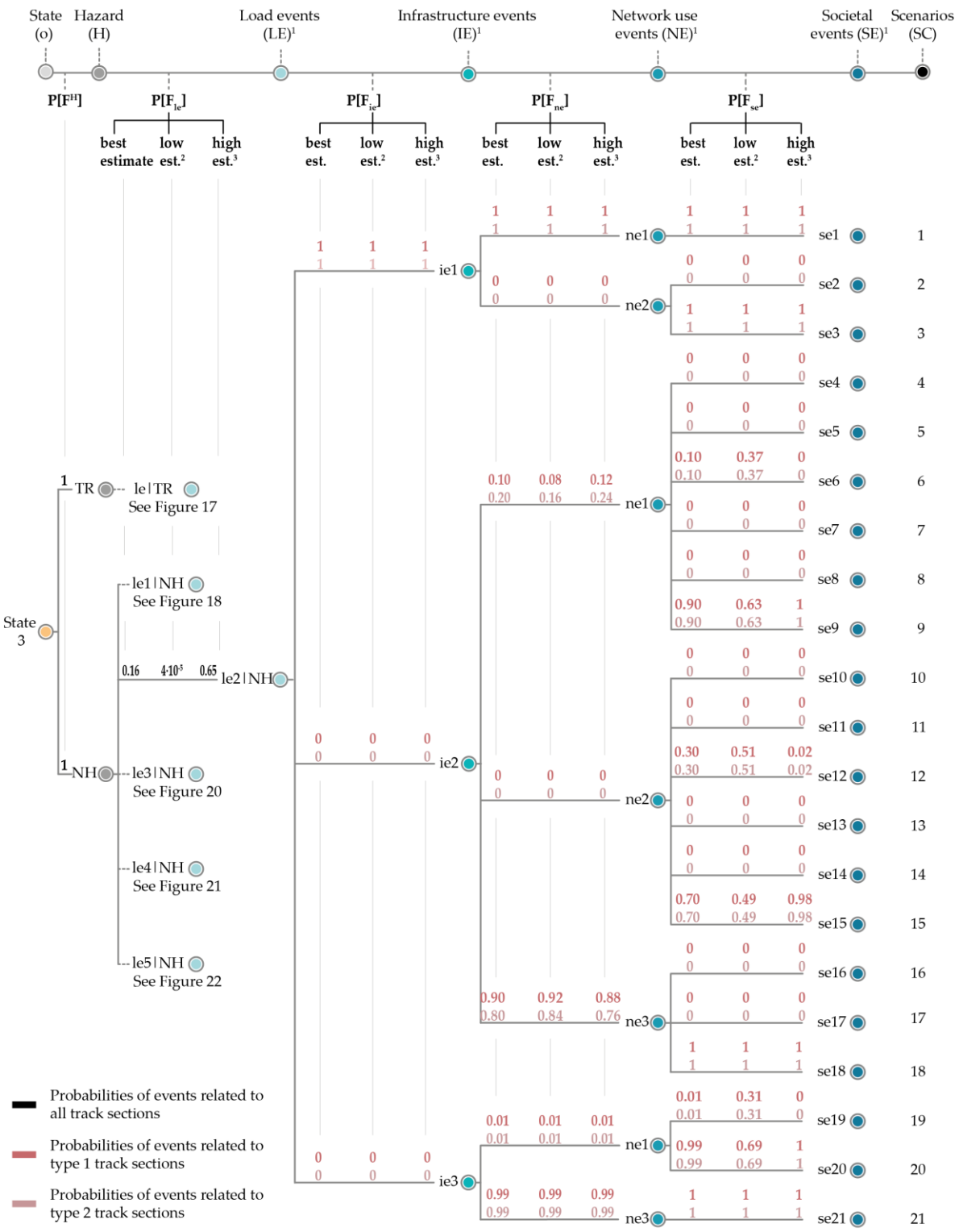
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

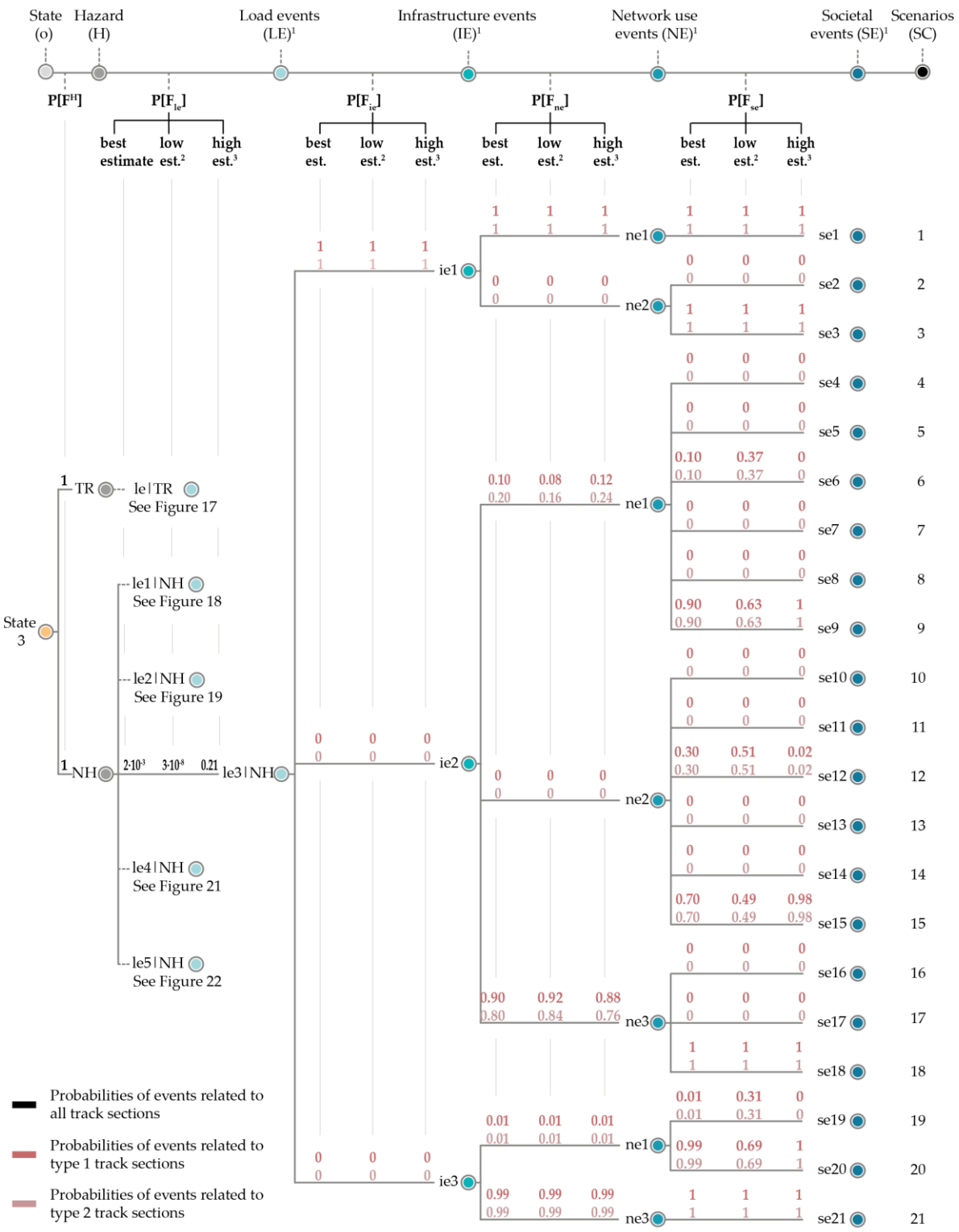
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 18. Event tree and probabilities used for the estimation of risk related to track sections in state 3 due to natural hazard and load event le1.



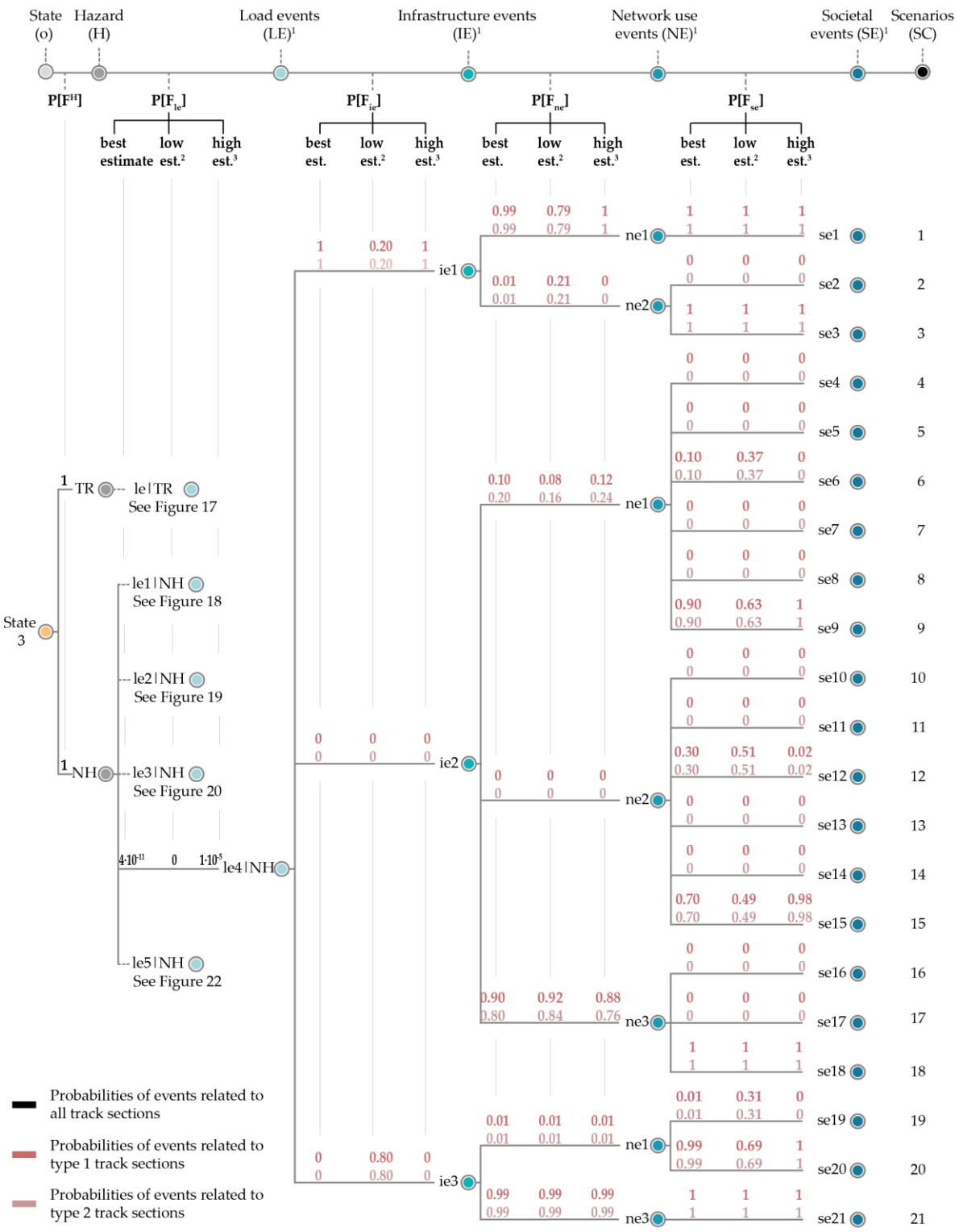
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 19. Event tree and probabilities used for the estimation of risk related to track sections in state 3 due to natural hazard and load event le2.



All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 20. Event tree and probabilities used for the estimation of risk related to track sections in state 3 due to natural hazard and load event le3.



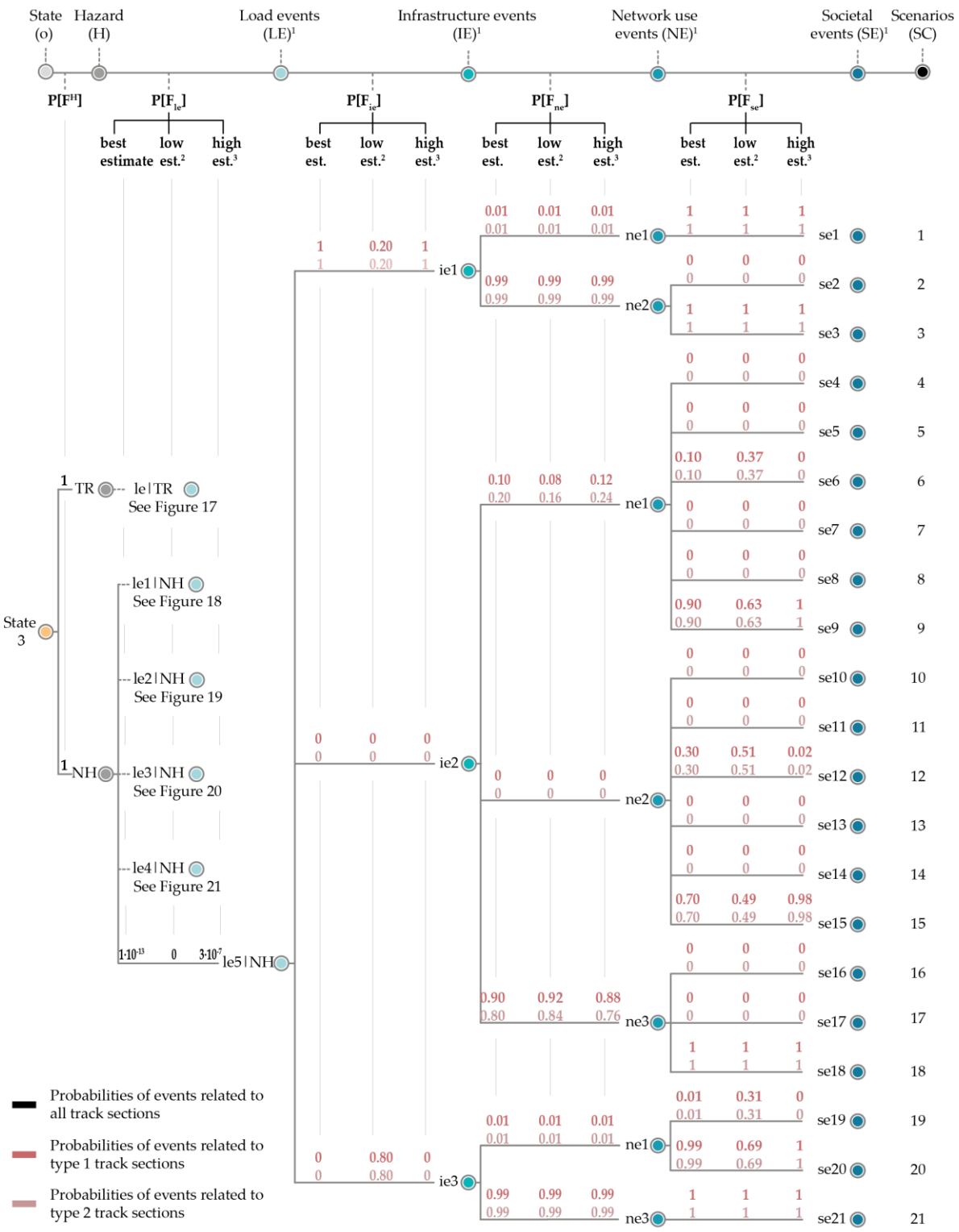
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 21. Event tree and probabilities used for the estimation of risk related to track sections in state 3 due to natural hazard and load event le4.



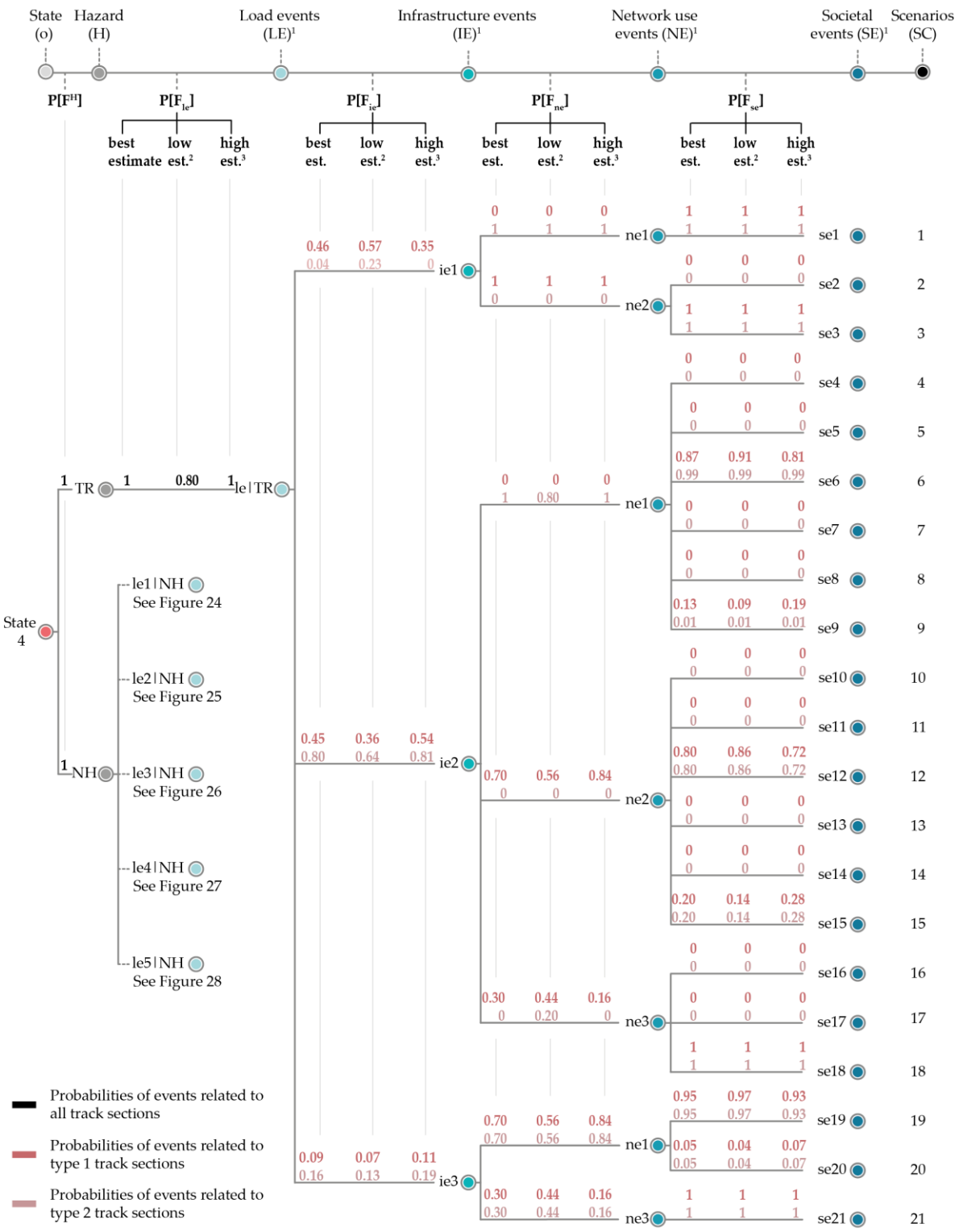
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 22. Event tree and probabilities used for the estimation of risk related to track sections in state 3 due to natural hazard and load event le5.



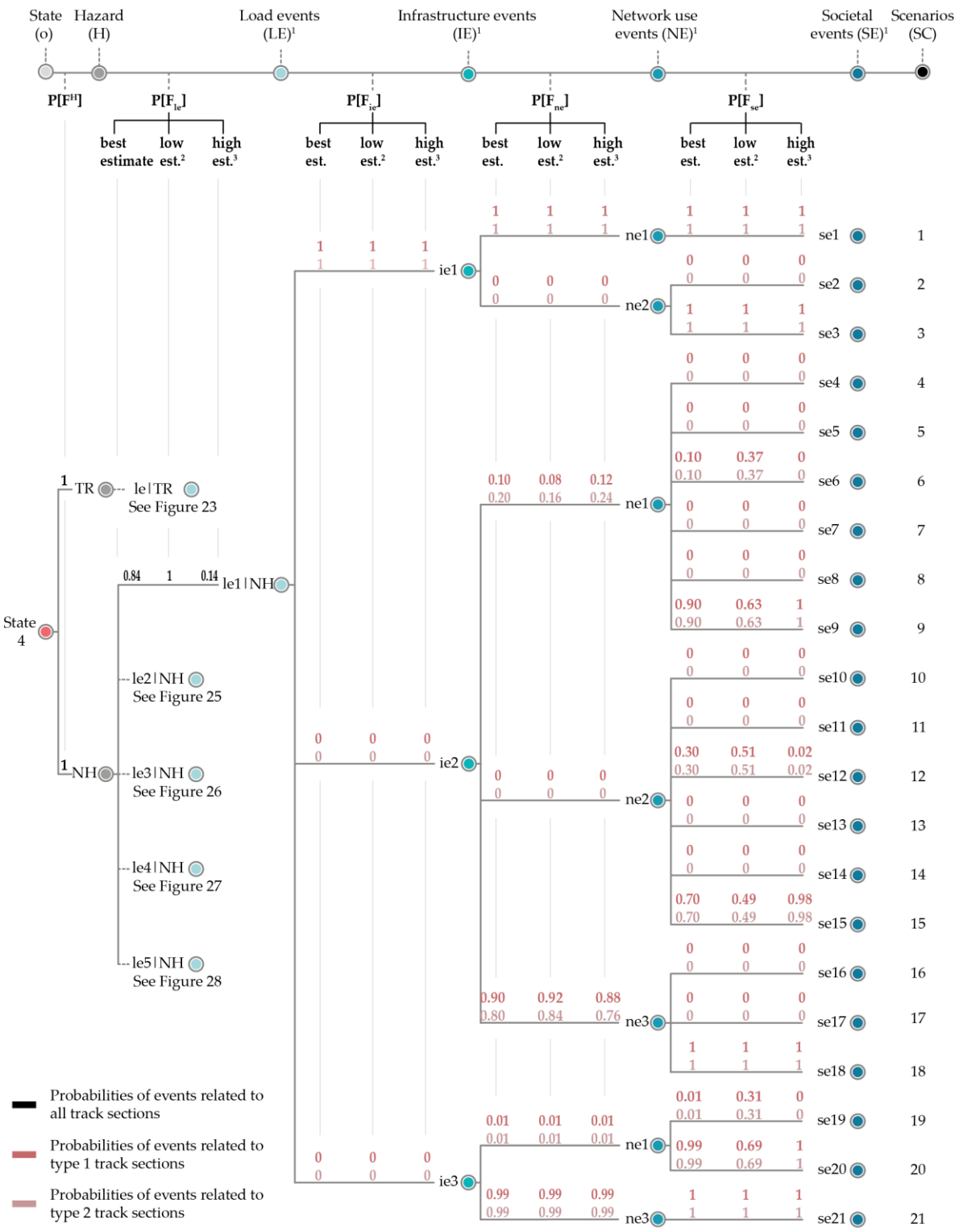
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 23. Event tree and probabilities used for the estimation of risk related to track sections in state 4 due to traffic.



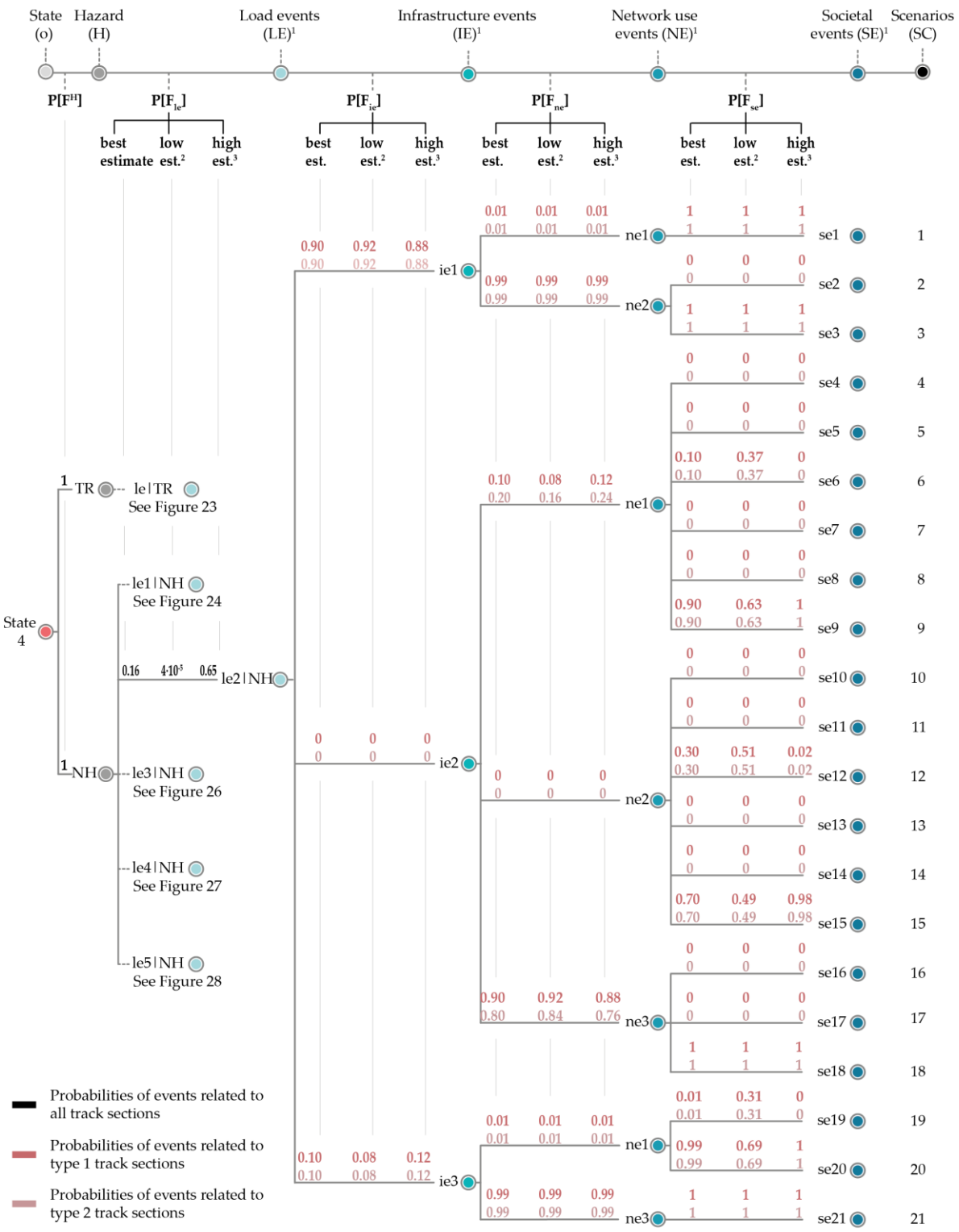
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

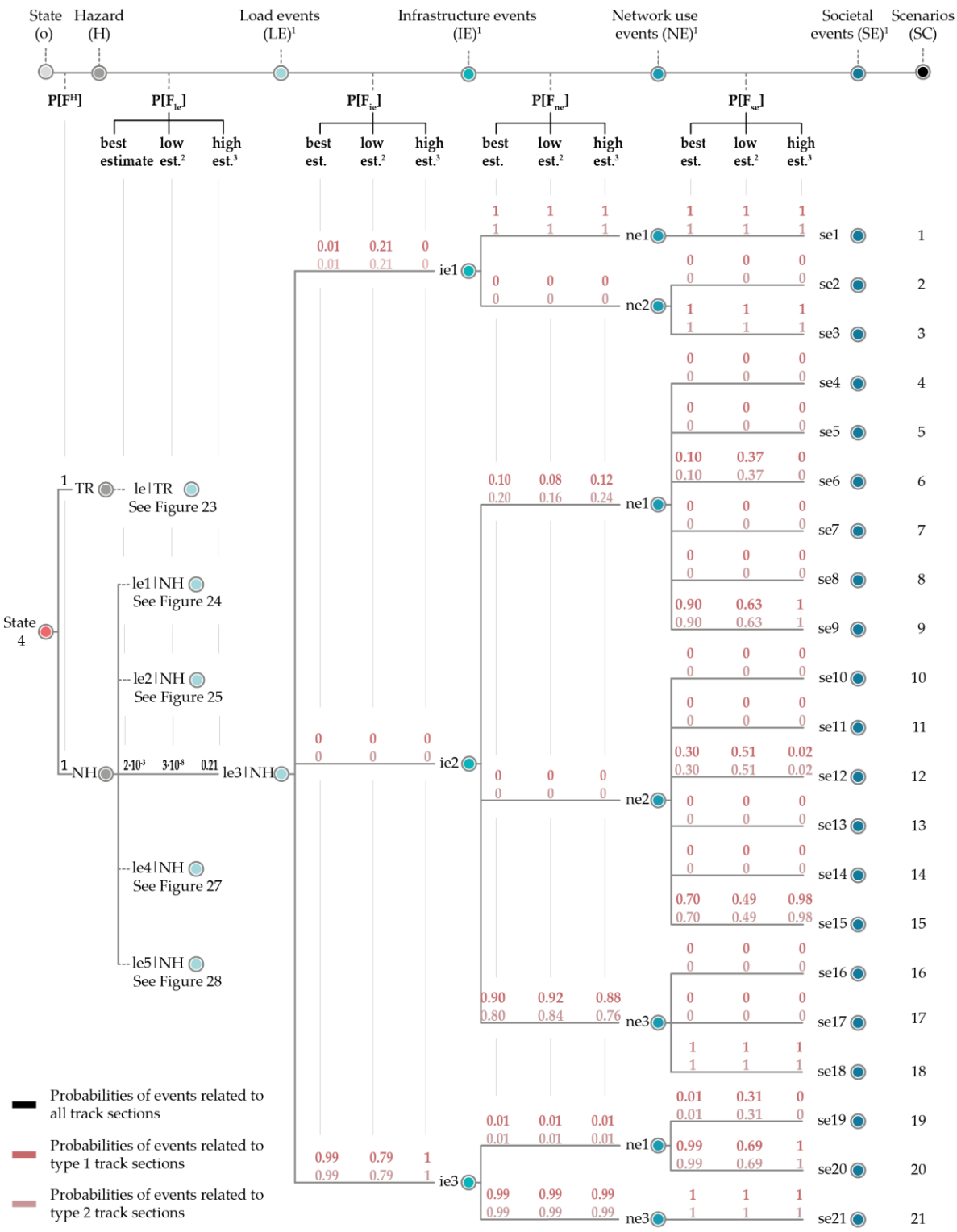
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 24. Event tree and probabilities used for the estimation of risk related to track sections in state 4 due to natural hazard and load event le1.



All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.
[1] See Tables 6 - 10 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 25. Event tree and probabilities used for the estimation of risk related to track sections in state 4 due to natural hazard and load event le2.



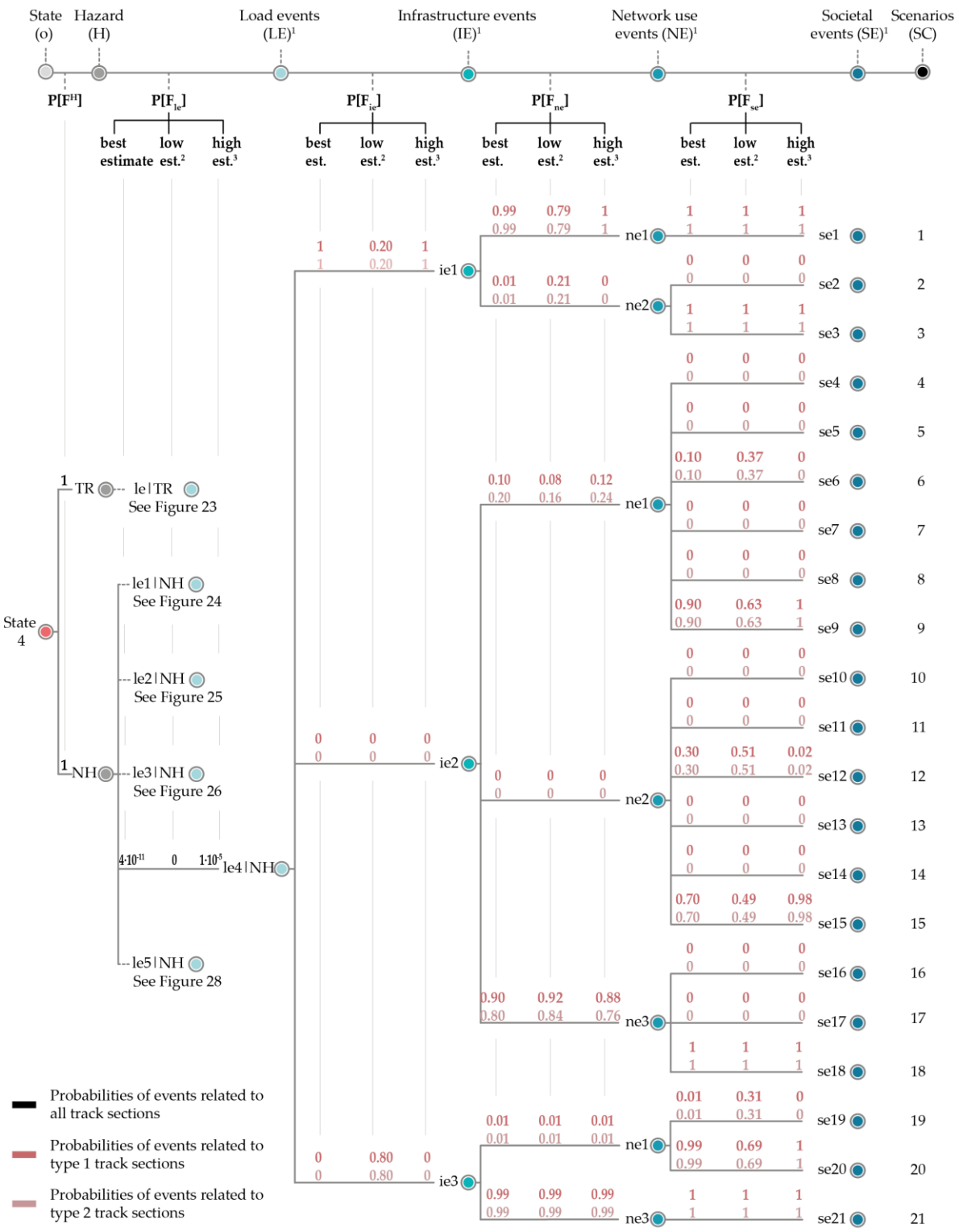
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 26. Event tree and probabilities used for the estimation of risk related to track sections in state 4 due to natural hazard and load event le3.



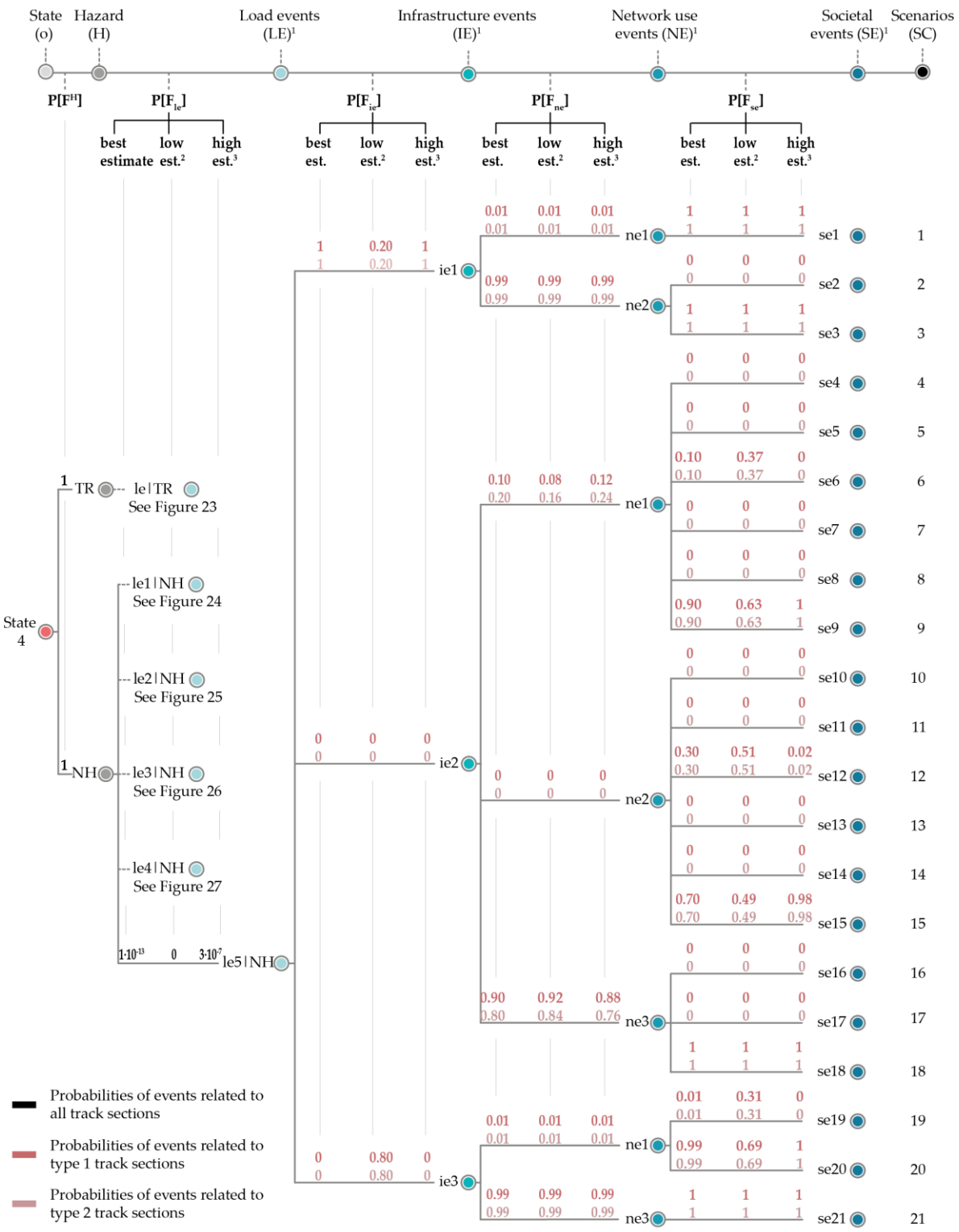
All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 27. Event tree and probabilities used for the estimation of risk related to track sections in state 4 due to natural hazard and load event le4.



All the probabilities shown have been rounded, and therefore, their sum might not be equal to one.

[1] See Tables 6 - 10 for the description of the events.

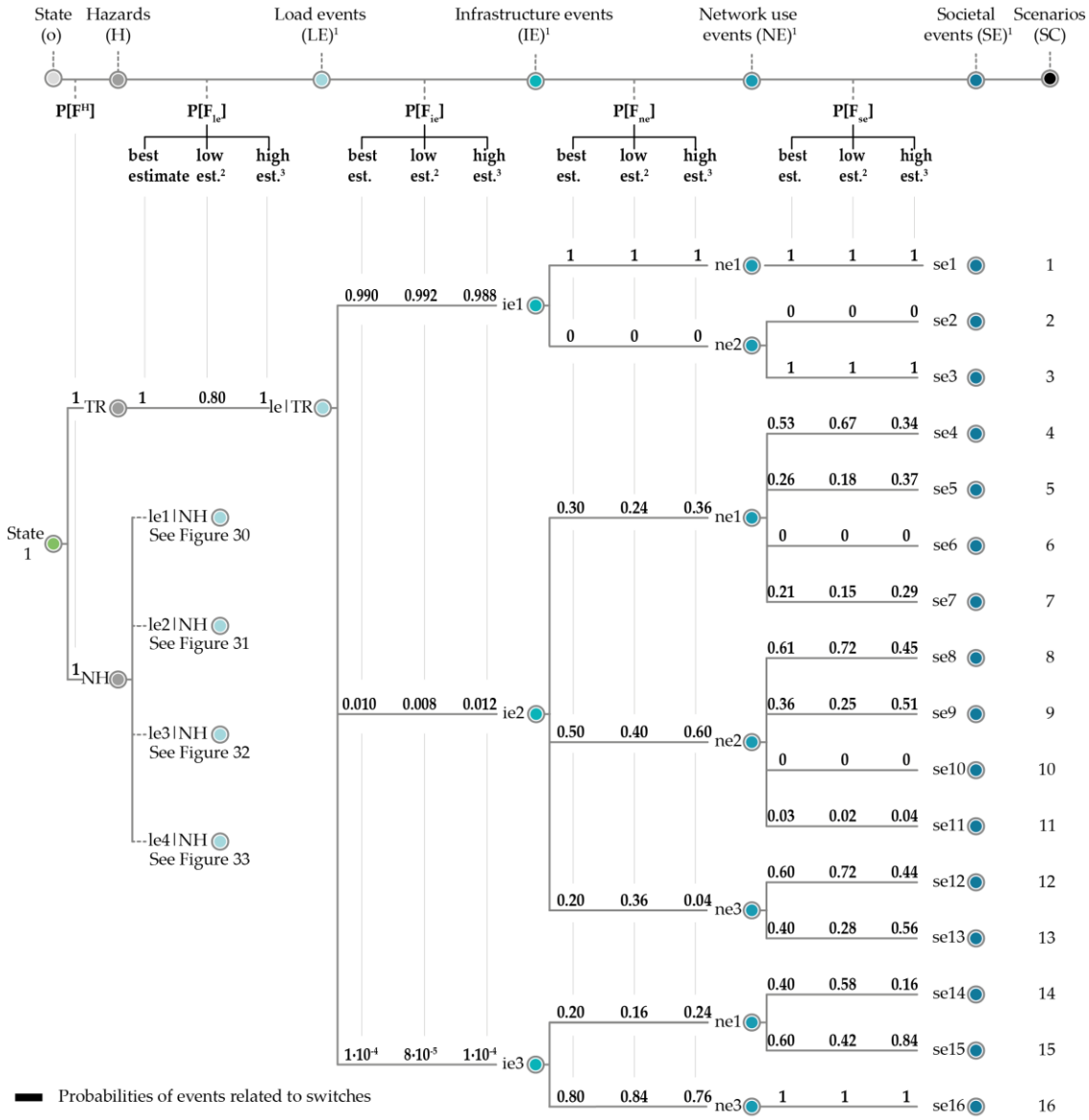
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 28. Event tree and probabilities used for the estimation of risk related to track sections in state 4 due to natural hazard and load event le5.

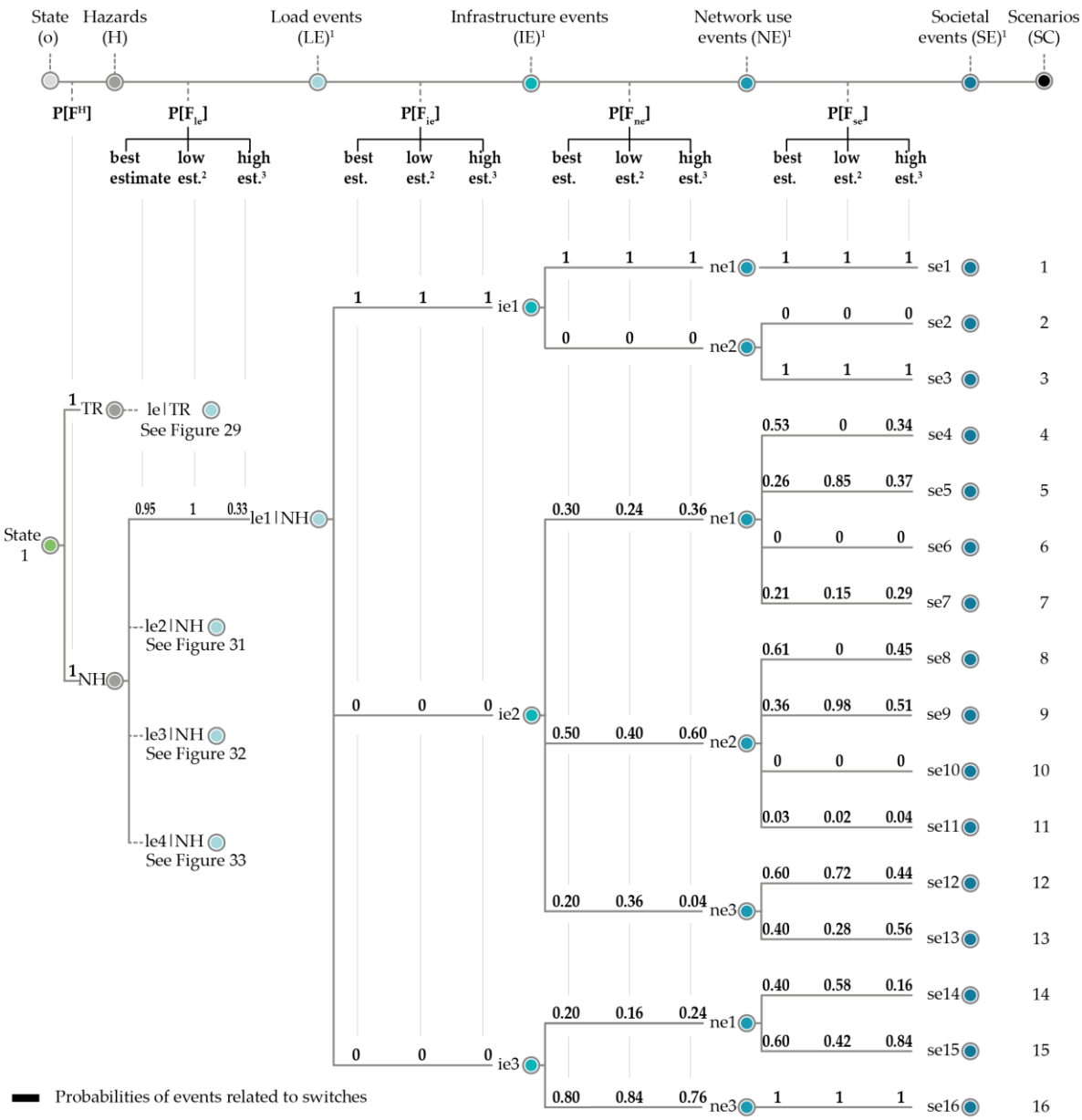
6.2.2. Switches

Figures 29-48 depict the event trees and the estimates of event probabilities used for the estimation of risk related to switches.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 29. Event tree and probabilities used for the estimation of risk related to switches in state 1 due to traffic.



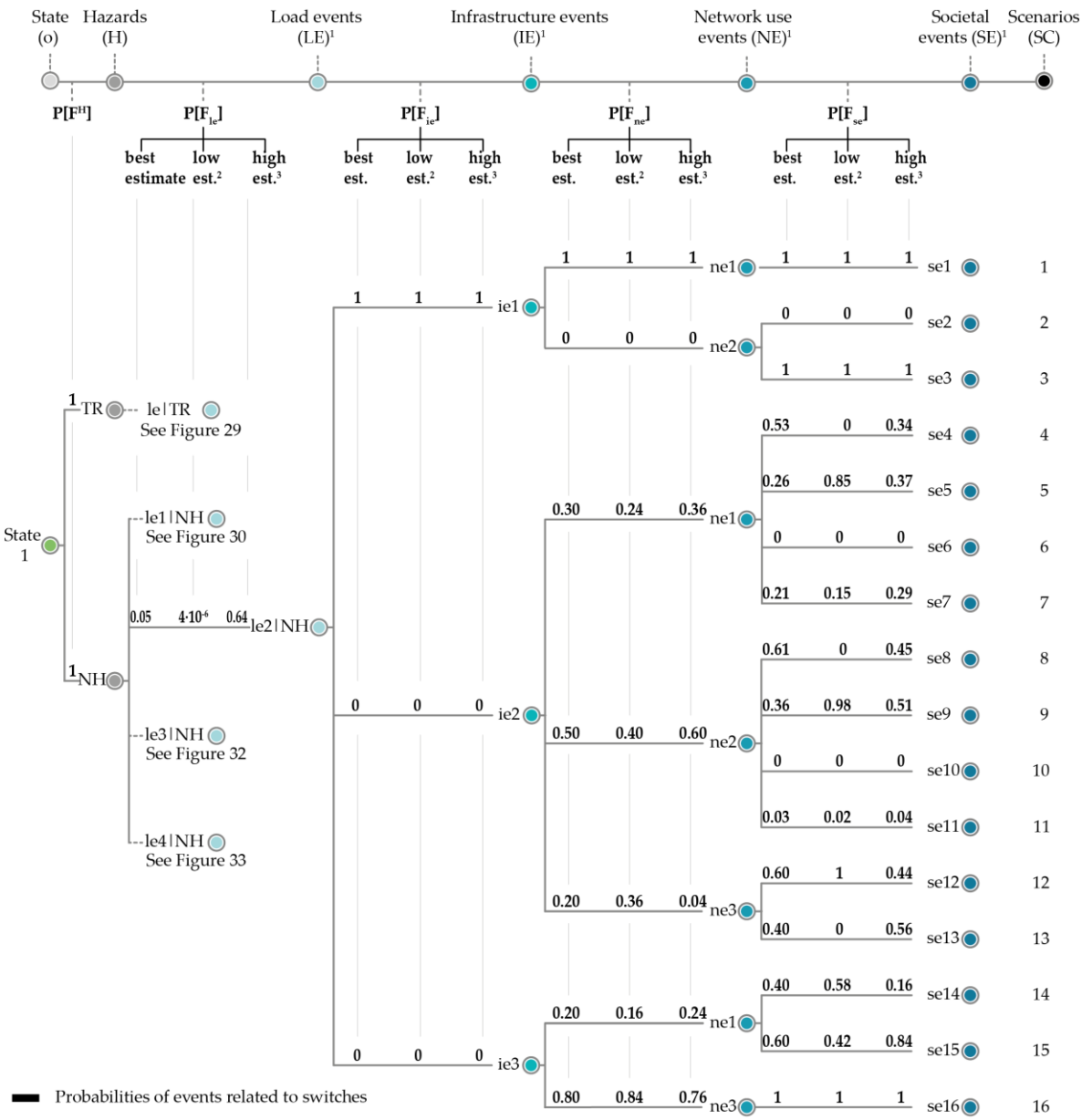
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 11 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

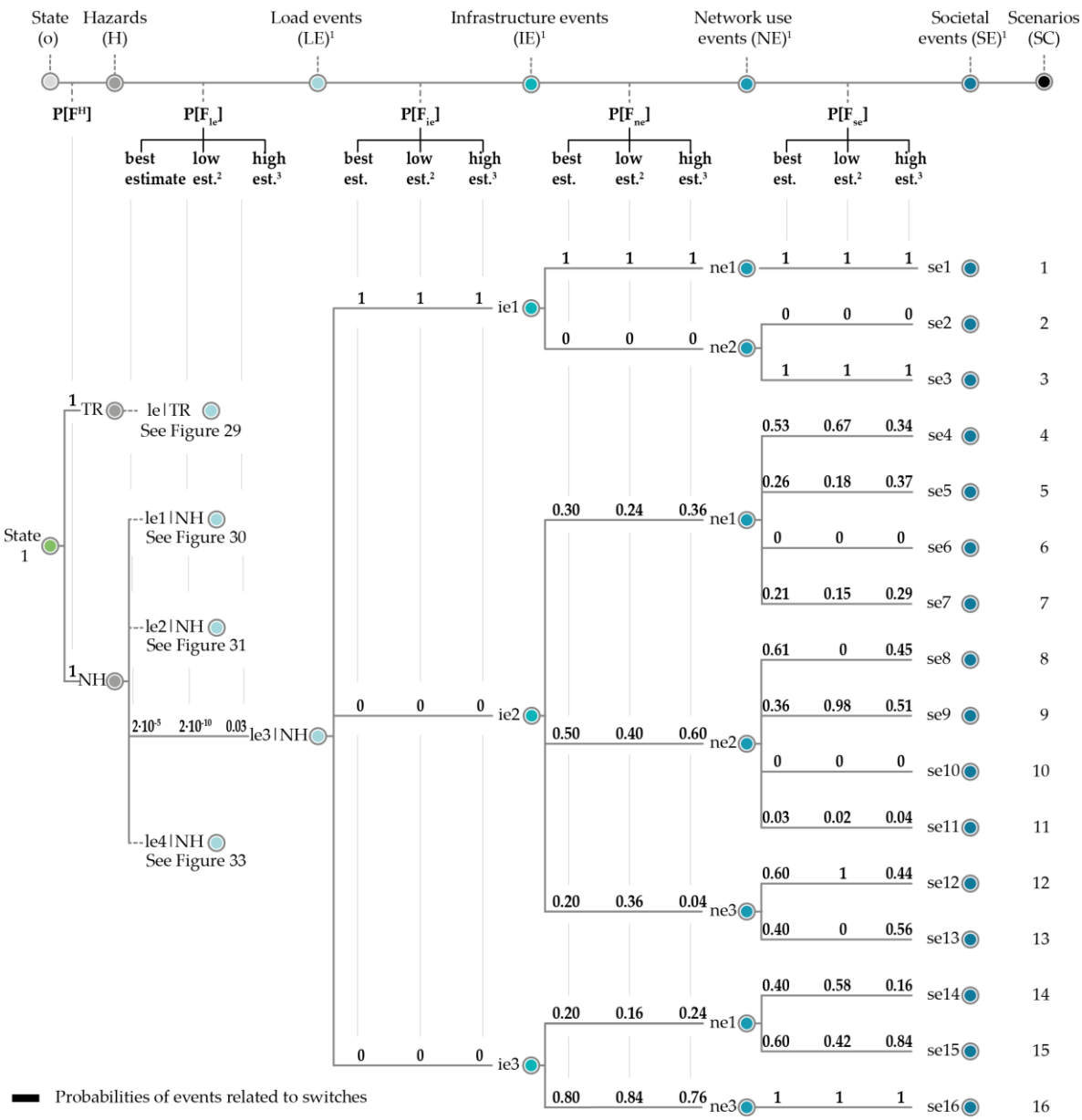
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 30. Event tree and probabilities used for the estimation of risk related to switches in state 1 due to natural hazard and load event le1.



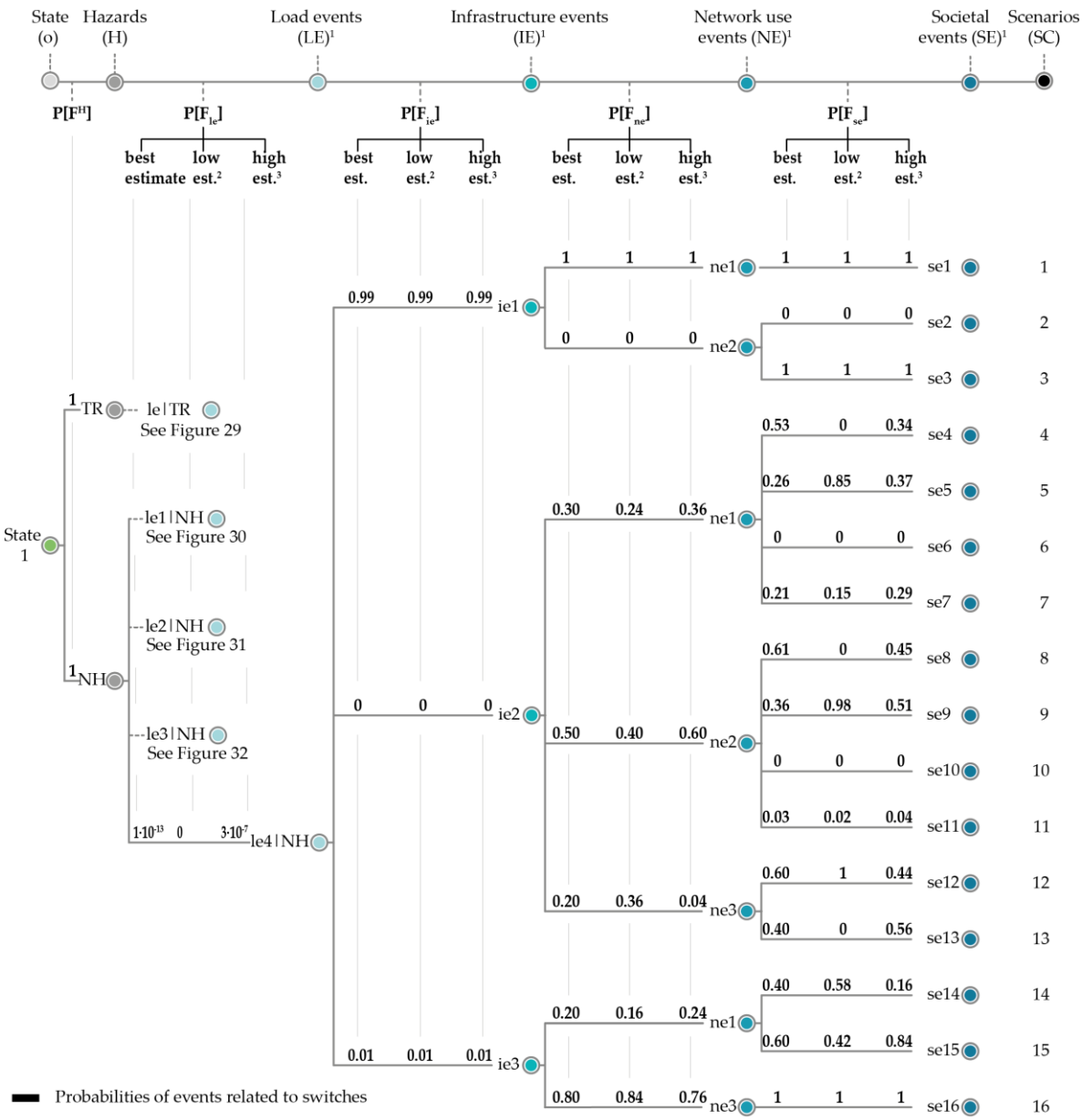
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 31. Event tree and probabilities used for the estimation of risk related to switches in state 1 due to natural hazard and load event le2.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 32. Event tree and probabilities used for the estimation of risk related to switches in state 1 due to natural hazard and load event le3.



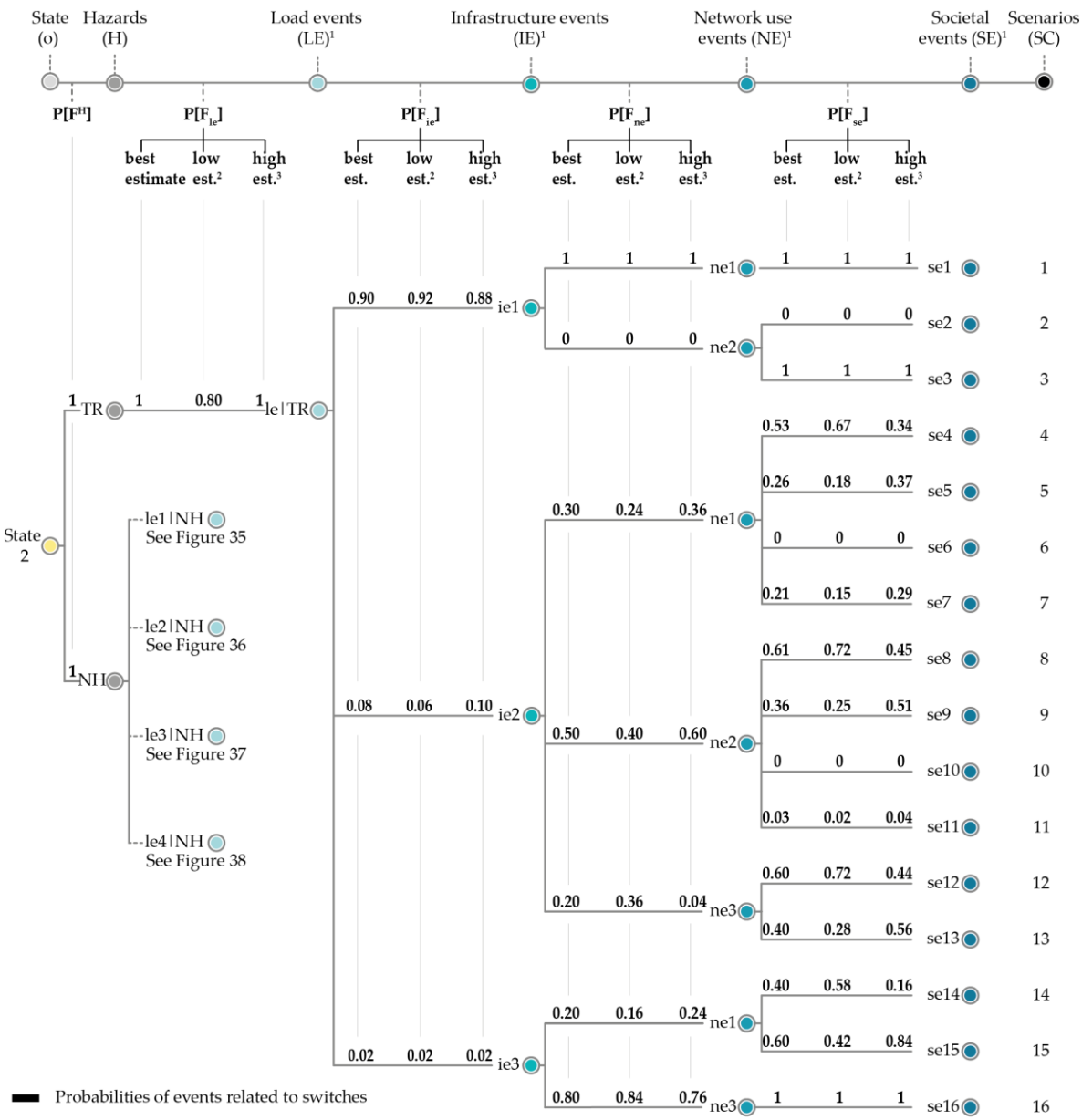
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 11 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

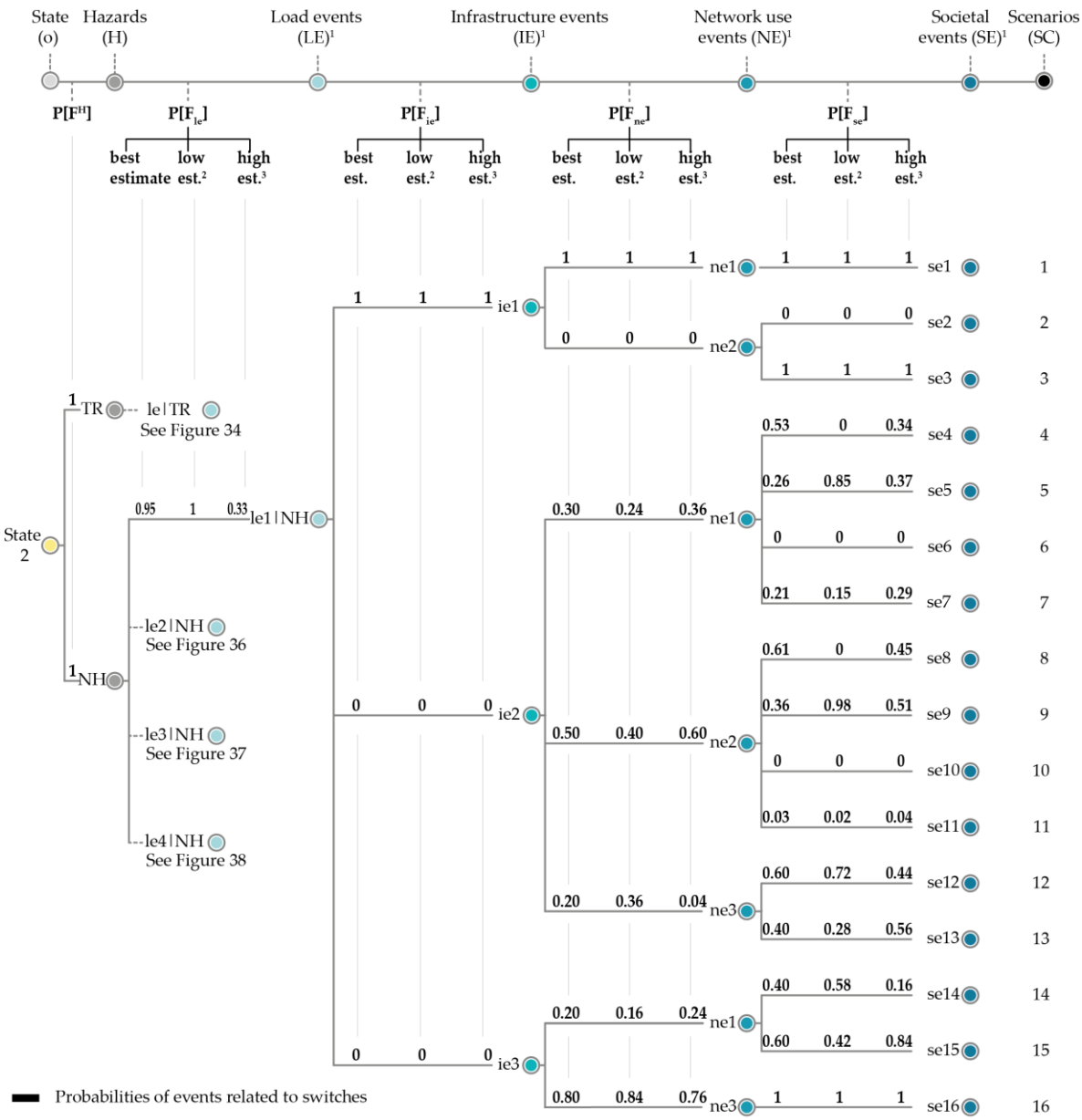
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 33. Event tree and probabilities used for the estimation of risk related to switches in state 1 due to natural hazard and load event le4.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 34. Event tree and probabilities used for the estimation of risk related to switches in state 2 due to traffic.



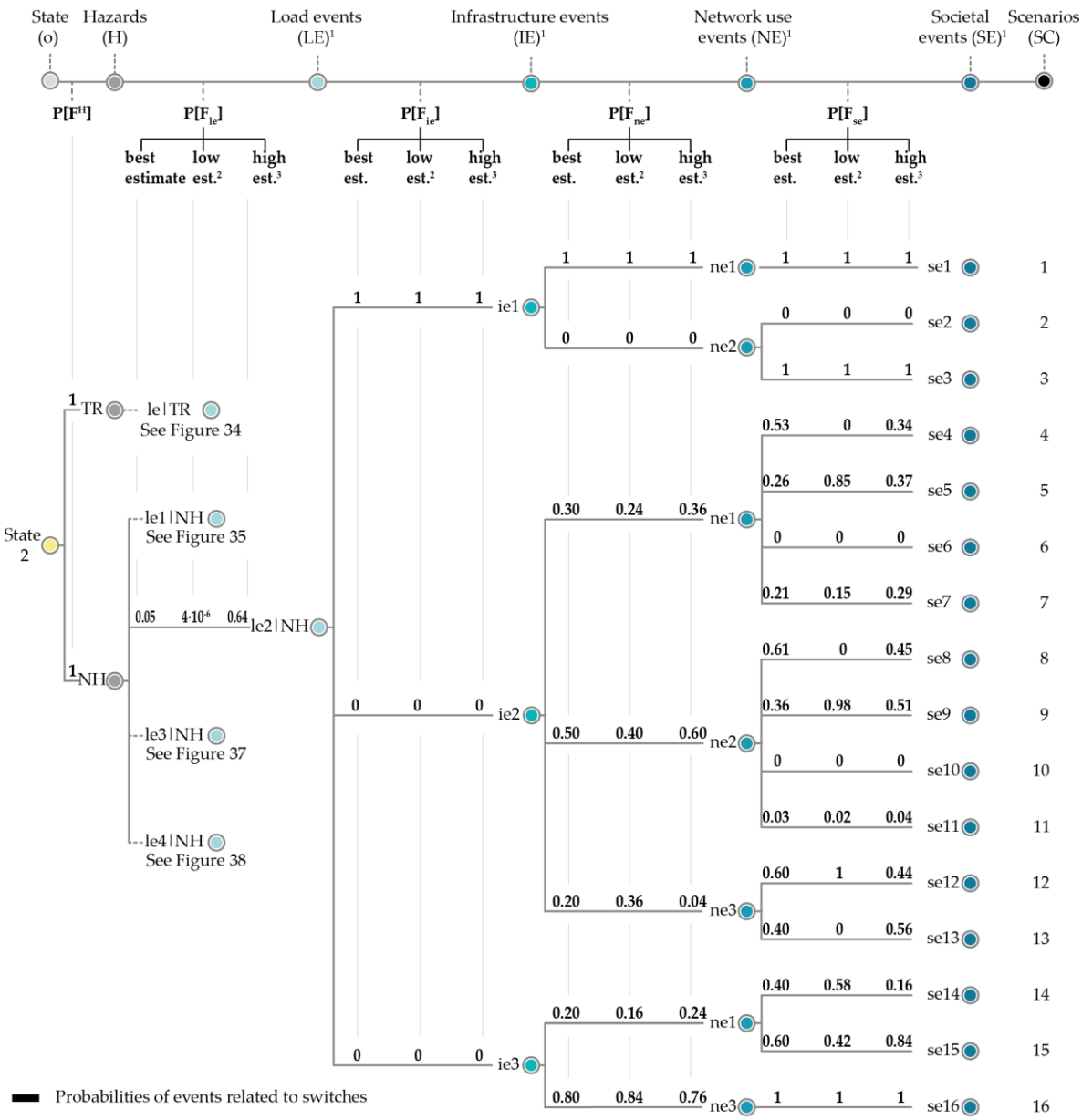
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 11 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 35. Event tree and probabilities used for the estimation of risk related to switches in state 2 due to natural hazard and load event le1.



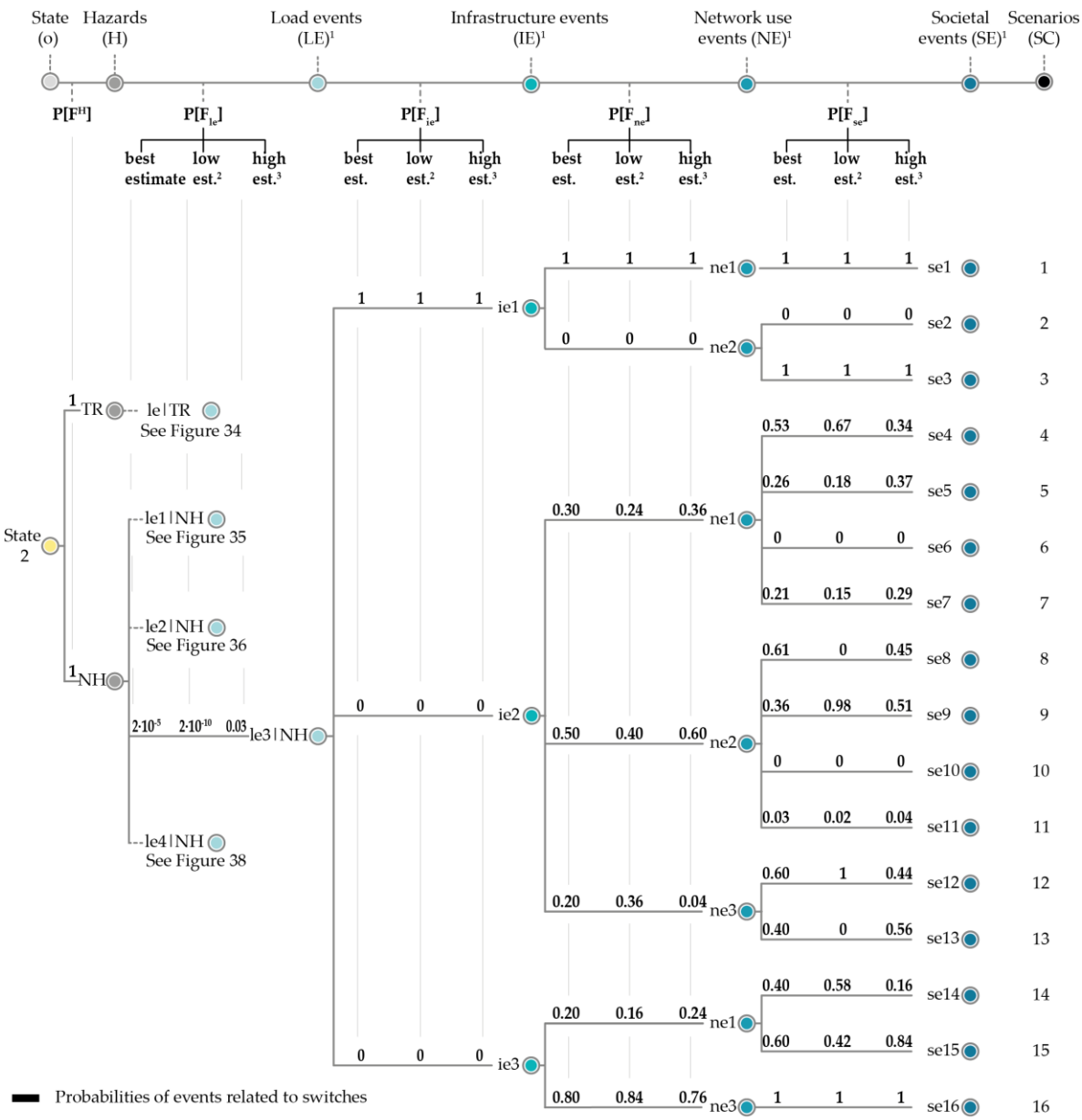
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 11 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

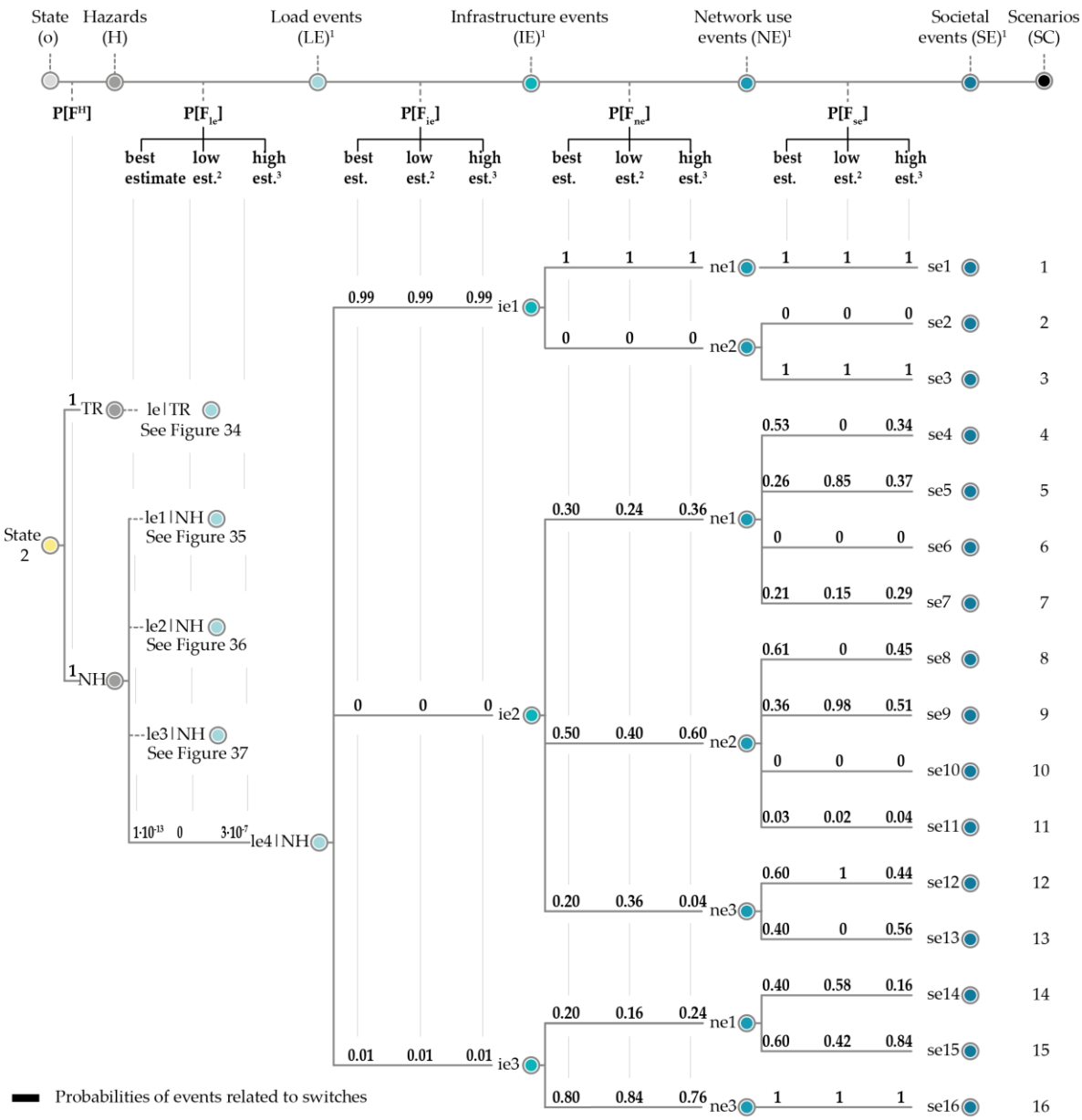
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 36. Event tree and probabilities used for the estimation of risk related to switches in state 2 due to natural hazard and load event le2.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 37. Event tree and probabilities used for the estimation of risk related to switches in state 2 due to natural hazard and load event le3.



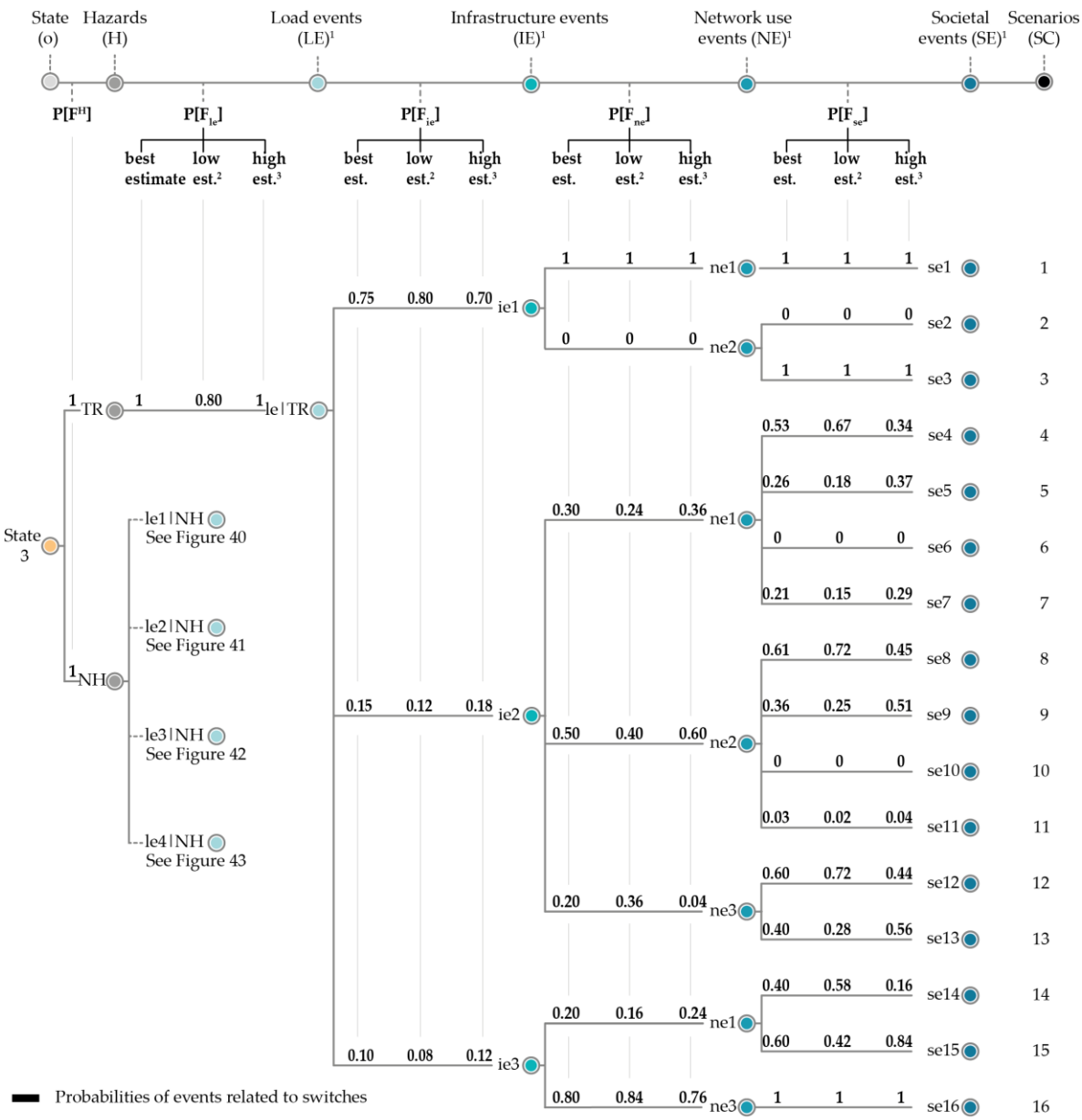
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 11 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

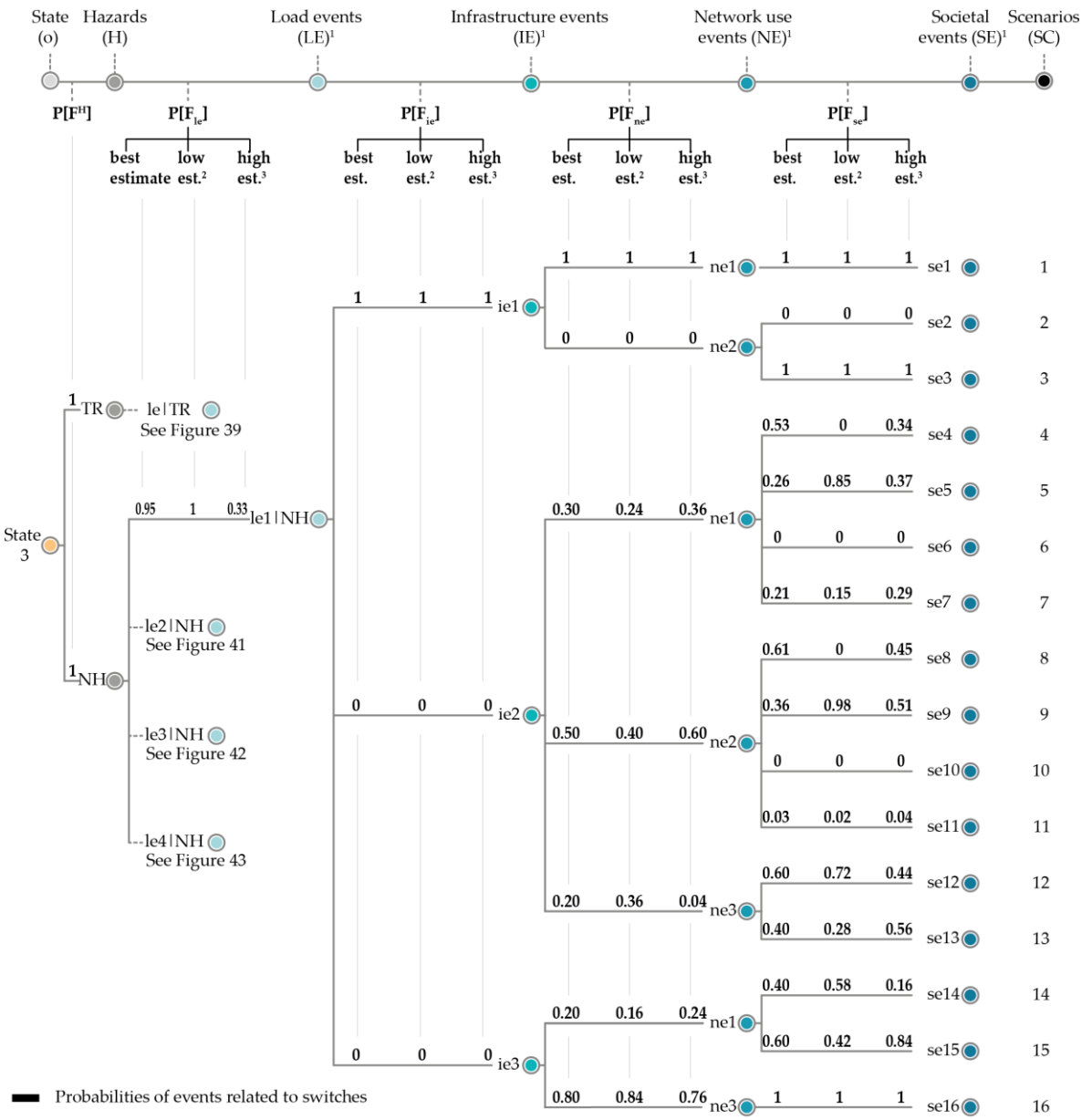
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 38. Event tree and probabilities used for the estimation of risk related to switches in state 2 due to natural hazard and load event le4.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 39. Event tree and probabilities used for the estimation of risk related to switches in state 3 due to traffic.



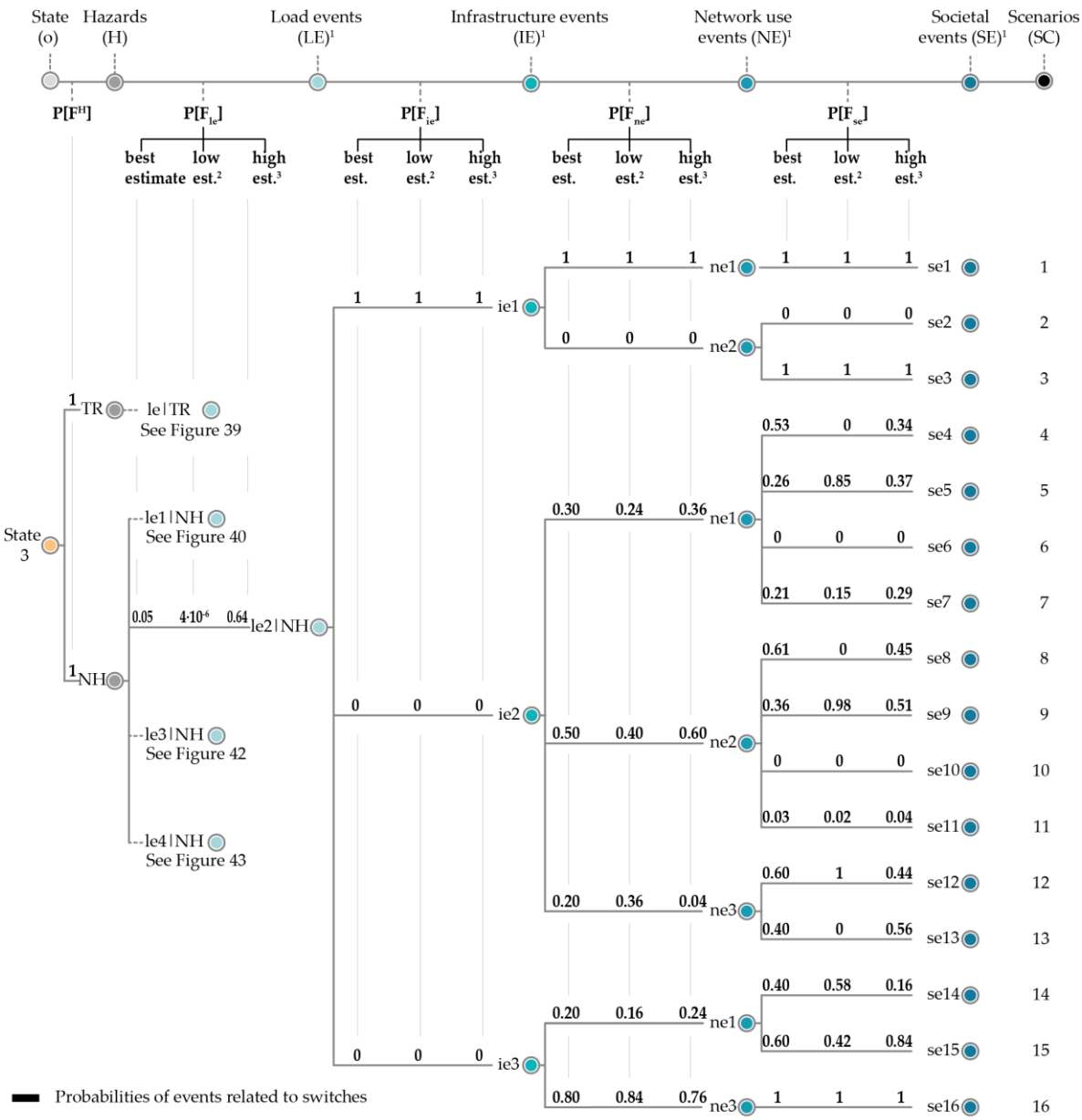
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 11 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

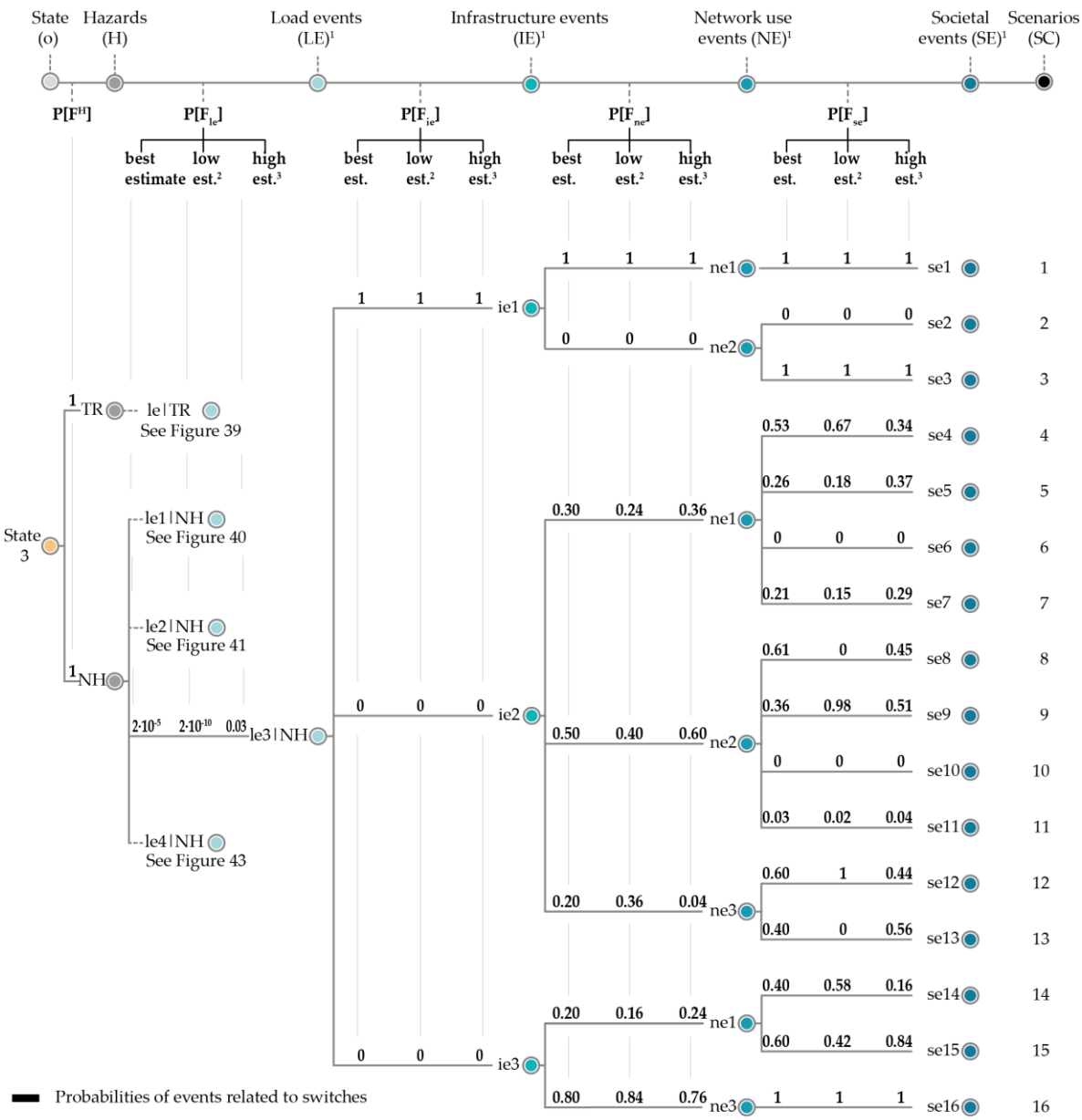
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 40. Event tree and probabilities used for the estimation of risk related to switches in state 3 due to natural hazard and load event le1.



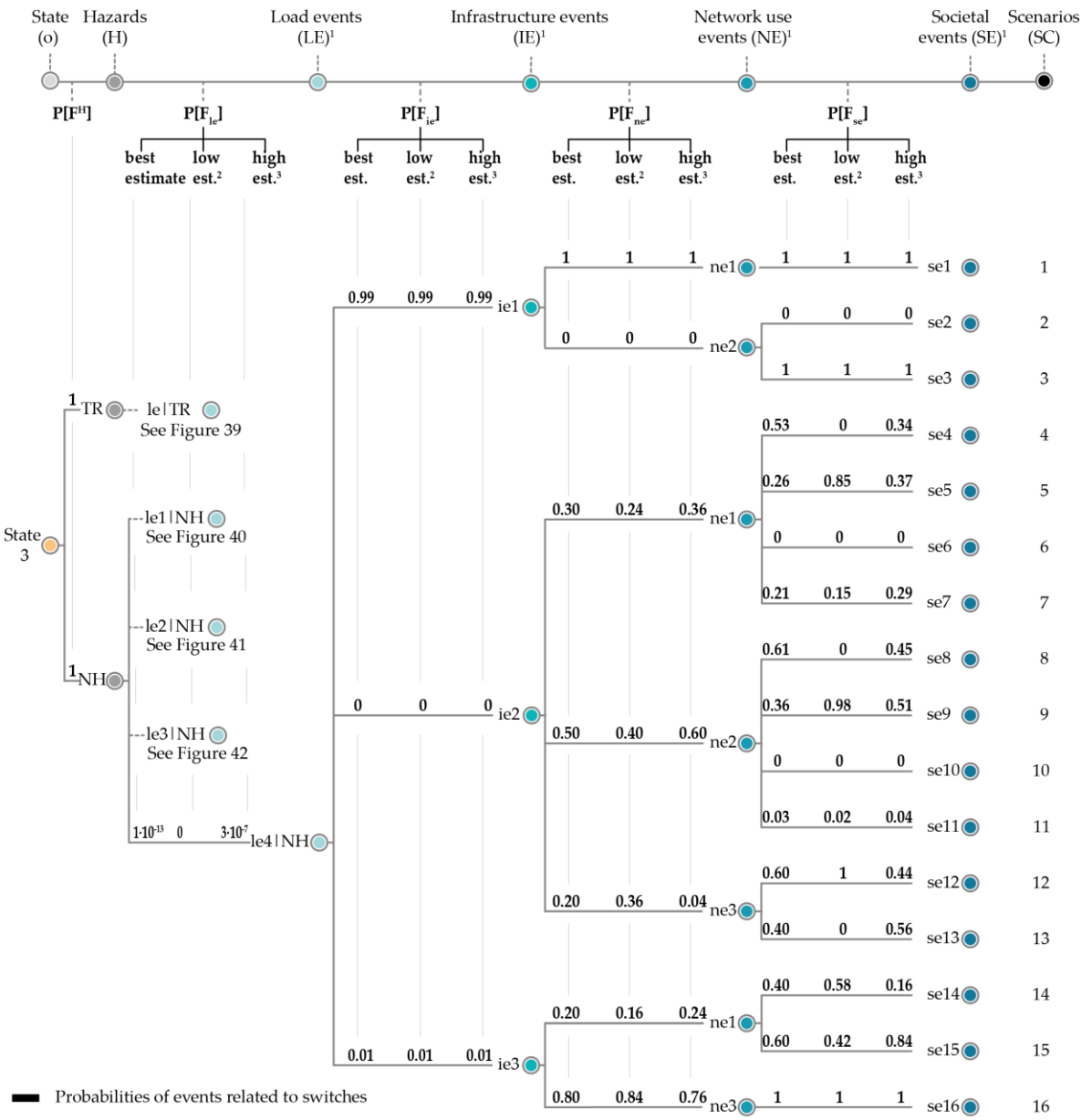
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 41. Event tree and probabilities used for the estimation of risk related to switches in state 3 due to natural hazard and load event le2.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 42. Event tree and probabilities used for the estimation of risk related to switches in state 3 due to natural hazard and load event le3.



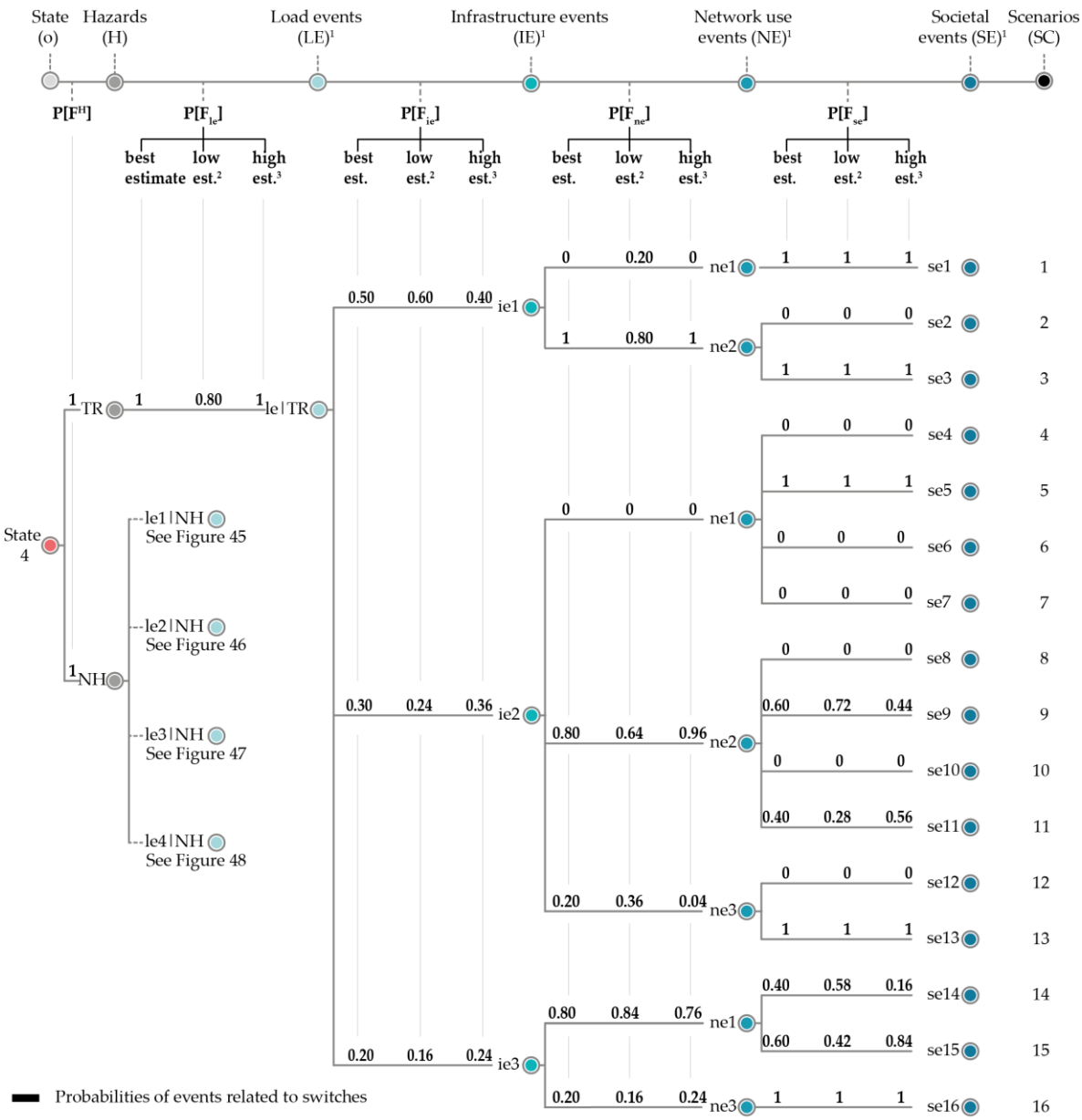
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 11 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

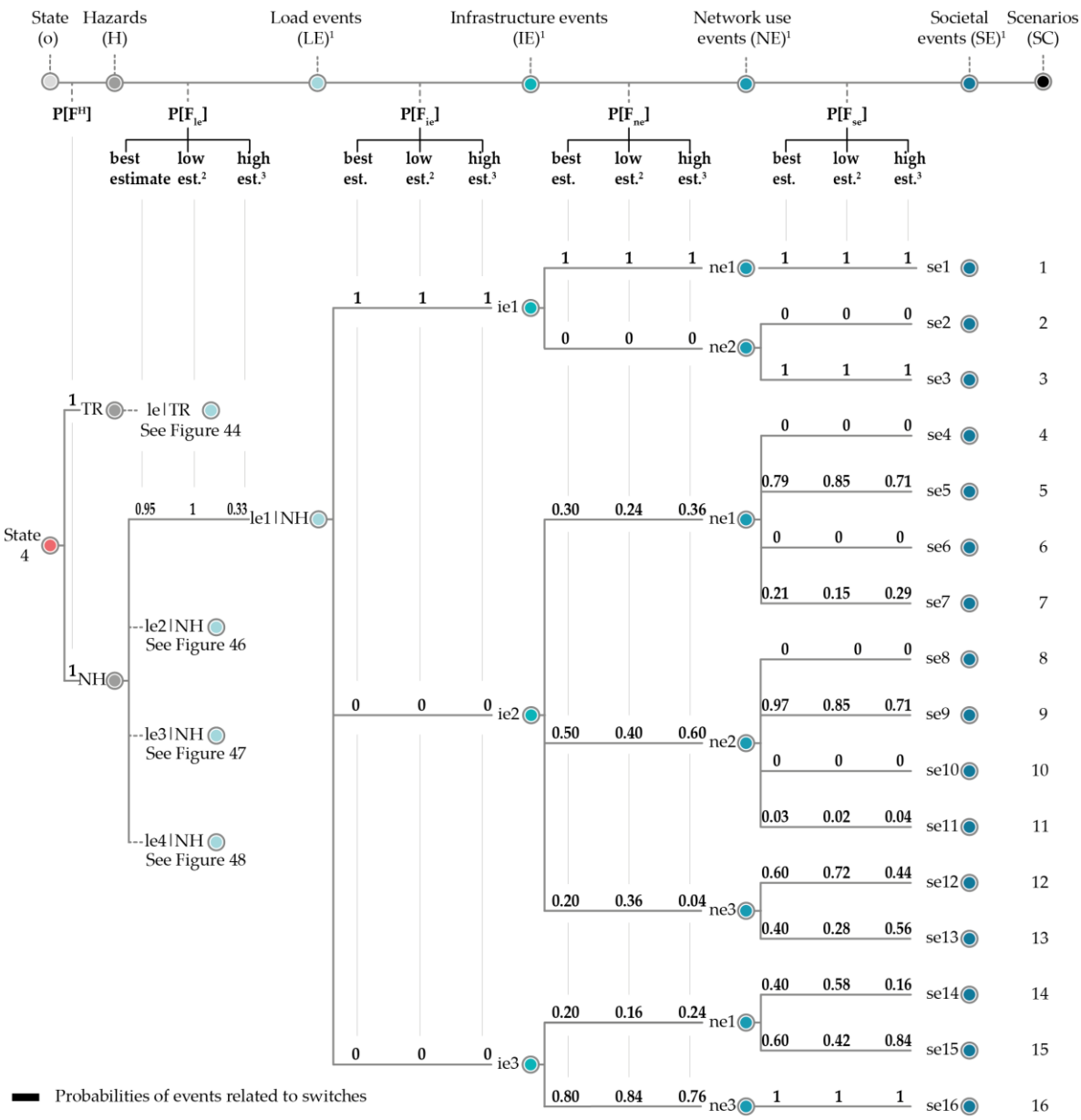
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 43. Event tree and probabilities used for the estimation of risk related to switches in state 3 due to natural hazard and load event le4.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 44. Event tree and probabilities used for the estimation of risk related to switches in state 4 due to traffic.



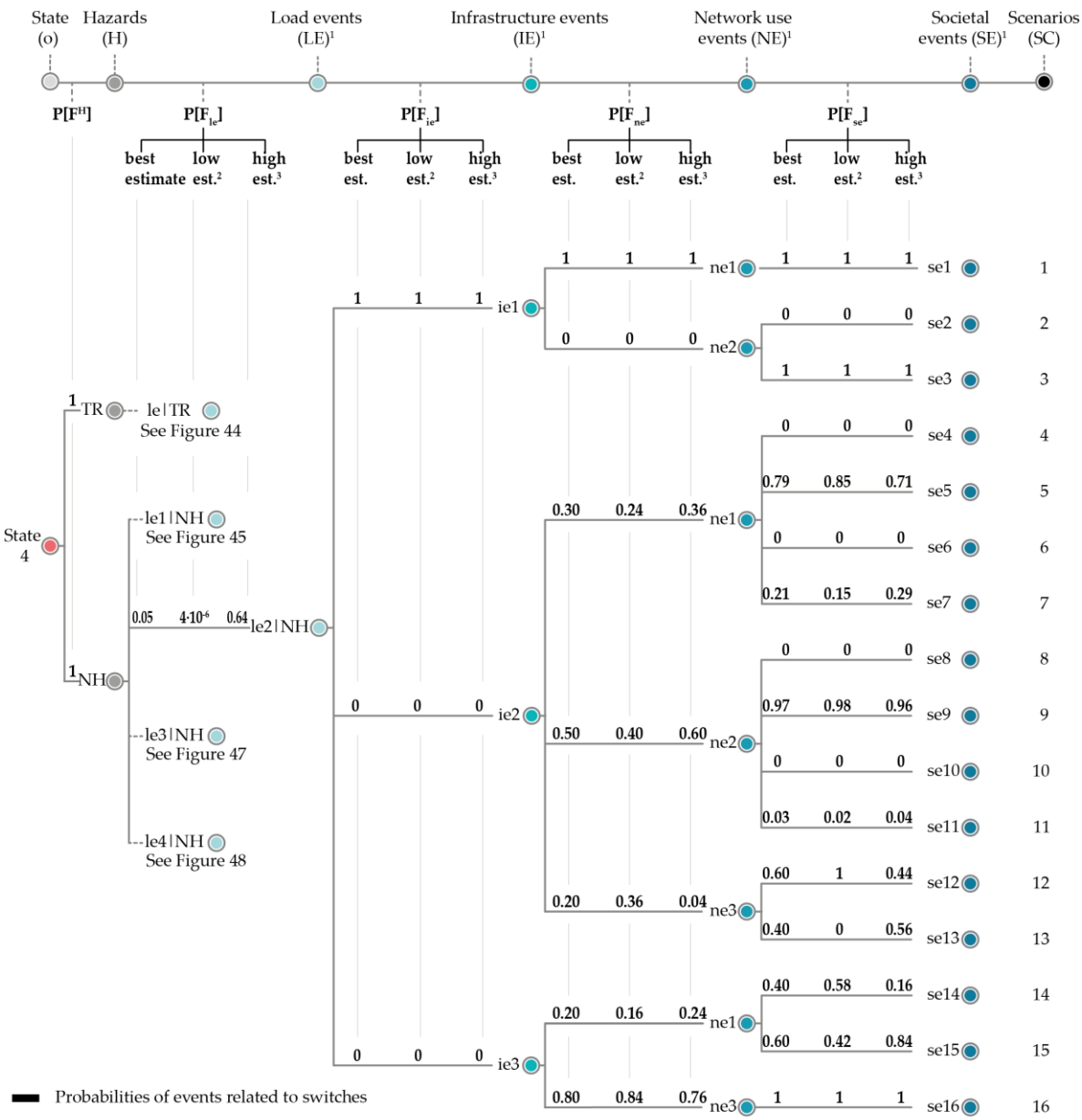
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 11 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

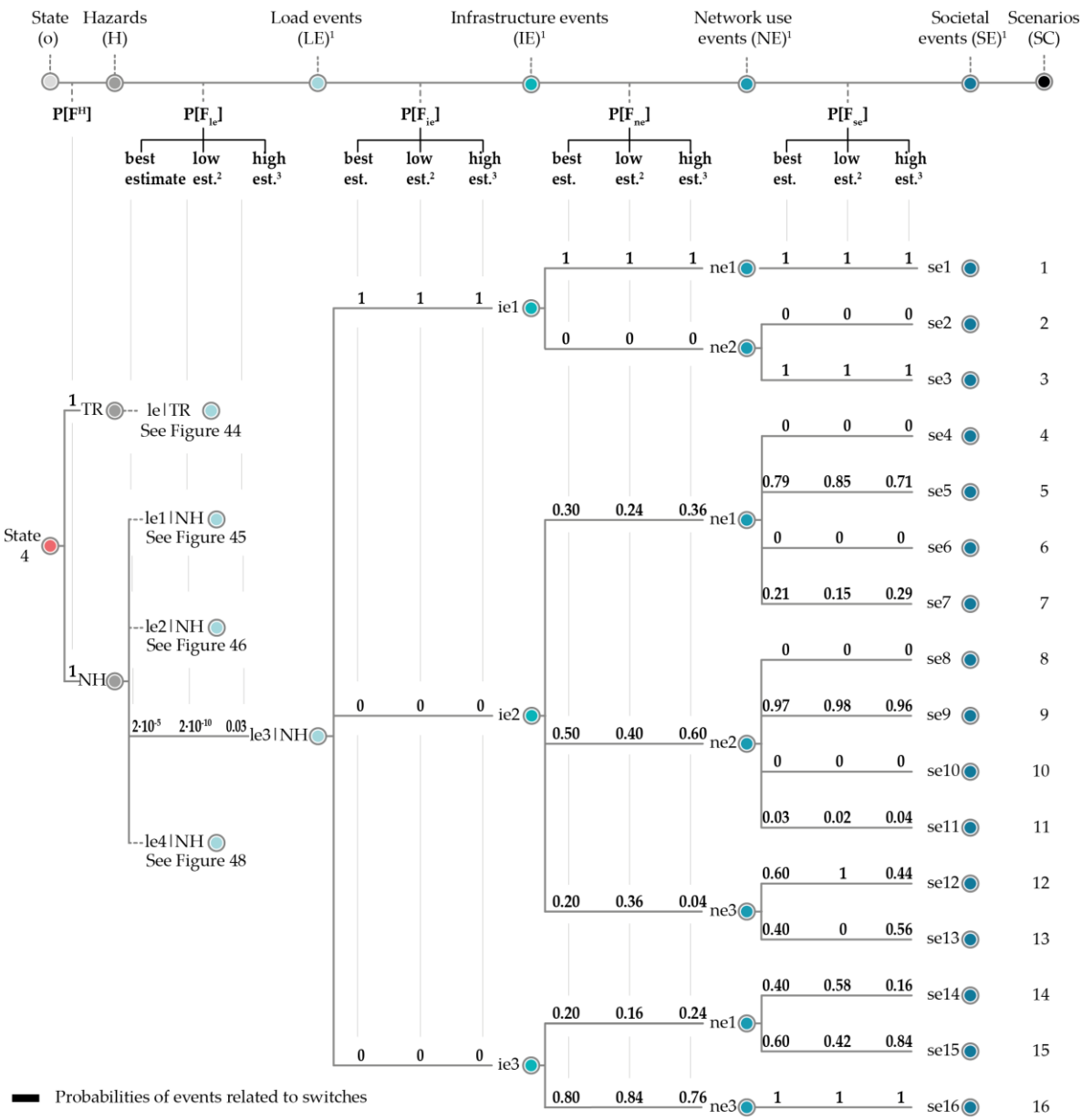
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 45. Event tree and probabilities used for the estimation of risk related to switches in state4 due to natural hazard and load event le1.



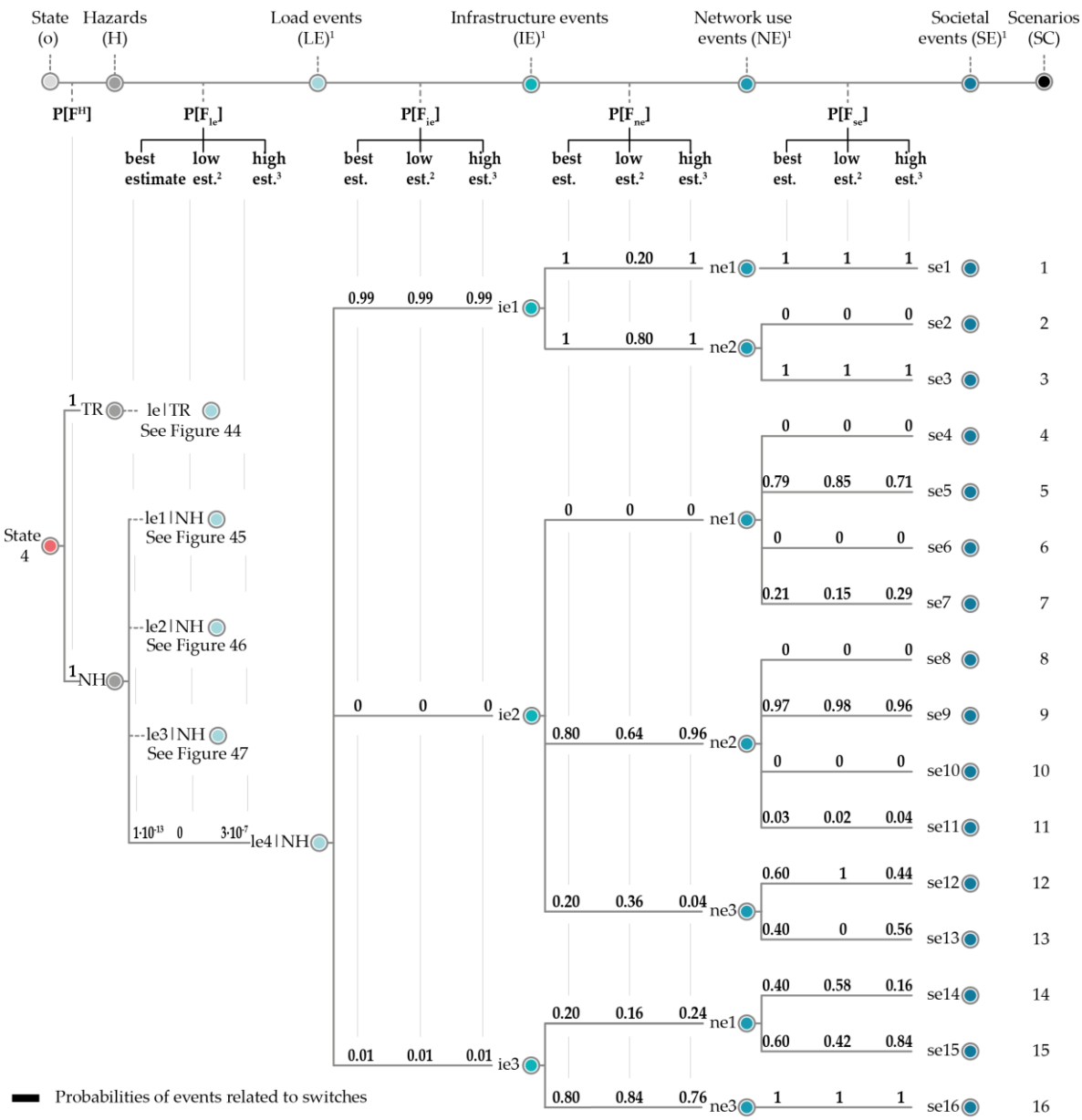
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 46. Event tree and probabilities used for the estimation of risk related to switches in state 4 due to natural hazard and load event le2.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 11 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 47. Event tree and probabilities used for the estimation of risk related to switches in state 4 due to natural hazard and load event le3.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 11 for the description of the events.

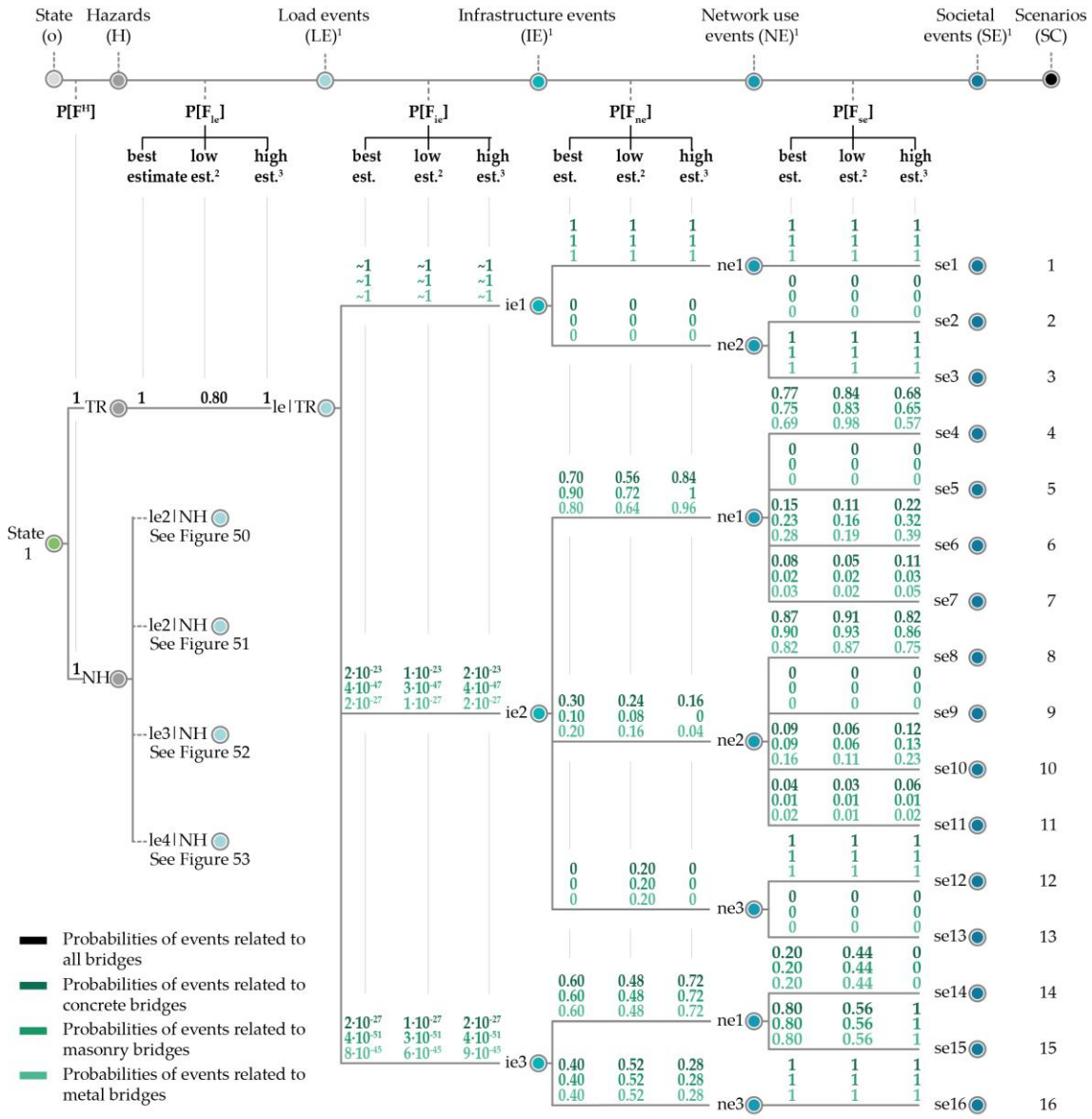
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 48. Event tree and probabilities used for the estimation of risk related to switches in state 4 due to natural hazard and load event le4.

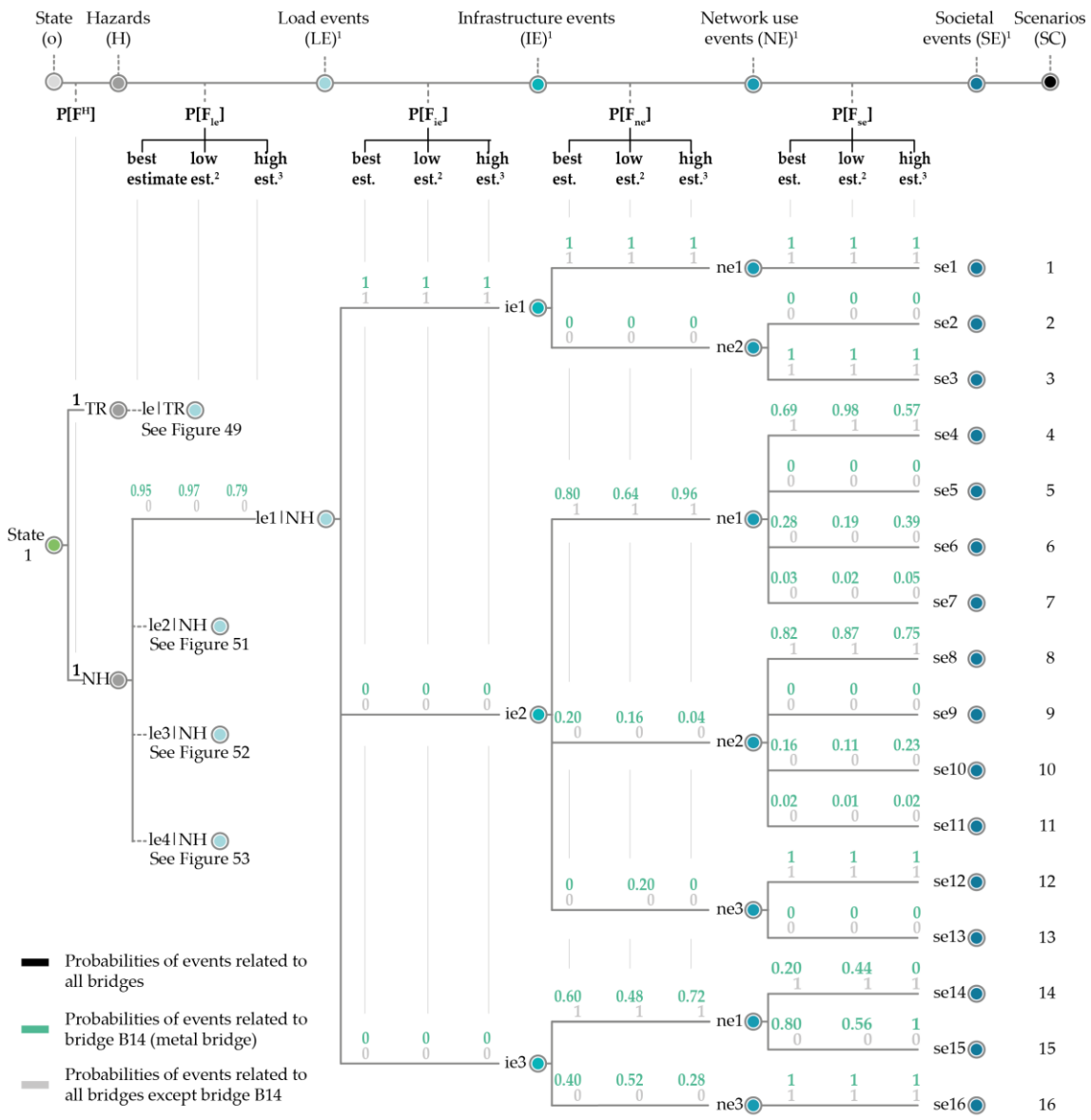
6.2.3. Bridges

Figures 49-68 depict the event trees and the estimates of event probabilities used for the estimation of risk related to bridges.



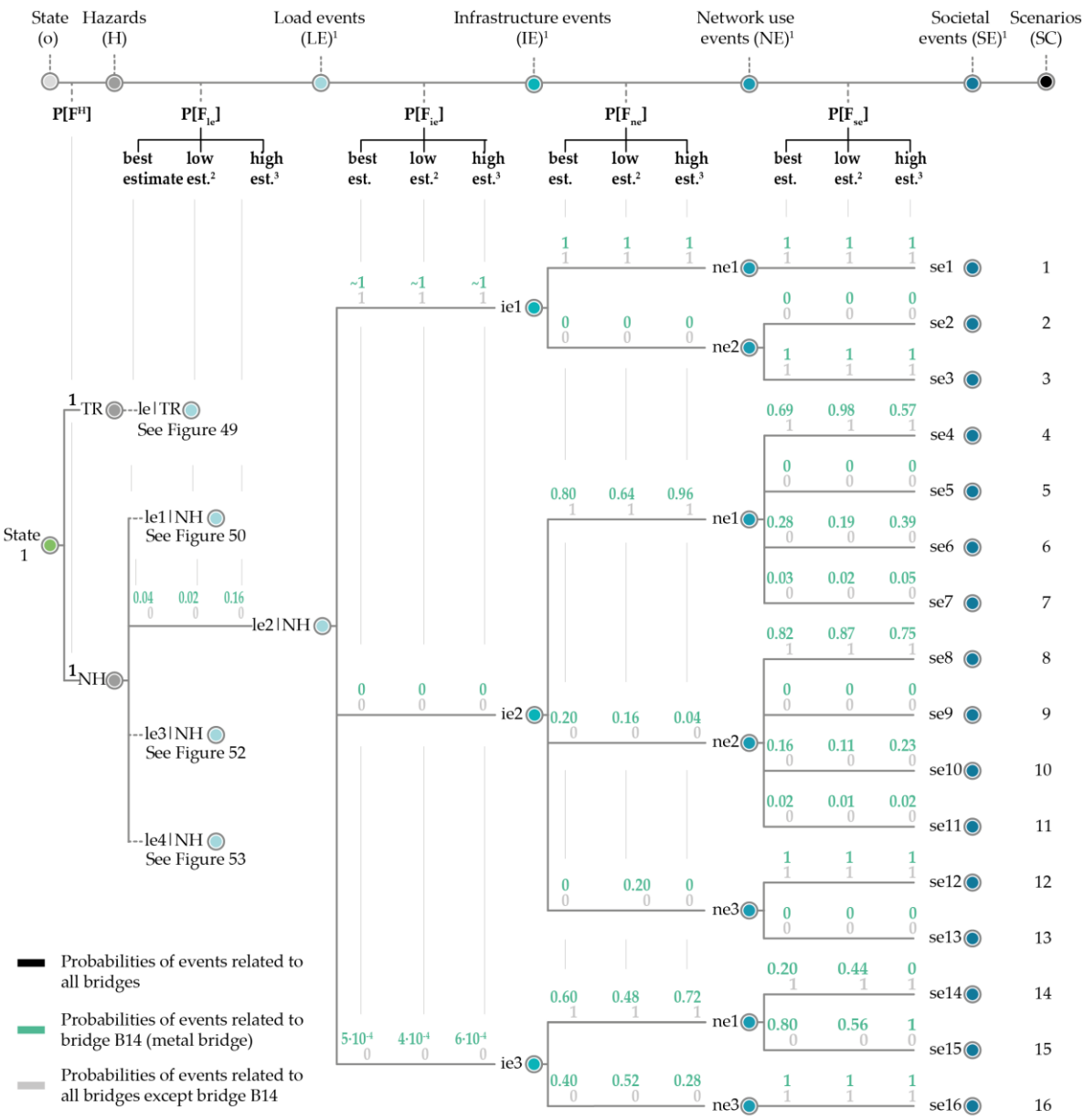
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 12 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 49. Event tree and probabilities used for the estimation of risk related to bridges in state 1 due to traffic.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 12 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 50. Event trees and probabilities used for the estimation of risk related to bridges in state 1 due to natural hazard and load event le1.



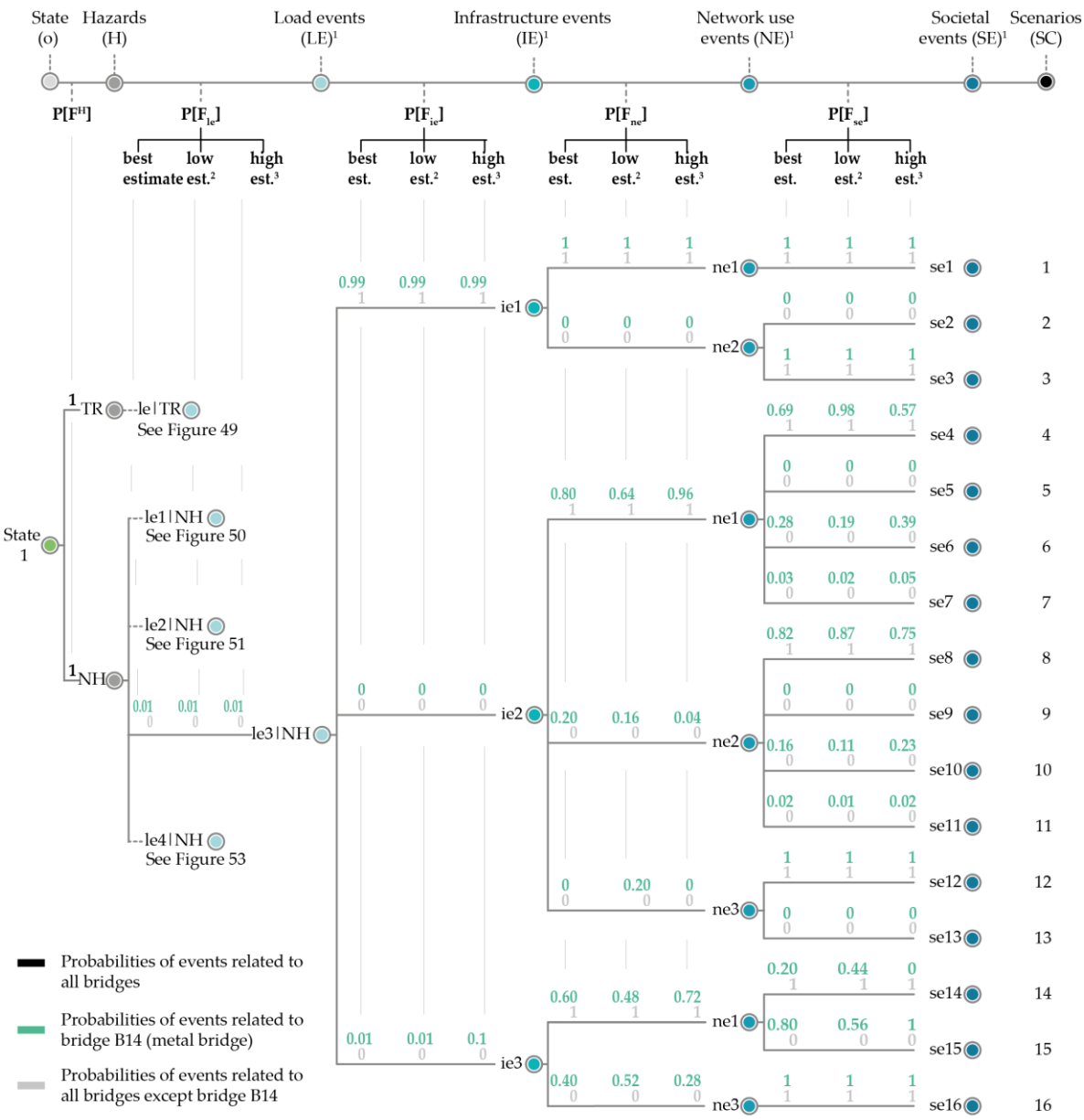
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

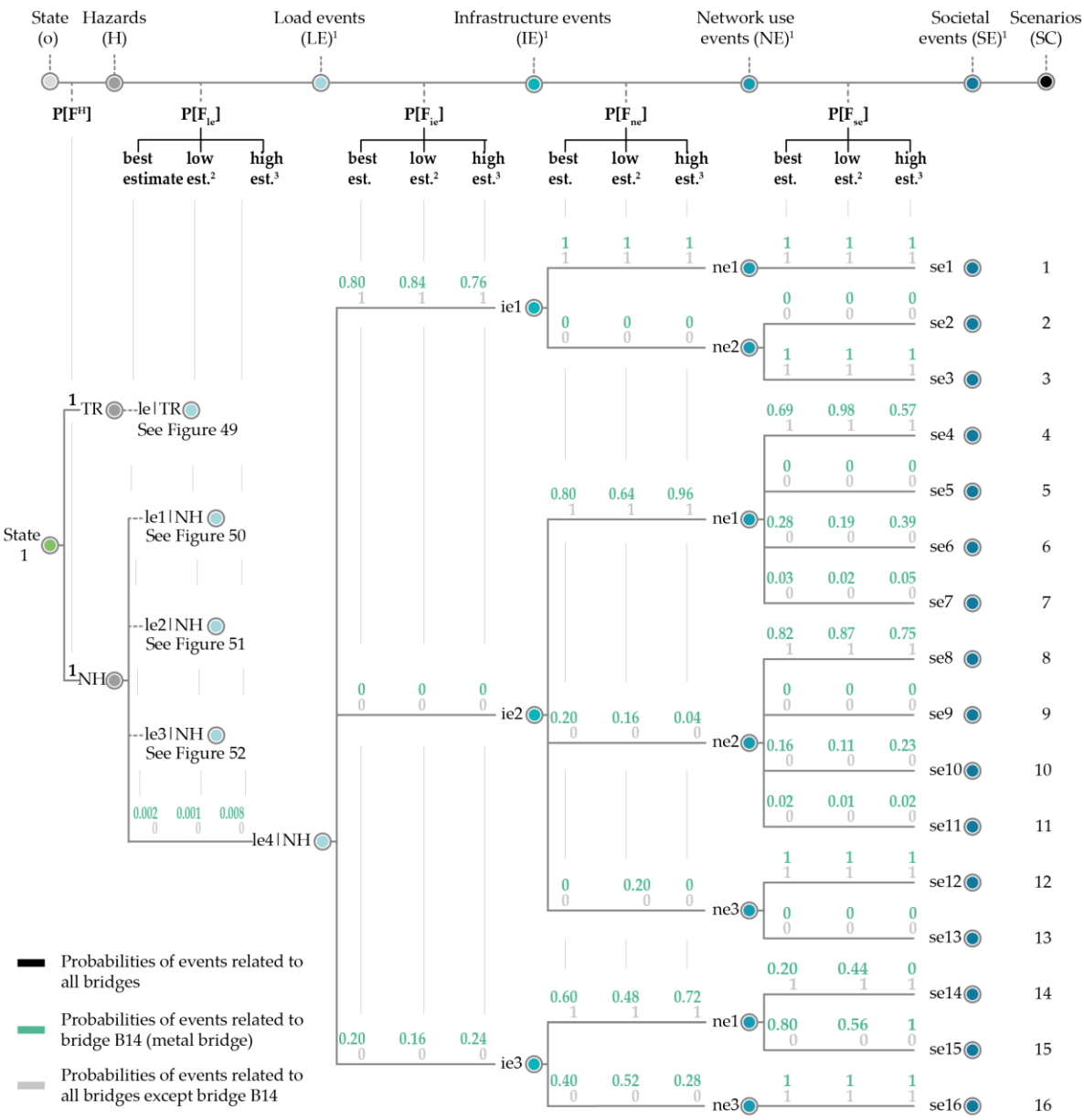
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 51. Event trees and probabilities used for the estimation of risk related to bridges in state 1 due to natural hazard and load event le2.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 12 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 52. Event trees and probabilities used for the estimation of risk related to bridges in state 1 due to natural hazard and load event le3.



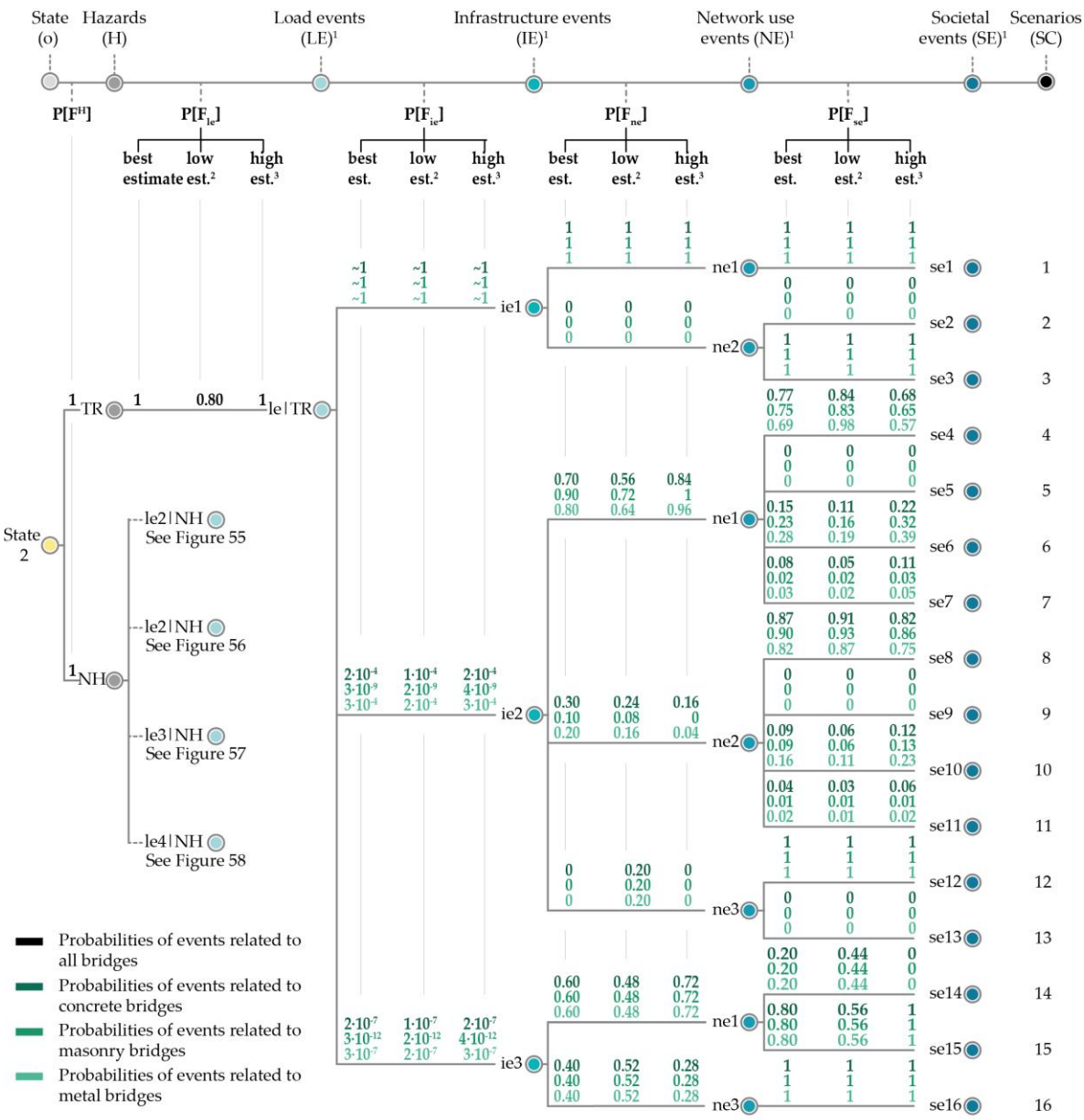
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 53. Event trees and probabilities used for the estimation of risk related to bridges in state 1 due to natural hazard and load event le4.



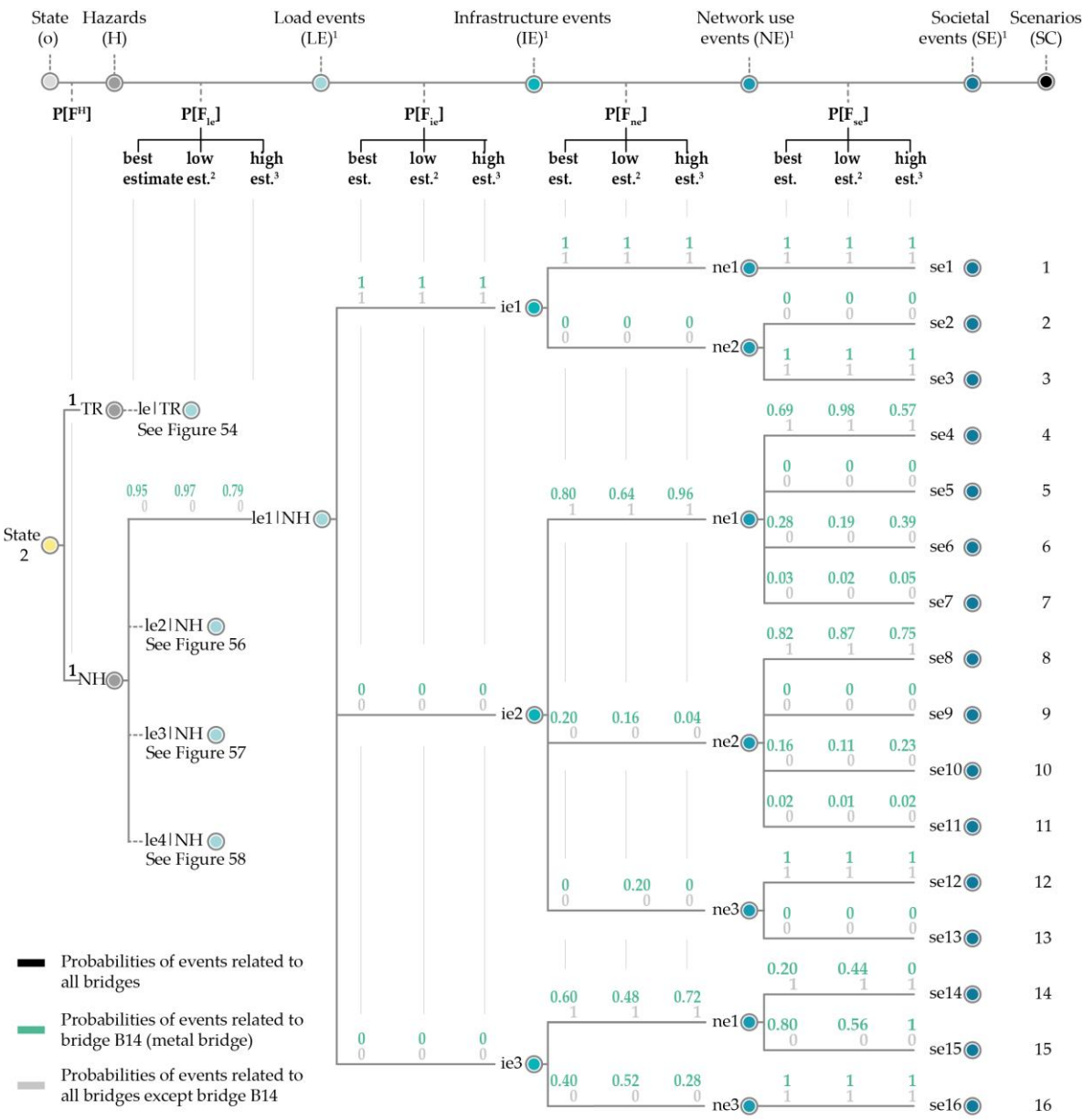
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

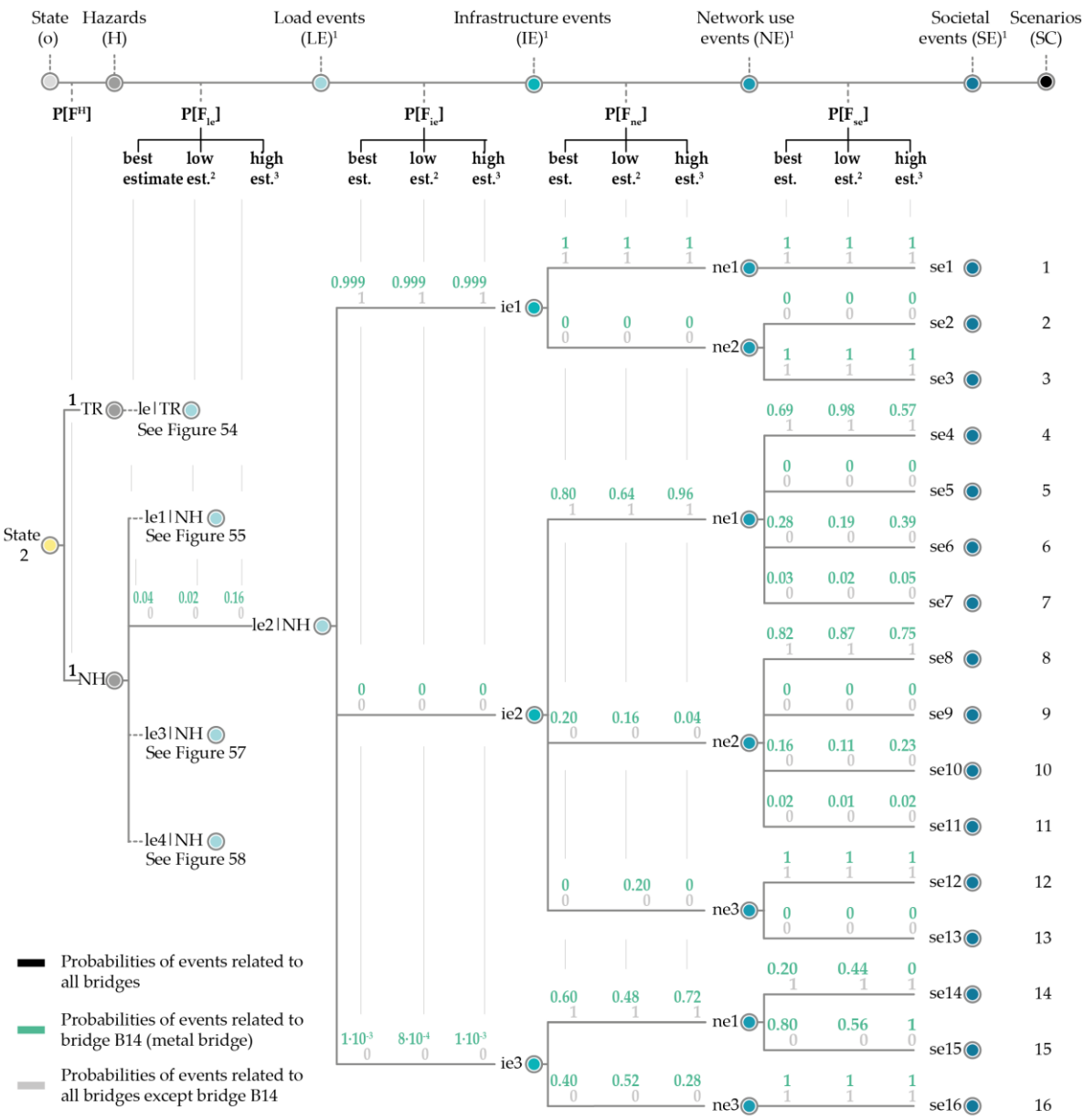
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 54. Event trees and probabilities used for the estimation of risk related to bridges in state 2 due to traffic.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 12 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 55. Event trees and probabilities used for the estimation of risk related to bridges in state 2 due to natural hazard and load event le1



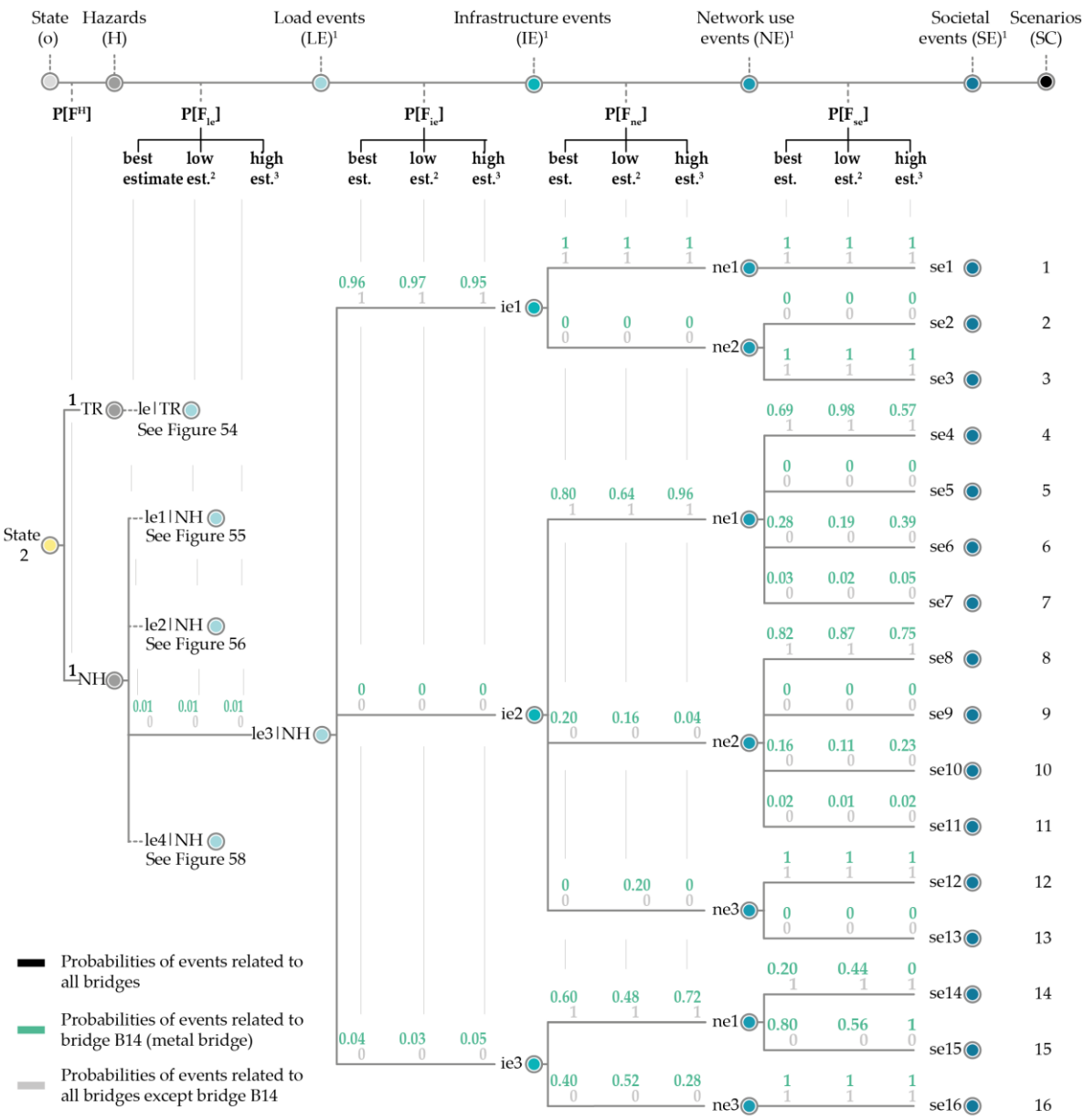
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

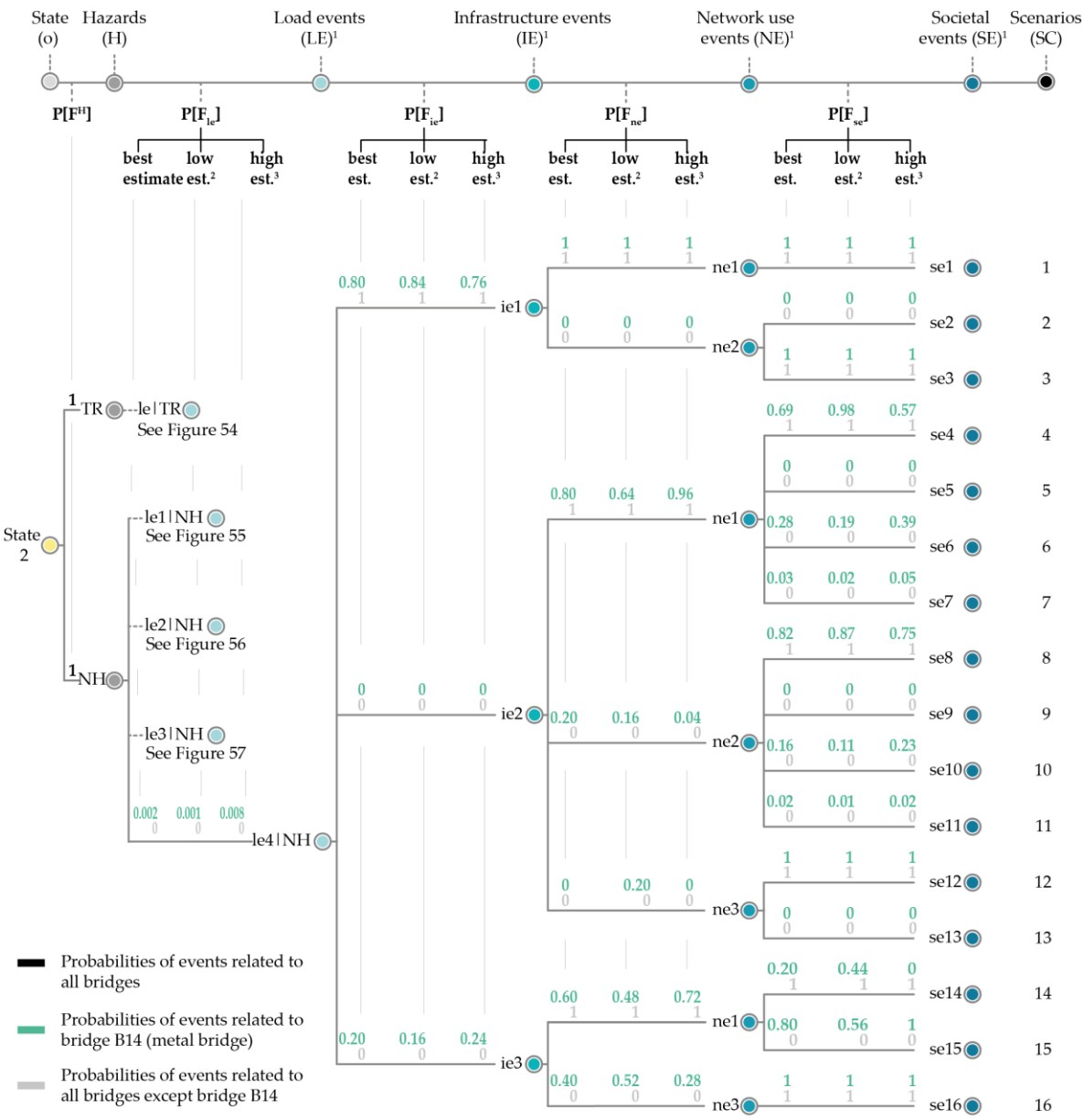
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 56. Event trees and probabilities used for the estimation of risk related to bridges in state 2 due to natural hazard and load event le2.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 12 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 57. Event trees and probabilities used for the estimation of risk related to bridges in state 2 due to natural hazard and load event le3.



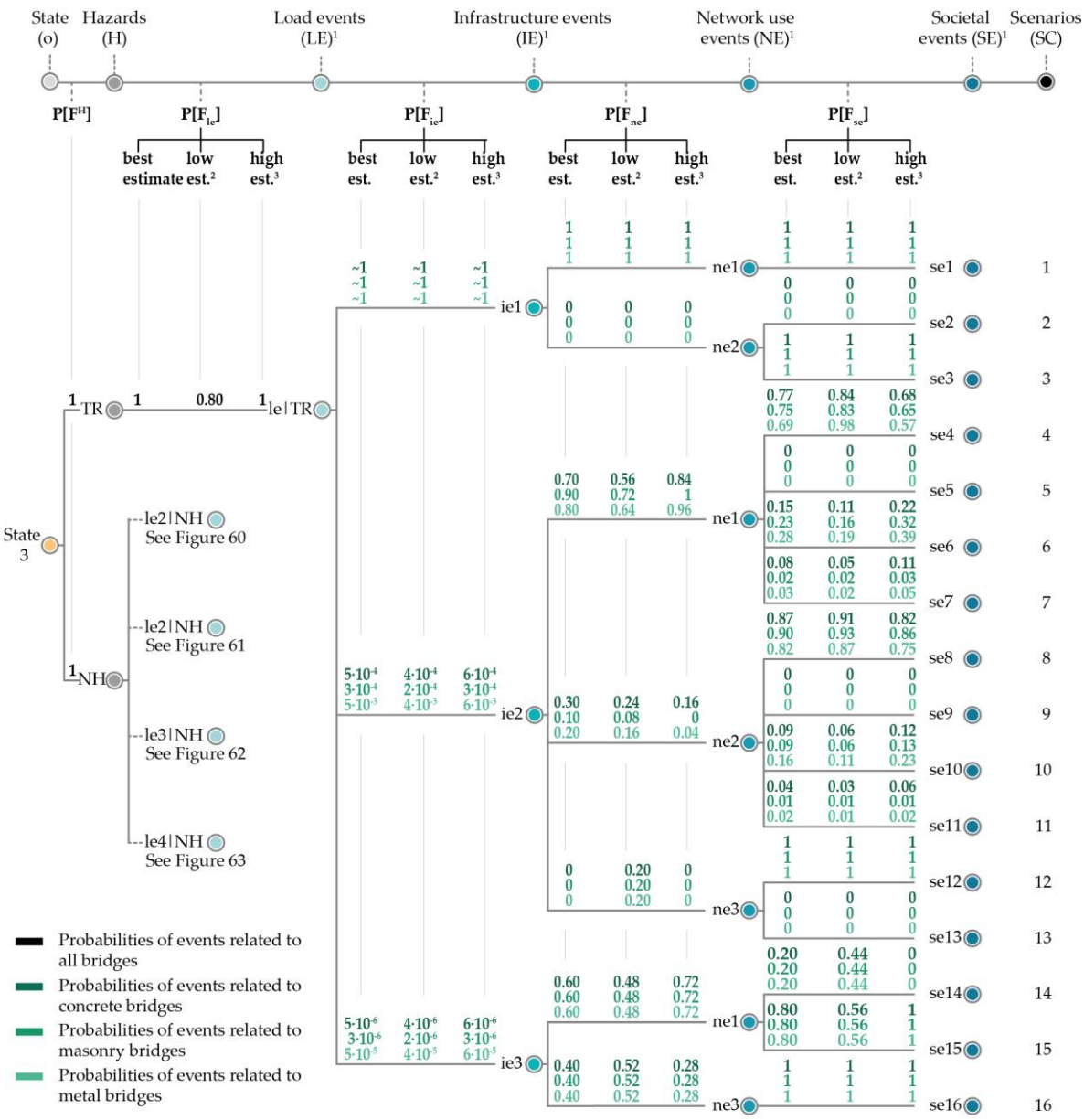
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 58. Event trees and probabilities used for the estimation of risk related to bridges in state 2 due to natural hazard and load event le4.



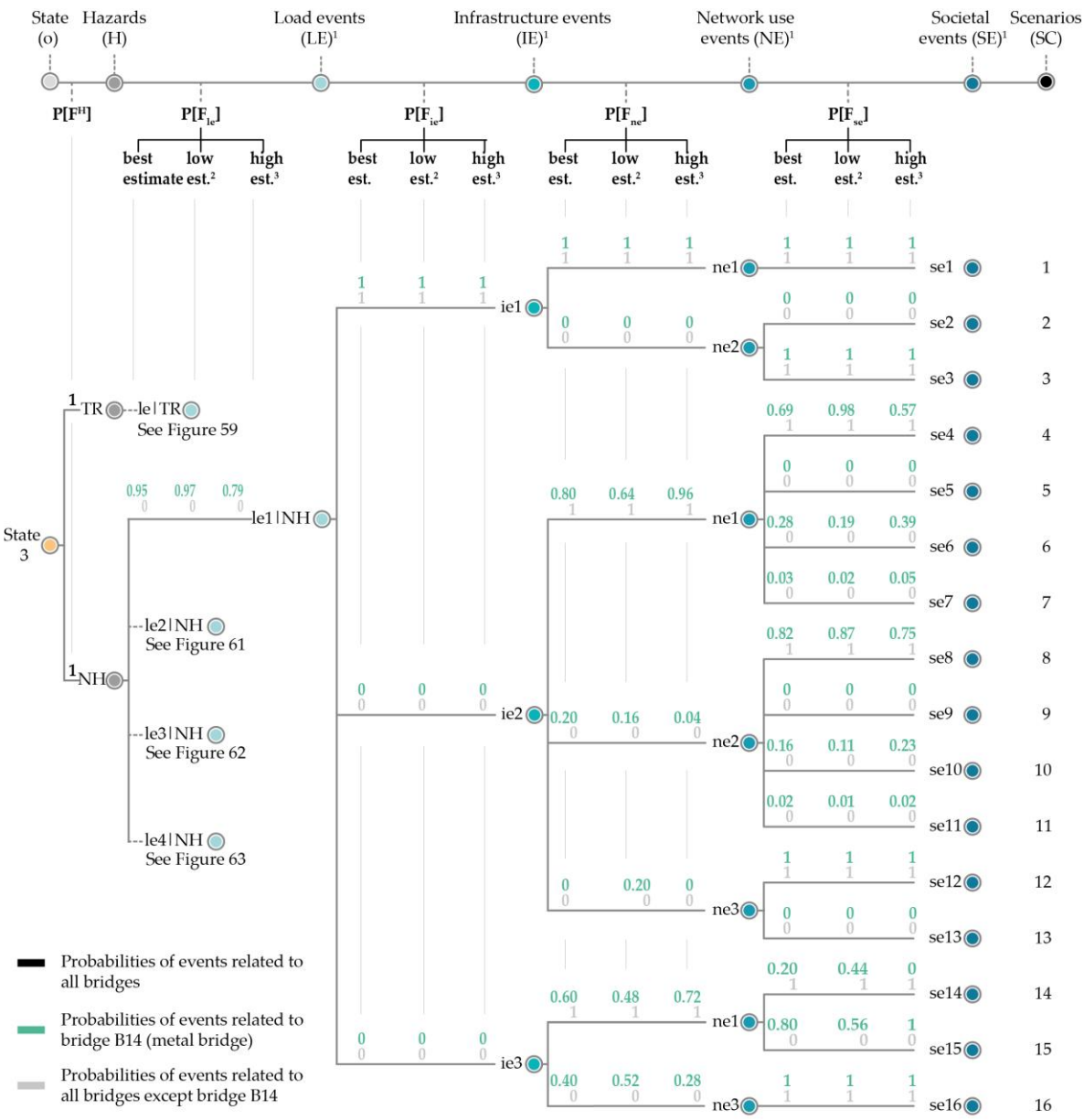
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

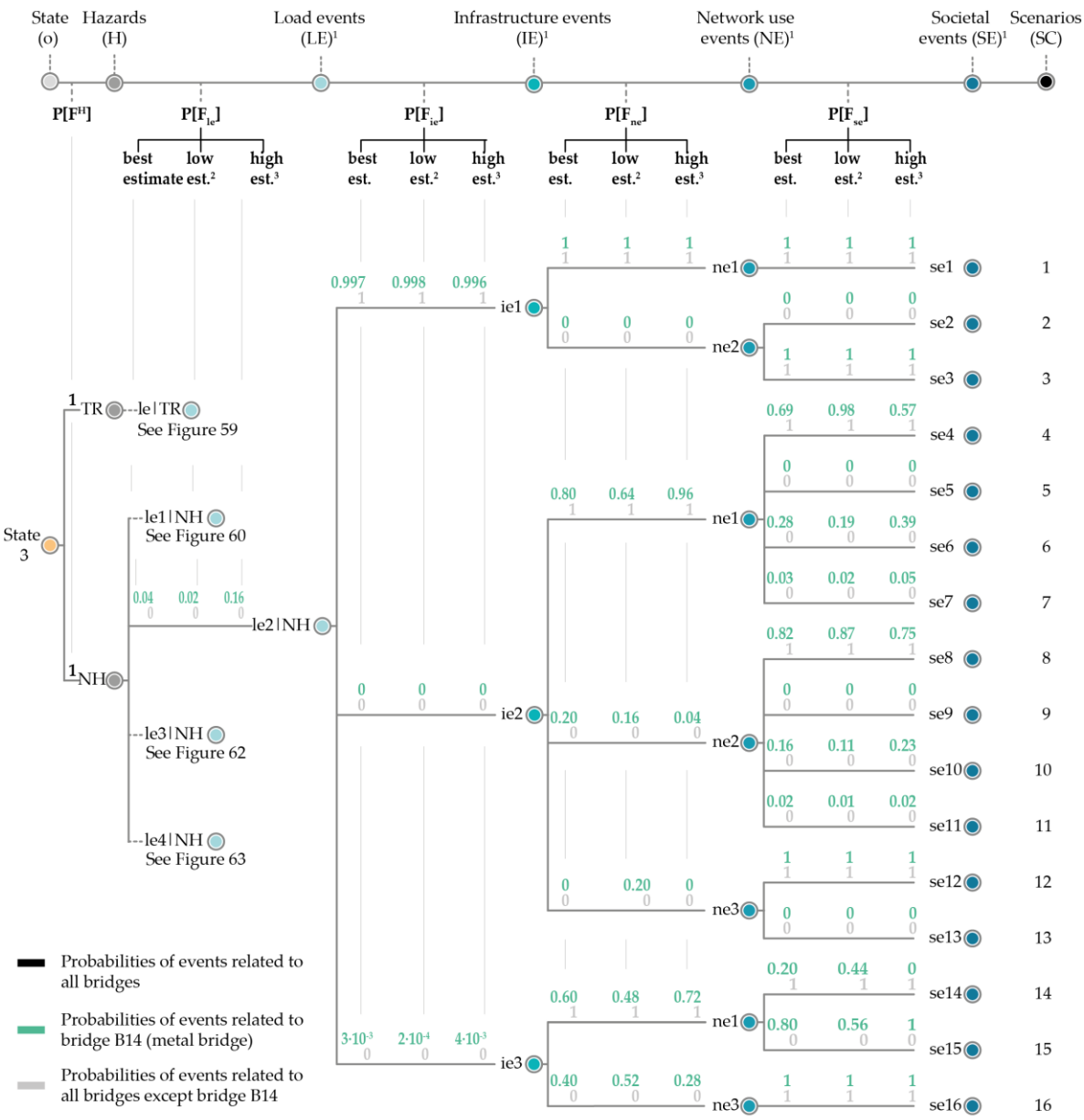
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 59. Event trees and probabilities used for the estimation of risk related to bridges in state 3 due to traffic.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 12 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 60. Event trees and probabilities used for the estimation of risk related to bridges in state 3 due to natural hazard and load event le1.



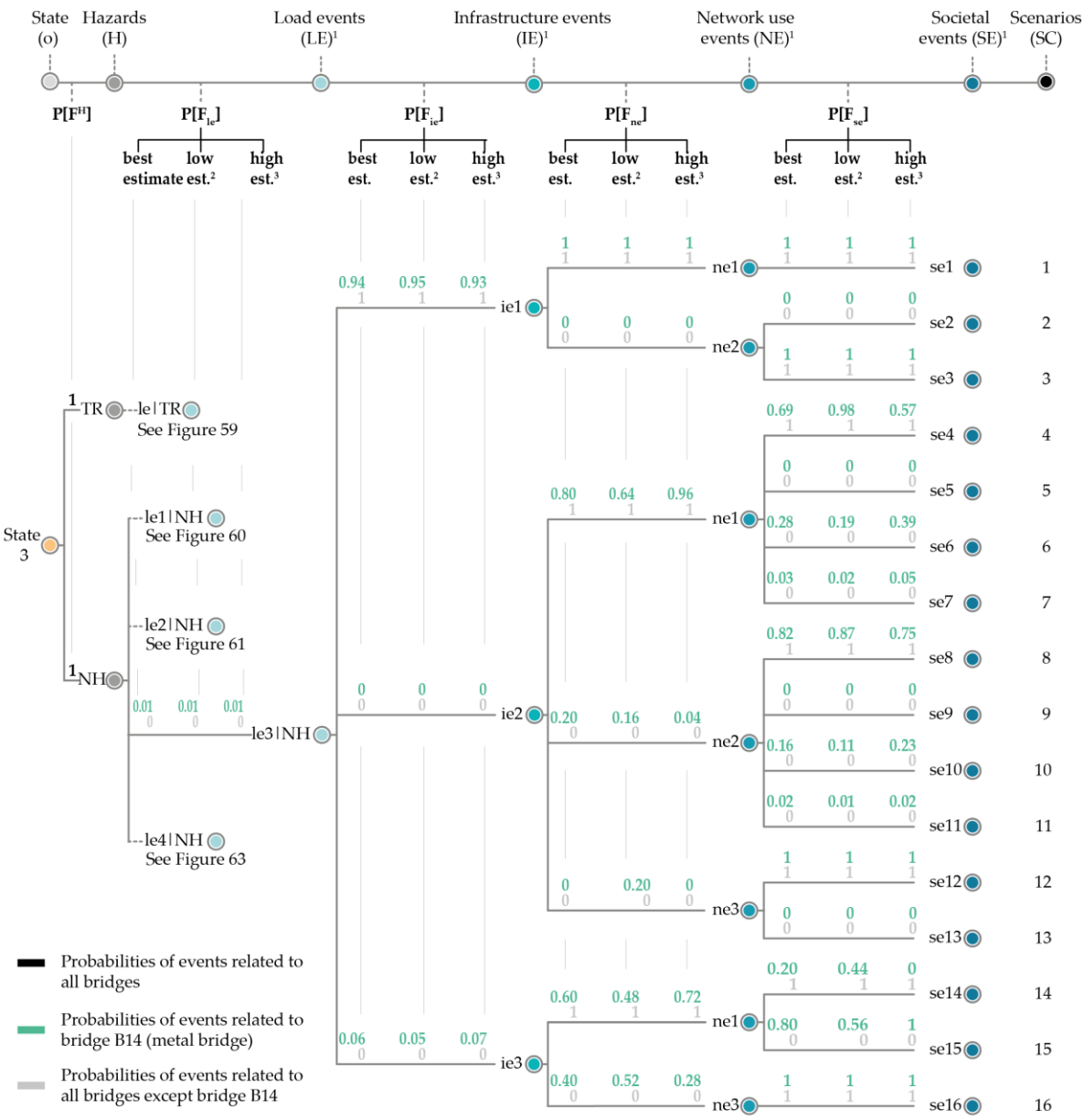
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

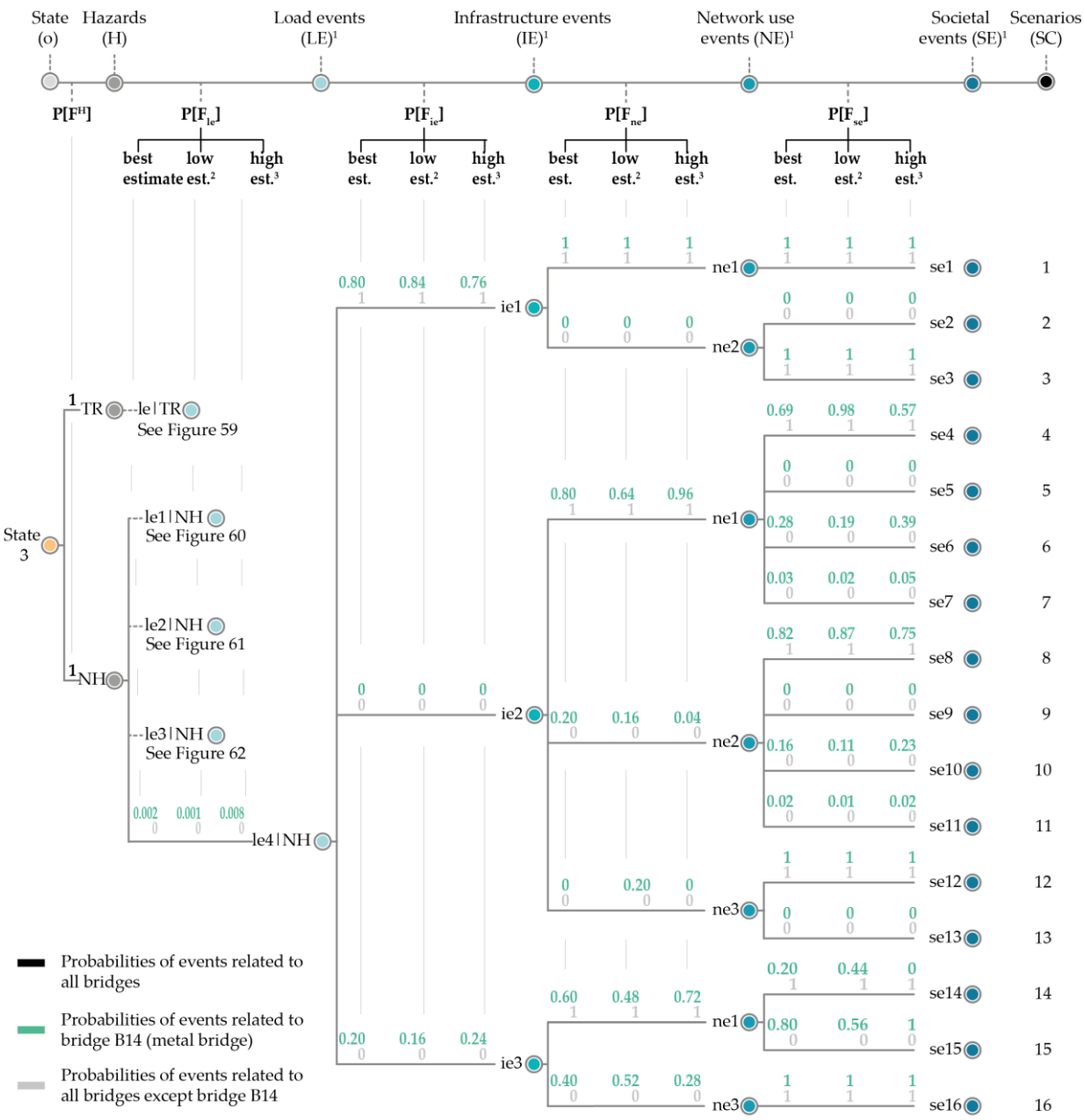
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 61. Event trees and probabilities used for the estimation of risk related to bridges in state 3 due to natural hazard and load event le2.



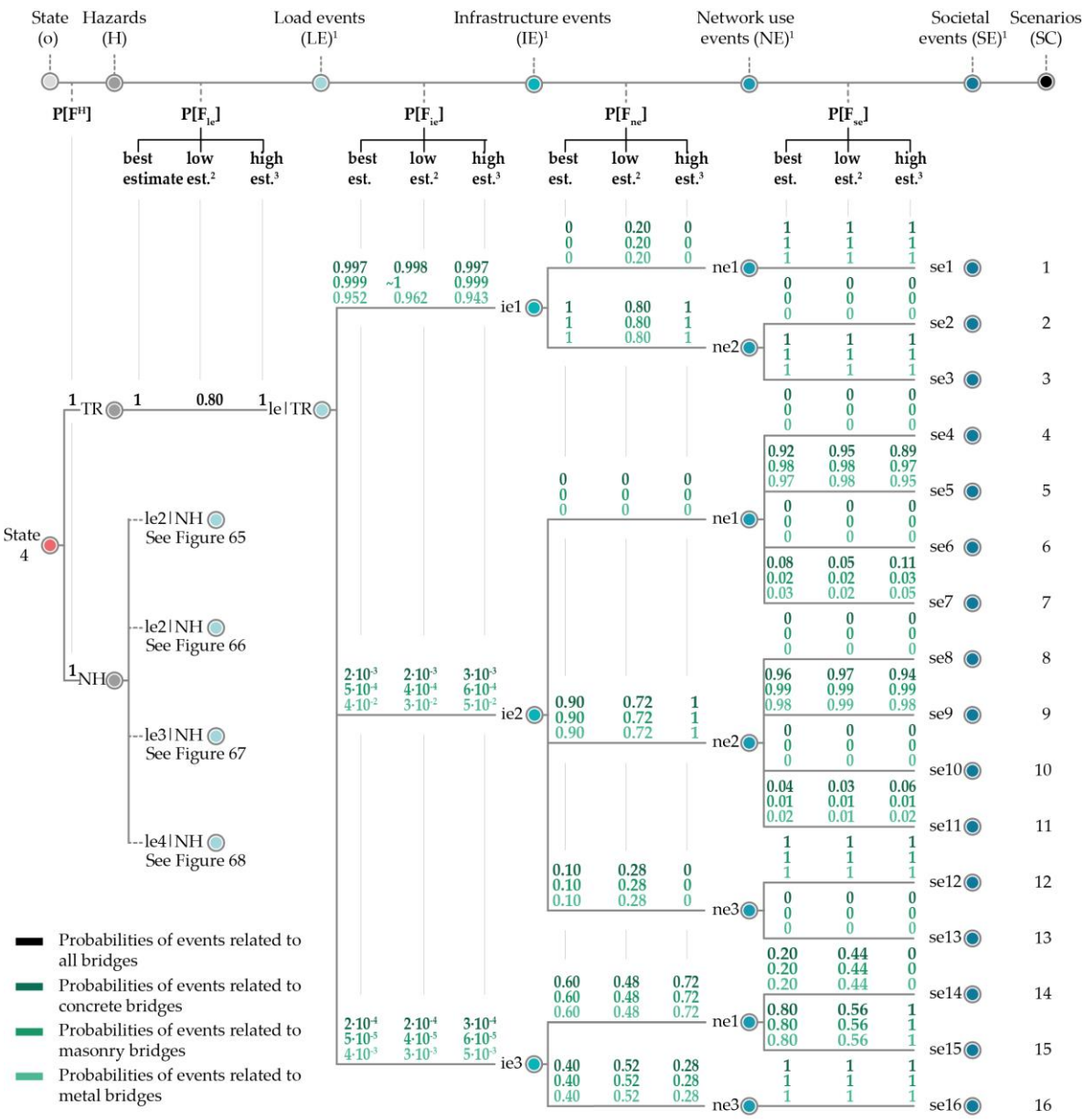
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 12 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 62. Event trees and probabilities used for the estimation of risk related to bridges in state 3 due to natural hazard and load event le3.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 12 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 63. Event trees and probabilities used for the estimation of risk related to bridges in state 3 due to natural hazard and load event le4.



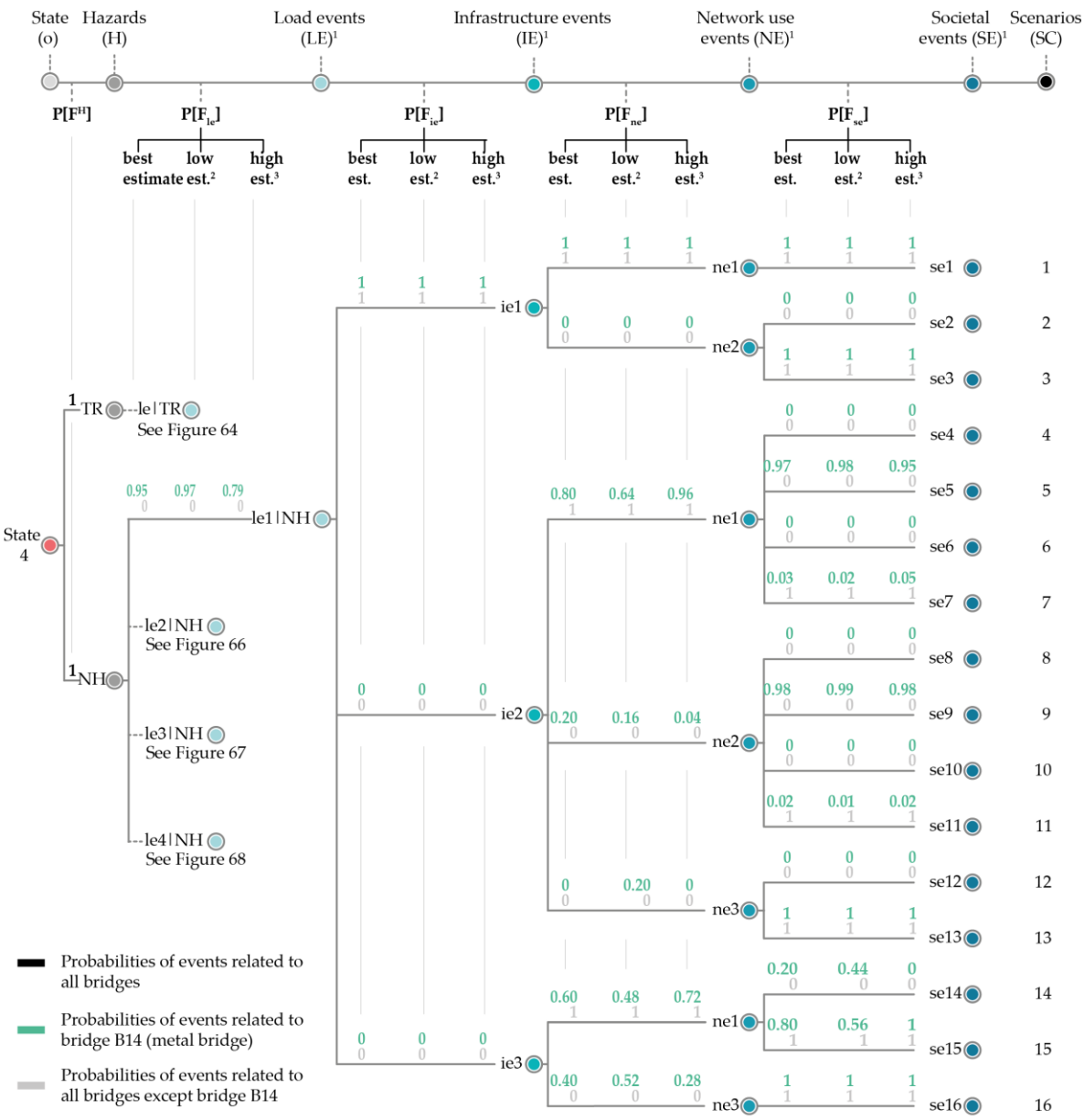
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

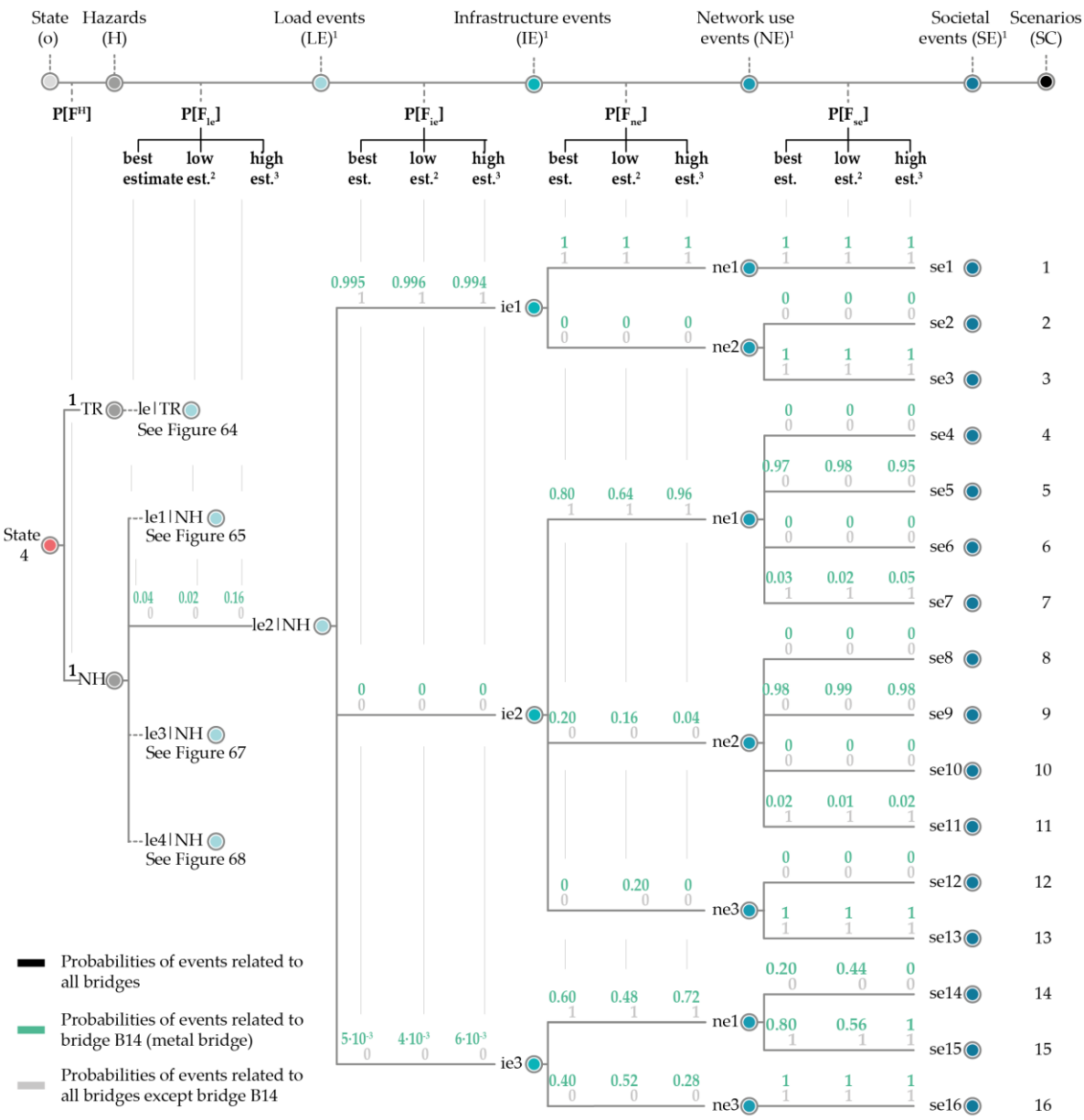
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 64. Event trees and probabilities used for the estimation of risk related to bridges in state 4 due to traffic.



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.
[1] See Tables 6 - 8 and Table 12 for the description of the events.
[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.
[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 65. Event trees and probabilities used for the estimation of risk related to bridges in state 4 due to natural hazard and load event le1.



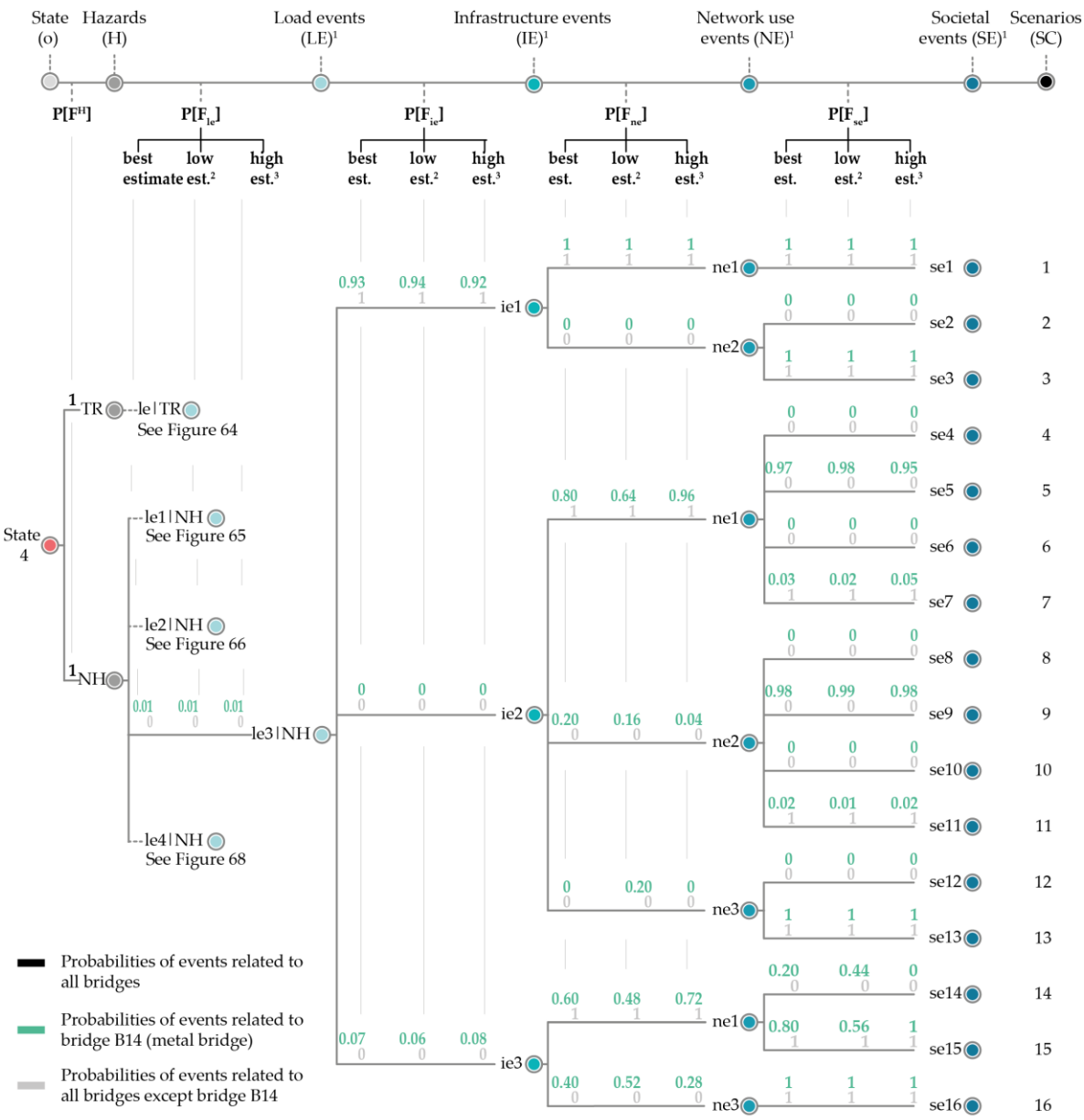
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 66. Event trees and probabilities used for the estimation of risk related to bridges in state 4 due to natural hazard and load event le2.



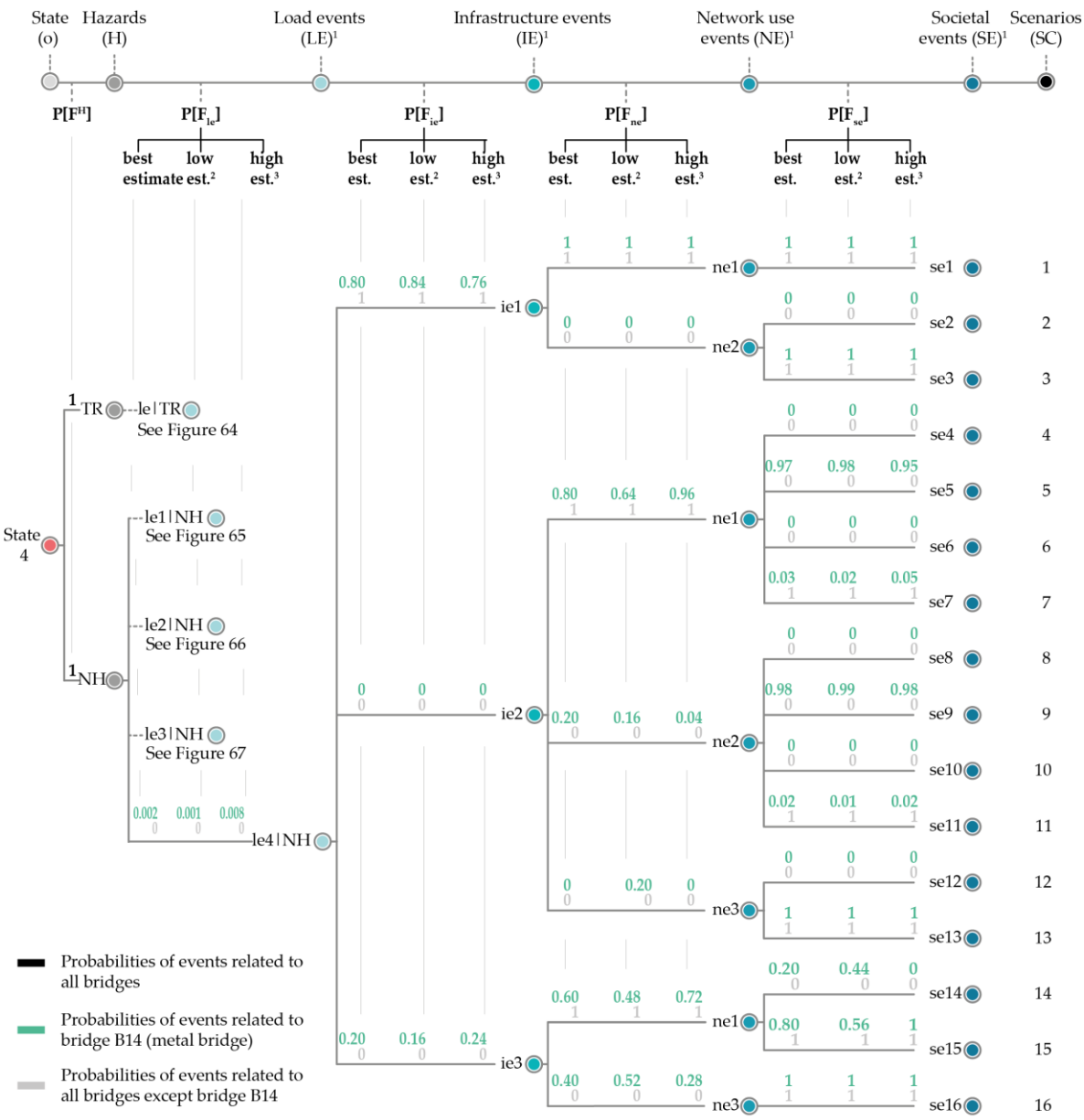
All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 67. Event trees and probabilities used for the estimation of risk related to bridges in state 4 due to natural hazard and load event le3



All the probabilities shown have been rounded,and therefore, their sum might not be equal to one.

[1] See Tables 6 - 8 and Table 12 for the description of the events.

[2] The probabilities shown under the label "low estimates" were used to estimate the low risks. They are smaller than the best estimates for the events leading to severe consequences and greater than the best estimates for the events leading to limited consequences.

[3] The probabilities shown under the label "high estimates" were used to estimate the high risks. They are greater than the best estimates for the events leading to severe consequences and smaller than the best estimates for the events leading to limited consequences.

Figure 68. Event trees and probabilities used for the estimation of risk related to bridges in state 4 due to natural hazard and load event le4.

7. Interventions

7.1. Types

The interventions can be either restoration interventions or risk-reducing interventions. They are presented in Table 13 for all the asset types.

Table 13. Interventions, *I*.

Type	**Track**		**Switches**		**Bridges**	
	Name	**Applicable**	**Name**	**Applicable**	**Name**	**Applicable**
Restoration, *QI*	Tamping	after minor damage	Grinding or welding	after minor damage	Strengthening	after minor damage
	Rail renewal and tamping	after minor damage				
	Renewal	in state 4 or after minor or severe damage	Renewal	in state 4 or after minor or severe damage	Renewal	in state 4 or after minor or severe damage
Risk-reducing, *k*	Renewal	in states 1-4	Renewal	in states 1-4	Renewal	in states 1-4

7.2. Cost

Table 14 shows the estimates of costs used for restoration and risk-reducing interventions.

Table 14. Costs of restoration interventions, C_{QI}, and risk-reducing interventions, c_k.

Asset type	Intervention type	Intervention	Cost estimate, C_{QI} or c_k, in €			Unit
			Best	Low	High	
Track section type 1	Restoration (QI)	Tamping	7	7	8	€ per m of length
		Rail replacement and tamping	113	102	124	
		Track replacement	1'200	1'080	1'320	
	Risk-reducing (k)	Renewal	1'200	1'080	1'320	
Track section type 2	Restoration (QI)	Tamping	7	7	8	
		Rail replacement and tamping	113	102	124	
		Renewal	1'200	1'080	1'320	
	Risk-reducing (k)	Renewal	1'200	1'080	1'320	
Switches	Restoration (QI)	Grinding or welding	10'000	9'000	11'000	per asset
		Renewal	250'000	225'000	275'000	
	Risk-reducing (k)	Renewal	250'000	225'000	275'000	
Concrete bridge	Restoration (QI)	Strengthening	100'000	50'000	300'000	per m² deck surface area
		Renewal	500'000	250'000	1'500'000	
	Risk-reducing (k)	Renewal	500'000	250'000	1'500'000	
Masonry bridge	Restoration (QI)	Strengthening	150'000	200'000	1'200'000	
		Renewal	400'000	50'000	300'000	
	Risk-reducing (k)	Renewal	400'000	50'000	300'000	
Metal bridge	Restoration (QI)	Strengthening	100'000	50'000	300'000	
		Renewal	300'000	150'000	900'000	
	Risk-reducing (k)	Renewal	300'000	150'000	900'000	

7.3. Duration of traffic restrictions

Table 15 shows the estimates of the duration of traffic restrictions used for restoration and risk-reducing interventions.

Table 15. Duration of traffic restrictions, *DD*, due to restoration and risk-reducing interventions.

Asset type	**Intervention type**	**Intervention**	**Duration of speed restriction, $DD_{SPR|QI}$ or $DD_{SPR|k}$, in hours due to the execution of the intervention on one unit of the asset**			**Duration of closure, $DD_{CL|QI}$ or $DD_{CL|k}$, in hours due to the execution of the intervention on one unit of the asset**		
			Best	**Low**	**High**	**Best**	**Low**	**High**
Track section type 1	Restoration (QI)	Tamping	0	0	0	0.0022	0.0020	0.0026
		Rail replacement and tamping	0	0	0	0.0010	0.0009	0.0012
	Risk-reducing (k)	Replacement	168	168	168	0.0084	0.0076	0.0101
		Renewal	168	168	168	0.0084	0.0076	0.0101
Track section type 2	Restoration (QI)	Tamping	0	0	0	0.0022	0.0020	0.0026
		Rail replacement and tamping	0	0	0	0.0007	0.0006	0.0008
	Risk-reducing (k)	Replacement	168	168	168	0.0084	0.0076	0.0101
		Renewal	168	168	168	0.0084	0.0076	0.0101
Switches	Restoration (QI)	Grinding or welding	0	0	0	3	3	4
	Risk-reducing (k)	Replacement	0	0	0	36	32	43
		Renewal	0	0	0	36	32	43
Concrete bridge	Restoration (QI)	Strengthening	12	3	24	10	3	30
	Risk-reducing (k)	Replacement	42	11	84	120	30	360
		Renewal	42	11	84	120	30	360
Masonry bridge	Restoration (QI)	Strengthening	12	3	24	10	3	30
	Risk-reducing (k)	Replacement	42	11	84	120	30	360
		Renewal	42	11	84	120	30	360
Metal bridge	Restoration (QI)	Strengthening	12	3	24	10	3	30
	Risk-reducing	Replacement	42	11	84	120	30	360
		Renewal	42	11	84	120	30	360

	(k)

7.4. Environmental impact

Table 16 shows the estimates of the environmental costs used for the calculation of the environmental impact of restoration and risk-reducing interventions.

Table 16. Environmental costs of interventions, $C_{e|I}$.

Asset type	**Intervention type**	**Intervention**	**Environmental cost estimate, $C_{e|QI}$ or $c_{e|k}$, in € due to the execution of the intervention on one unit of the asset**		
			Best	**Low**	**High**
Track section type 1	Restoration (QI)	Tamping	10	5	20
		Rail replacement and tamping	15	8	30
		Replacement	21	11	42
	Risk-reducing (k)	Renewal	21	11	42
Track section type 2	Restoration (QI)	Tamping	10	5	20
		Rail replacement and tamping	15	8	30
		Replacement	21	11	42
	Risk-reducing (k)	Renewal	21	11	42
Switches	Restoration (QI)	Grinding or welding	155	78	310
		Replacement	215	108	430
	Risk-reducing (k)	Renewal	215	108	430
Concrete bridge	Restoration (QI)	Strengthening	347	174	694
		Replacement	1'155	578	2'310
	Risk-reducing (k)	Renewal	1'155	578	2'310
Masonry bridge	Restoration (QI)	Strengthening	504	252	1'008
		Replacement	1'155	578	2'310
	Risk-reducing (k)	Renewal	1'155	578	2'310
Metal bridge	Restoration (QI)	Strengthening	504	252	1'008
		Replacement	1'155	578	2'310
	Risk-reducing (k)	Renewal	1'155	578	2'310

8. Site restorations

8.1. Types

The site restoration types are given in Table 17.

Table 17. Site restorations, *QS*.

Track sections		Switches		Bridges	
Notation	**Description**	**Notation**	**Description**	**Notation**	**Description**
qs1.1T	Restoring the site after minor track damage and before tamping	qs1S	Restoring the site after minor switch damage and before grinding or welding	qs1B	Restoring the site after minor bridge damage and before strengthening
qs1.2T	Restoring the site after minor track damage, and before rail replacement and tamping of the track section	qs2S	Restoring the site after minor switch damage and before switch renewal	qs2B	Restoring the site after minor bridge damage and before bridge renewal
qs2	Restoring the site after minor track damage and before track section renewal	qs3S	Restoring the site after severe switch damage and before switch renewal	qs3B	Restoring the site after severe bridge damage and before bridge renewal
qs3T	Restoring the site after severe track damage and before track section renewal	qs4S	Restoring the site after an accident due to minor switch damage	qs4B	Restoring the site after an accident due to severe bridge damage
qs4T	Restoring the site after an accident due to minor track damage	qs5S	Restoring the site after an accident due to severe switch damage	qs5B	Restoring the site after an accident due to severe bridge damage
qs5T	Restoring the site after an accident due to severe track damage				

8.2. Cost

Table 18 shows the estimates of the costs used for site restoration.

Table 18. Costs of site restoration, C_{QS}.

Asset type	**Site restoration type**[1]	**Cost estimate, c_{QS}, per asset damage in million €**			**Asset type**	**Site restoration type**[1]	**Cost estimate, c_{QS}, per asset damage in million €**		
		Best	**Low**	**High**			**Best**	**Low**	**High**
Track section type 1	$qs1.1_T$	0.001	0.001	0.003	Concrete bridge	$qs1_B$	0.01	0.01	0.03
	$qs1.2_T$	0.001	0.001	0.003		$qs2_B$	0.05	0.03	0.15
	qs2	0.002	0.001	0.006		$qs3_B$	0.10	0.05	0.30
	$qs3_T$	0.01	0.01	0.03		$qs4_B$	1.10	0.55	2.20
	$qs4_T$	0.10	0.05	0.30		$qs5_B$	6.00	3.00	12.00
	$qs5_T$	0.60	0.30	1.80	Masonry bridge	$qs1_B$	0.02	0.01	0.05
Track section type 2	$qs1.1_T$	0.001	0.001	0.003		$qs2_B$	0.04	0.02	0.12
	$qs1.2_T$	0.001	0.001	0.003		$qs3_B$	0.10	0.05	0.30
	qs2	0.002	0.001	0.006		$qs4_B$	1.10	0.55	2.20
	$qs3_T$	0.01	0.01	0.03		$qs5_B$	6.00	3.00	12.00
	$qs4_T$	0.10	0.05	0.30	Metal bridge	$qs1_B$	0.01	0.01	0.03
	$qs5_T$	0.60	0.30	1.80		$qs2_B$	0.03	0.02	0.09
Switches	$qs1_S$	0.0001	0.0001	0.0003		$qs3_B$	0.08	0.04	0.24
	$qs2_S$	0.0003	0.0002	0.0009		$qs4_B$	1.10	0.55	2.20
	$qs3_S$	0.0004	0.0002	0.0012		$qs5_B$	6.00	3.00	12.00
	$qs4_S$	0.05	0.03	0.15					
	$rs5_S$	0.15	0.08	0.45					

[1] See Table 17 for the description

8.3. Duration of traffic restrictions due to site restoration

Table 19 shows the estimates of the duration of traffic restrictions used for site restoration.

Table 19. Duration of traffic restrictions due to site restoration, DT_{QS}.

Asset type	Site restoration type[1]	Estimate for the duration of the speed restriction, $DT_{SPR\|QS}$, in hours due to site restoration per asset damage			Estimate for the duration of the closure, $DT_{CL\|QS}$, in hours due to site restoration per asset damage		
		Best	Low	High	Best	Low	High
Track section type 1	$qs1.1_T$	12	3	24	3	1	9
	$qs1.2_T$	12	3	24	5	1	15
	$qs2$	12	3	24	10	3	30
	$qs3_T$	12	3	24	24	6	72
	$qs4_T$	0	0	0	78	20	156
	$qs5_T$	0	0	0	78	20	156
Track section type 2	$qs1.1_T$	12	3	24	3	1	9
	$qs1.2_T$	12	3	24	5	1	15
	$qs2$	12	3	24	10	3	30
	$qs3_T$	12	3	24	24	6	72
	$qs4_T$	0	0	0	78	20	156
	$qs5_T$	0	0	0	78	20	156
Switches	$qs1_S$	12	3	24	1	0	3
	$qs2_S$	42	11	84	3	1	9
	$qs3_S$	42	11	84	5	1	15
	$qs4_S$	0	0	0	78	20	156
	$qs5_S$	0	0	0	93	23	186
Concrete bridge	$qs1_B$	12	3	24	10	3	30
	$qs2_B$	42	11	84	120	30	360
	$qs3_B$	42	11	84	168	42	504
	$qs4_B$	0	0	0	78	24	150
	$qs5_B$	0	0	0	78	24	150
Masonry bridge	$qs1_B$	12	3	24	10	3	30
	$qs2_B$	42	11	84	120	30	360
	$qs3_B$	42	11	84	168	42	504
	$qs4_B$	0	1	2	78	20	156
	$qs5_B$	0	0	0	93	23	186
Metal bridge	$qs1_B$	12	3	24	10	3	30
	$qs2_B$	42	11	84	120	30	360
	$qs3_B$	42	11	84	168	42	504
	$qs4_B$	0	0	0	144	36	288
	$qs5_B$	0	0	0	144	36	288

[1] See Table 17 for the description

8.4. Environmental impact due to site restorations

Table 20 shows the estimates of the environmental costs used for the calculation of the environmental impact of site restoration due to damages and accidents.

Table 20. Environmental costs of site restoration, $C_{e|QS}$.

Asset type	Site restoration type[1]	Environmental cost estimate per site damage, *QS*, in €		
		Best	**Low**	**High**
Track section type 1	$qs1.1_T$ and $qs1.2_T$	19	10	38
	$qs2_T$ and $qs3_T$	57	29	114
	$qs4_T$ and $qs5_T$	38	19	76
Track section type 2	$qs1.1_T$ and $qs1.2_T$	19	10	38
	$qs2_T$ and $qs3_T$	57	29	114
	$qs4_T$ and $qs5_T$	38	19	76
Switches	$qs1_S$ and $qs2_S$	192	96	384
	$qs3_S$	576	288	1'152
	$qs4_S$ and $qs5_S$	384	192	768
Concrete bridge	$qs1_B$ and $qs2_B$	809	405	1'618
	$qs3_B$	2'427	1'214	4'854
	$qs4_B$ and $qs5_B$	1'618	809	3'236
Masonry bridge	$qs1_B$ and $qs2_B$	1'155	578	2'310
	$qs3_B$	3'465	1'733	6'930
	$qs4_B$ and $qs5_B$	2'310	1'155	4'620
Metal bridge	$qs1_B$ and $qs2_B$	504	252	1'008
	$qs3_B$	1'512	756	3'024
	$qs4_B$ and $qs5_B$	1'008	504	2'016

[1] See Table 17 for the description

9. Number of fatalities and injuries

Table 21 shows the estimates of the number of fatalities and injuries used for the estimation of costs due to accidents.

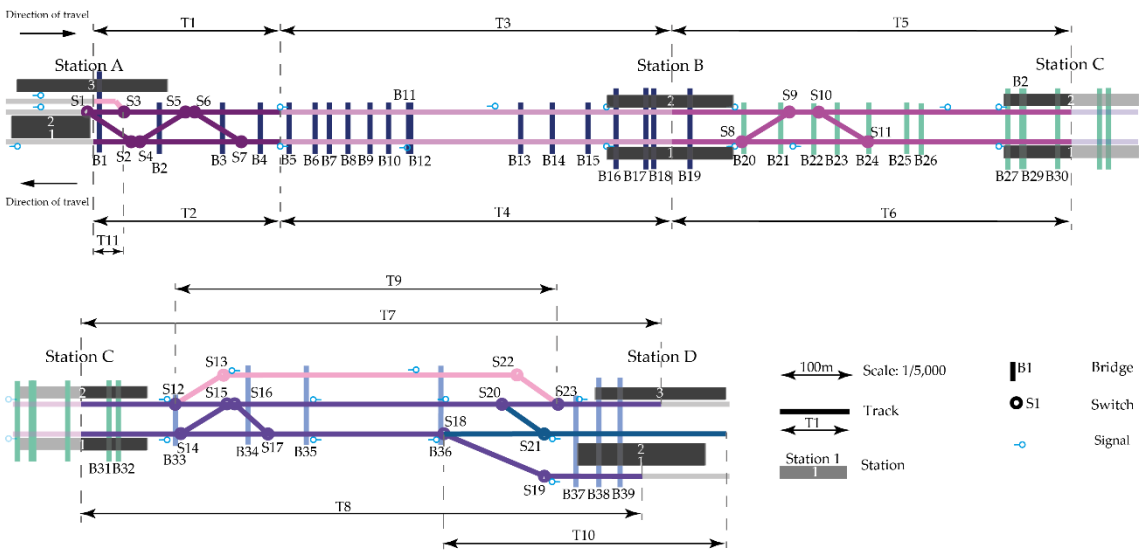
Table 21. Number of fatalities and injuries.

Asset type	Type of accident impact	Estimate of fatalities or injuries, *Z*, due to an accident after minor damage			Estimate of fatalities or injuries, *Z*, due to an accident after severe damage		
		Best	Low	High	Best	Low	High
Track sections (type 1 and 2)	Fatalities	0.006	0.003	0.011	0.051	0.045	0.053
	Injuries	0.004	0.002	0.009	0.040	0.035	0.042
Switches	Fatalities	0.011	0.006	0.023	0.045	0.034	0.051
	Injuries	0.009	0.004	0.018	0.350	0.026	0.040
Bridges (concrete, masonry and metal)	Fatalities	0.12	0.04	0.60	2.3	1.8	2.4
	Injuries	0.26	0.09	1.33	5.0	4.0	5.2

10. Additional travel time

A model was developed to estimate the additional travel time for each asset due to the implementation of traffic restrictions, i.e. speed restrictions or closure, for one hour. The model was based on the mathematical framework Kronecker Algebra, presented in [1], to assess whether trains would be delayed or cancelled due to traffic restrictions. If trains were to be cancelled, they would need to be replaced by bus services. For those trips, an additional travel time of 10 minutes per passenger was considered. The model took into account the asset's location, the signalling map, and the timetable during peak and off-peak hours on a weekday as well as on a weekend day. In the case of train delays, every train delay was calculated in minutes to estimate the additional travel time per passenger. The network operates eighteen hours per day.

The number of passengers per train was estimated based on the traffic volume of Station C, which is the station with the highest traffic volume in the Republic of Ireland [2]. The traffic through this station was considered 1/3 of its total daily traffic. The estimates of the additional travel time due to one-hour closures are shown in **Figure 69** for each asset. It was found that no additional travel time occurs if maximum speed restrictions are imposed on any of the assets in the network.



Additional travel time D_h in minutes per hour of assets' closure

Label	Impact on timetable	Period	Best estimate	Low est.	High est.
	no delay	Weekday	0	0	0
		Weekend	0	0	0
	5min delay per train	Weekday	36,179	28,943	72,358
		Weekend	4,735	3,788	9,470
	Cancelled trains	Weekday	80,966	64,773	161,932
		Weekend	25,716	20,573	51,432
	Cancelled trains	Weekday	9,730	7,784	19,460
		Weekend	1,714	1,371	3,428
	5min delay per train	Weekday	13,443	10,754	26,886
		Weekend	4,273	3,418	8,546

Label	Impact on timetable	Period	Best estimate	Low est.	High est.
	Cancelled trains	Weekday	80,656	64,525	25,639
		Weekend	25,639	20,511	51,278
	5min delay per train	Weekday	9,555	7,644	19,110
		Weekend	2,759	2,759	2,207
	Cancelled trains	Weekday	57,330	45,864	114,660
		Weekend	16,554	13,243	33,108
	3min delay per train	Weekday	5,733	4,586	11,466
		Weekend	1,655	1,324	3,310

Figure 69. Additional travel time estimates per hour of assets' closure, DT_{CL}.

An asset failure can occur at any time during either a 24-hour weekday or a 24-hour day at the weekend. This means that the additional travel time due to restoration interventions, site restorations and accidents, was estimated by assuming that the later have 5/7 probability of occurring during a weekday and 2/7 probability to occur during the weekend. The risk-reducing interventions were considered to be executed during a 24-hour day at the weekend.

11. Unit costs

The unit costs of time, fatalities and injuries are presented in **Table 22**. [3] and [4] were used as references for these values.

Table 22. Unit costs.

Variable	Best estimate	Low estimate	High estimate	Unit
Unit cost of time, u_t	0.515	0.343	1.030	€ per hour of additional travel time
Unit cost of fatalities, u_Z	2,000,000	1,333,333	4,000,000	€ per fatality
Unit cost of injuries, u_Z	300,000	200,000	600,000	€ per injury

References

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