Seismic Risk Assessment for Production Scenario "Basispad Kabinet" for the Groningen field

Addendum to:

Induced Seismicity in Groningen Assessment of Hazard, Building Damage and Risk (November 2017)

June 2018

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Errata:

Since the document was submitted to the Ministry of Economic Affairs and Climate Policy, the following extensions have been incorporated:

- A summary in Dutch (Nederlandse Samenvatting) has been added.
- On page 46 the word North-East has been replaced by North-West in the second paragraph.
- In figure 5.7 maps were shown for the even years only. Maps for the uneven years have been added.
- The numbering of the figures in section 5 has been corrected. The version shared with the Minister had two figures both labelled fig. 5.7.
- In Figure 5.8 maps were shown for the even years only. Also, here maps for the uneven years have been added.
- Appendix D has been added. This addresses the impact of a production scenario, based on exclusively cold temperature years, on the mean LPR.

Contents

Nederlandse Samenvatting

In de dreigings-, gebouwenschade- en risicoinschatting van november 2017 (Ref. 1), is het seismische risico voor een productiescenario van 24 miljard m^3 per jaar gepresenteerd. In een brief aan de Tweede Kamer (Ref. 2) presenteerde de Minister van Economische Zaken en Klimaat een nieuw productiescenario, het "Basispad Kabinet", dat een vermindering van de productie uit het Groningen-veld laat zien, die uiteindelijk zal leiden tot stopzetting van de productie in 2030.

Gebaseerd op dezelfde werkprocessen en modellen als gebruikt in Ref. 1, wordt in dit document een seismische dreigings- en risicoinschatting voor het productiescenario "Basispad Kabinet" gepresenteerd. De gevraagde resultaten van de dreigings- en risicoinschatting zijn gespecificeerd in de Verwachtingenbrief (Ref. 3) die de Minister van Economische Zaken en Klimaat op 2 mei 2018 aan de NAM stuurde. In deze Verwachtingenbrief wordt naast het rapport over de dreigings- en risicoinschatting ook een operationele strategie voor het gasjaar 2018/2019 gevraagd die de operationele implementatie van de nieuwe productiestrategie voor het Groninger systeem bevat (Ref.7). Samen met deze dreigings- en risicoinschatting is het overeenkomstige document "Bouwstenen voor Operationele Strategie Groningenveld 2018/2019" ingediend.

Rekening houdend met het Wijzigingsbesluit (Ref. 4), de inzichten die zijn verkregen in de optimalisatiestudie (Ref. 5) en het advies van SodM aan de Minister (Ref. 6) zijn productieprognoses gemaakt voor het scenario "Basispad Kabinet" op basis van de gemiddelde temperatuur voor een jaar, koude jaren en warme jaren. Als gevolg van de afnemende productie uit het Groningenveld, zal het aantal aardbevingen per jaar en de dreiging na verloop van tijd afnemen. Zo zal de kans op een aardbeving groter dan $M_L = 3{,}6$ (de aardbeving in Huizinge) naar verwachting in 2023 dalen tot ongeveer 7% per jaar. Ter vergelijking, in de risicoinschatting van november 2017, die gebaseerd is op een productiescenario van 24 miljard m^3 per jaar, zou deze kans in 2023 groter dan 20% per jaar zijn. Dezelfde reductie komt ook tot uitdrukking in de dreigingskaarten. De grootste PGA in de dreigingskaart (gebaseerd op een herhaaltijd van eens in de 475 jaar) zal naar verwachting afnemen van de huidige 0,18 g tot 0,11 g (de grootste PGA gemeten tot nu toe) in 2031. De dreiging zal echter niet gelijkmatig over het veld verminderen. In de latere jaren concentreert de dreiging zich vooral in het gebied ten noordoosten van Loppersum. Dit is consistent met de nivellering van de reservoirdruk gedurende deze latere jaren. Het gas uit het hogedrukgebied ten noordwesten van Loppersum zal naar het zuidoostelijke gebied met een lagere druk blijven stromen, waardoor de druk in dit noordwestelijke gebied verder zal afnemen.

Het lokale persoonlijk risico (LPR) werd voor elk gebouw in de regio van het Groningen veld voor elk jaar van de periode 2018-2027 geëvalueerd. In 2019 is er geen enkel gebouw dat niet voldoet aan de tijdelijk veiligheidsnorm van 10^{-4}/jaar, maar zo'n 1.500 gebouwen voldoen niet aan de veiligheidsnorm van 10^{-5}/jaar voor aardbevingsrisico zoals vastgesteld door de Minister van Economische Zaken en Klimaat op advies van de Commissie Meijdam (Ref. 8 to 10). Dit aantal daalt echter in de loop van de tijd tot minder dan 100 gebouwen in 2024. Ter vergelijking, in de dreigings-, gebouwenschade- en risicoinschatting van november 2017 (Ref.1), die is gebaseerd op een productiescenario van 24 miljard m^3 per jaar, stijgt dit aantal gebouwen van 2.545 in 2019 naar 3.228 in 2023. Kaarten tonen aan dat gebouwen die de 10^{-5}/jaar Meijdam-norm overschrijden tegen 2024 allemaal ten noordwesten van Loppersum liggen.

De dreigings- en risicoinschatting is een probabilistische inschatting van het risico van afzonderlijke gebouwen in het Groningen-veld. De probabilistische inschatting van het aantal gebouwen waar de Meijdam-norm wordt overschreden, vertaalt zich niet direct in een weergave van de structurele versterking. De dreigings- en risicoinschatting biedt een hulpmiddel voor het stellen van prioriteiten bij bouwinspecties. Uiteindelijk zal de omvang van de daadwerkelijke versterking gebaseerd zijn op de inschatting van individuele gebouwen op basis van de NEN-NPR-bouwcode.

Op 6 juni 2018 stuurde de Minister van Economische Zaken en Klimaat een brief aan de Tweede Kamer met informatie over de voortgang van de maatregelen om de productie uit het Groningen-veld te beëindigen (Ref. 11). In deze brief wordt verwezen naar een aantal aanvullende maatregelen die nog niet waren opgenomen in het productiescenario “Basispad Kabinet” zoals gepresenteerd op 29 maart 2018. De risico-impact van een scenario op basis van deze aanvullende maatregelen om de vraag naar gas in Groningen te verminderen, is niet beoordeeld, maar zou het risico verder verlagen ten opzichte van de schattingen in dit rapport.

References

1. Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017, NAM (Jan van Elk and Dirk Doornhof), November 2017.
2. Letter to Parliament “Gaswinning Groningen”, 29th March 2018, Minister of Economic Affairs and Climate Policy.
3. Letter “Verwachtingenbrief aanvulling winningsplan Groningenveld 2016” to NAM, 2nd May 2018, Minister of Economic Affairs and Climate Policy.
4. Wijziging Instemmingsbesluit Winningsplan Groningenveld, Ministerie van Economische Zaken, Directoraat-Generaal Energie, Telecom & Mededinging, Directie Energie en Omgeving, 23 May 2017
5. Optimisation of the distribution of production over the Groningen field to reduce Seismicity, Leendert Geurtsen and Per Valvatne, December 2017.
6. Advies Groningen-gasveld n.a.v. aardbeving Zeerijp van 8 januari 2018 and Brief aan de minister over advies Groningen-gasveld dd. 1 februari, SodM, 1st February 2018.
7. Bouwstenen voor Operationele Strategie Groningenveld 2018/2019, NAM (with contributions from Gasterra and GTS transport Services), June 2018.
8. Eerste advies Adviescommissie ‘Omgaan met risico’s van geïnduceerde aardbevingen’ 23rd June 2015,
9. Tweede advies Omgaan met hazard- en risicoberekeningen in het belang van handelingsperspectief voor Groningen Adviescommissie ‘Omgaan met risico’s van geïnduceerde aardbevingen’ 29th October 2015,
10. Eindadvies Handelingsperspectief voor Groningen Adviescommissie ‘Omgaan met risico’s van geïnduceerde aardbevingen’ (Commissie-Meijdam), 14th December 2015,
11. Letter to Parliament “Betreft Voortgang maatregelen gaswinningsbrief”, 6 juni 2018, Minister of Economic Affairs and Climate Policy.

English Summary

In the Hazard, Building Damage and Risk Assessment of November 2017 (Ref. 1), the seismic risk for a 24 Bcm/year production scenario was presented. In a letter to Parliament (Ref. 2) the Minister of Economic Affairs and Climate Policy presented a new production scenario, “Basispad Kabinet”, which shows a reduction in production from the Groningen field, ultimately leading to cessation of production by 2030.

In this document, using the same workflow and models as used in Ref. 1, a seismic hazard and risk assessment for the production scenario “Basispad Kabinet” is presented. The required deliverables from the Hazard and Risk Assessment were specified in the Expectation Letter (Verwachtingenbrief) (Ref. 3), which the Minister of Economic Affairs and Climate Policy sent to NAM on 2nd May 2018. In this Expectation Letter, in addition to the Hazard and Risk Assessment report, also an Operational Strategy for gas-year 2018/2019 was requested which contains the operational implementation of the production strategy for the Groningen System (Ref. 7). Together with this Hazard and Risk Assessment, a document “Bouwstenen voor Operationele Strategie Groningenveld 2018/2019” will be submitted.

Taking into account the Wijzigingsbesluit (Ref. 4), the insights obtained in the Optimisation Study (Ref. 5) and the Advice to the Minister by SodM (Ref. 6) production forecasts were made for scenario “Basispad Kabinet” based on average temperature years, cold temperature years and warm temperature years. As a result of the declining production from the Groningen field, the seismic event rate and the hazard will reduce over time. For instance, the chance of an earthquake with a magnitude larger than M_L=3.6 (the magnitude of the Huizinge earthquake) is expected to reduce to some 7% per year by 2023. For reference, in the Risk Assessment of November 2017, which was based on a production scenario of 24 Bcm/year, this was expected to be more than 20% per year by 2023. The same reduction is also reflected in the hazard maps. The largest PGA in the hazard map (based on a 475 return-period) is expected to decline from the current 0.18 g to 0.11 g (the largest PGA measured to date) by 2031. However, the hazard will not reduce equally over the field. In the later years, the hazard is primarily located in the area North-East of Loppersum. This is consistent with the equilibration of reservoir pressures during these later years. The gas from the higher-pressure area to the North-West of Loppersum will continue to flow to the lower pressure South-Eastern area, causing a continued decrease of pressure in this area.

The Local Personal Risk (LPR) was assessed for each building in the Groningen area for each year of the period 2018-2027. During 2019, there is not a single building that does not meet the 10^{-4}/year temporary Safety Norm level, but some 1,500 buildings do not conform to the 10^{-5}/year Safety Norm level for earthquake risk set by the Minister of Economic Affairs and Climate Policy on advice of the Committee Meijdam (Ref. 8 to 10). However, this number declines with time to below 100 buildings by 2024. For reference, in the Hazard, Building Damage and Risk Assessment of November 2017 (Ref. 1), which was based on a 24 Bcm/year production scenario, this number of buildings increased from 2,545 in 2019 to 3,228 in 2023. Maps show that by 2024, buildings exceeding the 10^{-5}/year Meijdam Norm are all located North-West of Loppersum.

The Hazard and Risk Assessment is a probabilistic assessment of the risk of individual buildings located in the Groningen field area. The probabilistic estimate of the number of buildings where the Meijdam-Norm is exceeded, does not directly translate into an estimate of the structural strengthening scope. The Hazard and Risk Assessment provides a useful tool for prioritisation of building inspections. Ultimately the structural upgrading scope will be based on the assessment of individual buildings based on the NEN-NPR building code.

On 6/6/2018 the Minister of Economic Affairs sent a letter to Parliament informing on the progress of the measures to end production from the Groningen field (Ref.12). In this letter, a number of additional measures are referenced that were not yet incorporated in the ‘Basispad Kabinet as presented on 29th March 2018. The risk impact of a

scenario based on the maturation of these additional measures to reduce Groningen gas demand is not assessed, but would directionally reduce the risk further as compared to the estimates provided in this report.

References

1 Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017, NAM (Jan van Elk and Dirk Doornhof), November 2017.

2 Letter to Parliament "Gaswinning Groningen", 29th March 2018, Minister of Economic Affairs and Climate Policy.

3 Letter "Verwachtingenbrief aanvulling winningsplan Groningenveld 2016" to NAM, 2nd May 2018, Minister of Economic Affairs and Climate Policy.

4 Wijziging Instemmingsbesluit Winningsplan Groningenveld, Ministerie van Economische Zaken, Directoraat-Generaal Energie, Telecom & Mededinging, Directie Energie en Omgeving, 23 May 2017

5 Optimisation of the distribution of production over the Groningen field to reduce Seismicity, Leendert Geurtsen and Per Valvatne, December 2017.

6 Advies Groningen-gasveld n.a.v. aardbeving Zeerijp van 8 januari 2018 and Brief aan de minister over advies Groningen-gasveld dd. 1 februari, SodM, 1st February 2018.

7 Bouwstenen voor Operationele Strategie Groningenveld 2018/2019, NAM (with contributions from Gasterra and GTS transport Services), June 2018.

8 Eerste advies Adviescommissie 'Omgaan met risico's van geïnduceerde aardbevingen' 23rd June 2015,

9 Tweede advies Omgaan met hazard- en risicoberekeningen in het belang van handelingsperspectief voor Groningen Adviescommissie 'Omgaan met risico's van geïnduceerde aardbevingen' 29th October 2015,

10 Eindadvies Handelingsperspectief voor Groningen Adviescommissie 'Omgaan met risico's van geïnduceerde aardbevingen' (Commissie-Meijdam), 14th December 2015,

11 Letter to Parliament "Betreft Voortgang maatregelen gaswinningsbrief", 6 juni 2018, Minister of Economic Affairs and Climate Policy.

1 Introduction

Winningsplan 2016

In April 2016, NAM submitted the Groningen Winningsplan 2016 (Ref. 1) to the Minister of Economic Affairs and Climate Policy. This Winningsplan was accompanied by a Technical Addendum (Ref. 2) providing further background to the hazard and risk assessments used in the Winningsplan. The Mining Law requires that winningsplannen are approved by the Minister of Economic Affairs and Climate Policy. The approval was granted in the Instemmingsbesluit Winningsplan Groningenveld, issued on the 30th of September 2016 (Ref. 3).

Hazard and Risk Assessment November 2017

In response to the specific obligation in the Instemmingsbesluit, NAM prepared the report "Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017" (Ref. 5), which was submitted to the Minister of Economic Affairs and Climate Policy and to SodM on 1st November 2017. This describes the full hazard and risk assessment for induced seismicity in Groningen, starting from the production of gas (the cause) to the effects on people and buildings.

The Wijzigingsbesluit of 24th May 2017 (Ref. 4), limited the production in an average temperature year to 21.6 Bcm/year. However, in the Wijzigingsbesluit special circumstances were identified that could require an increase in the production from the field: (1) a year with lower than average ambient temperatures or (2) upsets in the gas production and distribution system. The Hazard and Risk Assessment of November 2017 (Ref. 5) was therefore prudently based on an average annual production level of 24 Bcm/year gas production, which covered these eventualities.

Complementary production scenarios

To assess the effect of different production scenarios on seismic risk, a complementary set of production scenarios covering a wide range of production levels was presented in the addendum to the November 2017 Hazard and Risk Assessment, in Reference 6, issued March 2018. The set of production scenarios analysed included the production aspirations as outlined in the Regeerakkoord (10/10/2017) and several production scenarios as included in reports by GTS, which were based on different utilisation of the existing nitrogen blending plant and the construction of an additional nitrogen blending plant. The same workflow and model suite was utilized as used in "Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017" issued March 2018 (Ref. 5).

Basispad Kabinet (29/3/2018)

The letter sent by the Minister of Economic Affairs and Climate Policy to Parliament (Kamerbrief) on 29th March 2018 (Ref. 7) announced the ambition of the cabinet to reduce the production from the Groningen field as soon as possible, leading to cessation of production around 2030. It contained annual production volumes for the period 2018-2031, which was labelled "Basispad Kabinet" (Fig. 1.1 and 1.2).

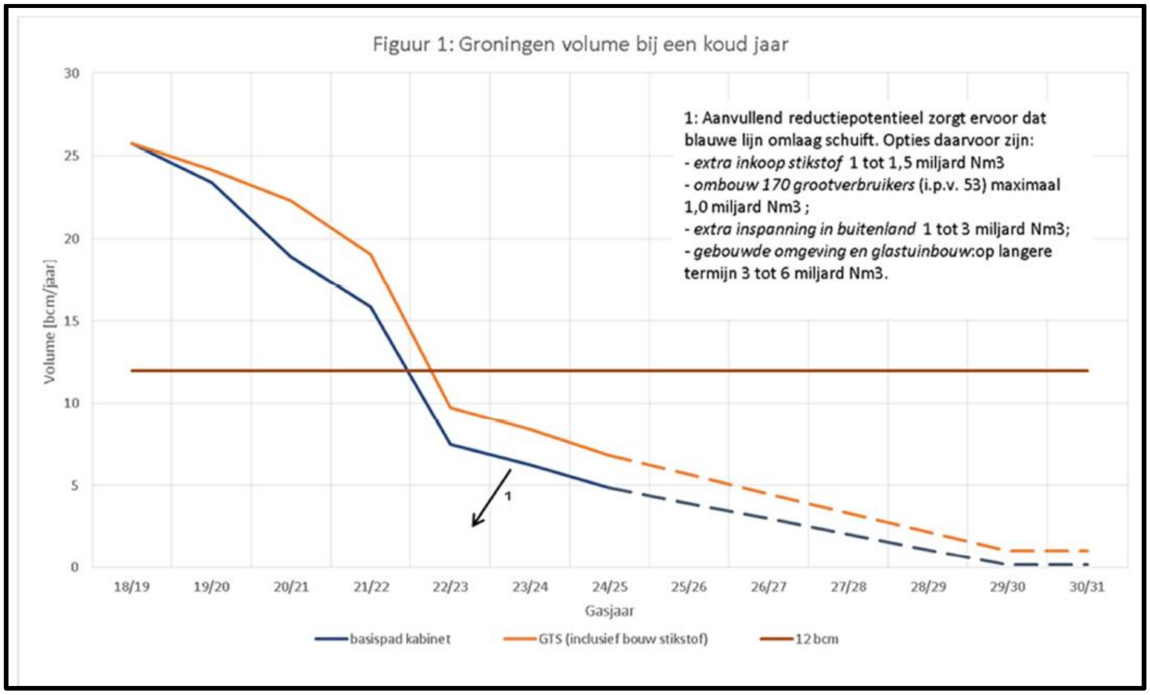


Figure 1.1 *Production scenario prepared by GTS (including construction of a nitrogen blending plant) in orange and production scenario "Basispad Kabinet" in blue from reference 7. Both these production scenarios are for a sequence of cold ambient temperature years.*

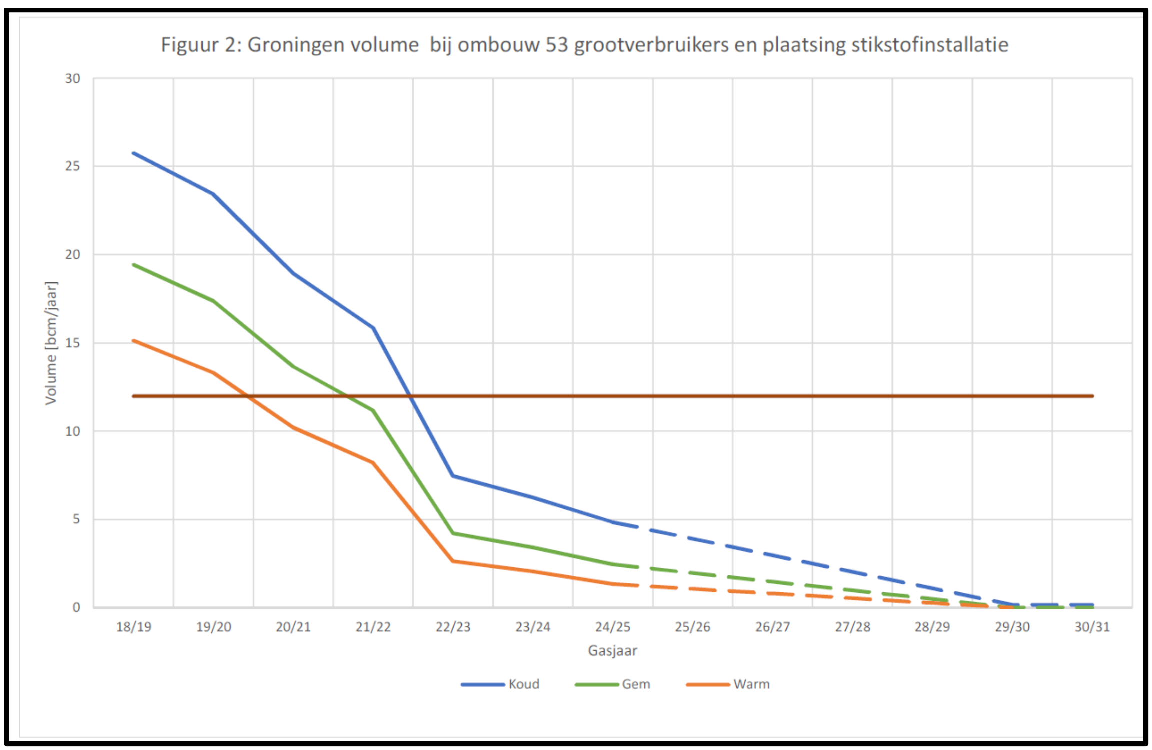


Figure 1.2 *Production scenario "Basispad Kabinet" for a sequence of cold temperature years (in blue), average temperature years (in green) and of warm temperature years (in orange) from refence 7.*

Expectation Letter (2/5/2018)

An Expectation Letter (Verwachtingenbrief) was sent to NAM on 2nd May 2018 (Ref. 8 and Appendix B) by the Minister of Economic Affairs and Climate Policy. It details the expectations for further NAM technical studies in preparation of a new Winningsplan decision (due by 15th November 2018 latest). NAM was requested to perform a hazard and risk assessment for the “Basispad Kabinet” scenario, to indicate the impact of the strong reduction of production on safety risk and the scope of the structural upgrading needed to comply with the Meijdam-Norm (Ref. 9 to 11). With the Expectation Letter the Minister of Economic Affairs and Climate Policy has provided the Groningen gas-quality demand dataset to NAM which served as basis for the HRA.

In an addendum to the Expectation Letter, the request was further described. NAM was requested to provide (translated from Expectation Letter) (Ref. 8):

1. *A Hazard & Risk Assessment based on the “basispad” of the cabinet for a cold, average and warm year, such that for the assessment of the warm and cold year the principle is used that the years preceding and following the warm or cold temperature year are average temperature years. This is based on an 85% utilisation of the combined use of Ommen and Wieringermeer. The detailed production (per month) is documented in an excel sheet shared digitally with NAM.*
2. *For the distribution of the production over the different production clusters and regions NAM will use the results of the Optimisation Study of December 2017, taking into account the volume restrictions imposed by SodM based on the Zeerijp-advice (1 February 2018).*
3. *NAM will as a reference perform a risk assessment for the 24 Bcm/year scenario of the Hazard and Risk Assessment of 1st November 2017.*
4. *For each production scenario the number of people and buildings at risk will be assessed in line with the advice of the Committee Meijdam. Both a mean value and the uncertainty band will be provided.*
5. *The results for both scenarios will be provided as:*
   a) *Annual assessment of risk (hazard maps and LPR-Curves) for each to the first 10 years.*
   b) *5-yearly assessment of risk for the next 15 years.*
   c) *NAM will provide for each scenario de following graphs:*
      i. *Buildings mean and uncertainty band LPR>10^{-4}/year against time;*
      ii. *Buildings mean and uncertainty band LPR>10^{-5}/year against time;*
   d) *Map of the locations of the buildings with a chance that these are member of a building typology with a chance of a fatality > 10^{-4}/year;*
   e) *Map of the locations of the buildings with a chance that these are member of a building typology with a chance of a fatality > 10^{-5}/year;*
   f) *NAM will also provide these data in a table.*
   g) *Table with all building typologies with a risk >10^{-4}/year and >10^{-5}/year.*

The current report provides the requested Hazard and Risk Assessment based on the requested optimisation strategy and present the associated maps and graphs.

It should be noted, the provided demand profiles sent 2nd May 2018 includes some small deviations from the “Basispad Kabinet” scenario as presented by the minister in his March 28th Letter to Parliament, because of different underlaying assumptions (Figure 1.3). Further on in this report, when “Basispad Kabinet” is mentioned, it will refer to these 2nd of May production profiles.

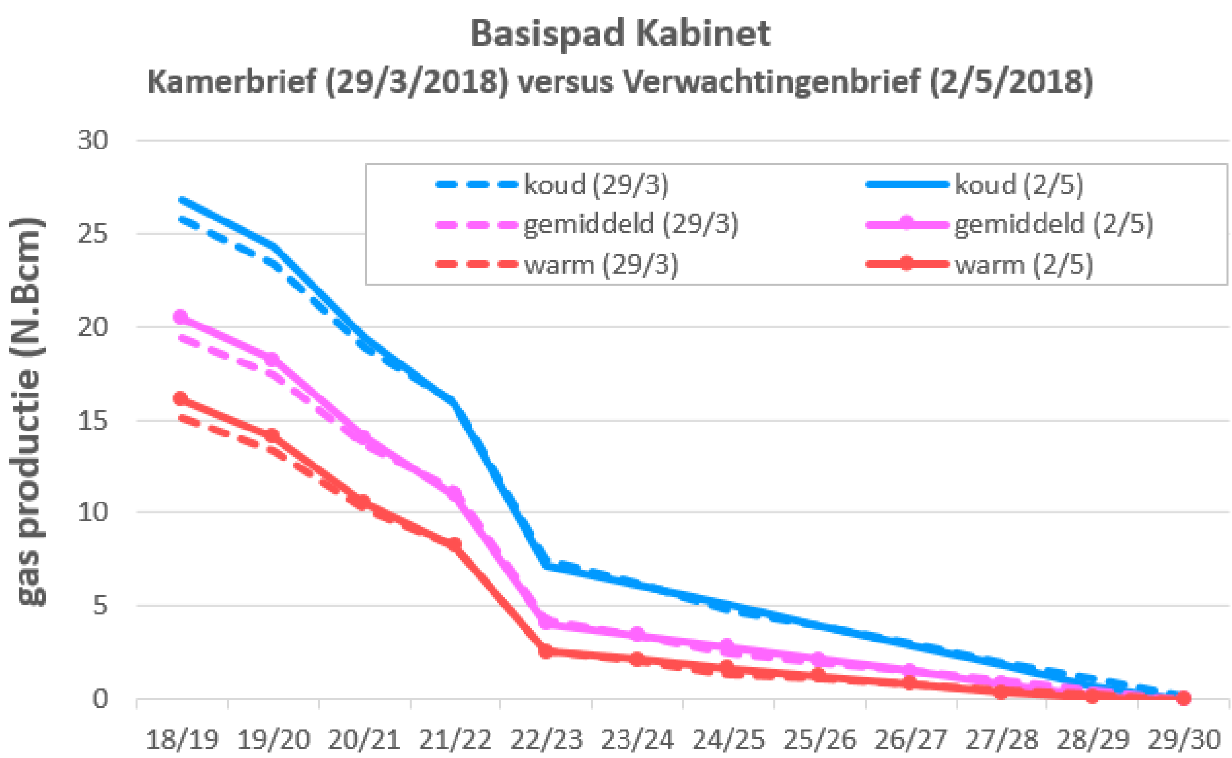


Figure 1.3 *"Basispad Kabinet" for the annual production from the Groningen field, Kamerbrief (29/3/2018) versus Expectation Letter (2/5/2018). Note small differences in the first two gas-years.*

Kamerbrief - Voortgang maatregelen gaswinningsbrief (6/6/2018)

On 6/6/2018 the Minister of Economic Affairs sent a letter to Parliament informing on the progress of the measures to end production from the Groningen field (Ref.12). In this letter, a number of additional measures are referenced that were not yet incorporated in the "Basispad Kabinet" as presented on 29th March 2018. The risk impact of a scenario based on the maturation of these additional measures to reduce Groningen gas demand is not assessed, but would directionally reduce the risk further as compared to the estimates provided in this report.

1.1 References

All reports referenced in this section prepared by NAM can be downloaded from the webpage "onderzoeksrapporten" on www.nam.nl.

1. Winningsplan Groningen – 2016, NAM, April 2016
2. Technical Addendum to the Winningsplan Groningen 2016 - Production, Subsidence, Induced Earthquakes and Seismic Hazard and Risk Assessment in the Groningen Field, Parts I to 5, Nederlandse Aardolie Maatschappij BV (Jan van Elk, Jeroen Uilenreef and Dirk Doornhof, eds), April 2016
3. Instemmingsbesluit Winningsplan Groningenveld, Ministerie van Economische Zaken, Directoraat-generaal Energie, Telecom & Mededinging, Directie Energie en Omgeving, 30 September 2016
4. Wijziging Instemmingsbesluit Winningsplan Groningenveld, Ministerie van Economische Zaken, Directoraat-Generaal Energie, Telecom & Mededinging, Directie Energie en Omgeving, 23 May 2017
5. Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017, NAM (Jan van Elk and Dirk Doornhof), November 2017.
6. Seismic risk assessment for a selection of seismic risk production scenarios for the Groningen field - Addendum to: Induced Seismicity in Groningen Assessment of Hazard, Building Damage and Risk (November 2017), Jan van Elk, Assaf Mar-Or, Leendert Geurtsen, Per Valvatne, Eddy Kuperus and Dirk Doornhof, March 2018.
7. Letter to Parliament "Gaswinning Groningen", 29th March 2018, Minister of Economic Affairs and Climate Policy.
8. Letter "Verwachtingenbrief aanvulling winningsplan Groningenveld 2016" to NAM, 2nd May 2018, Minister of Economic Affairs and Climate Policy.
9. Eerste advies Adviescommissie 'Omgaan met risico's van geïnduceerde aardbevingen' 23rd June 2015,
10. Tweede advies Omgaan met hazard- en risicoberekeningen in het belang van handelingsperspectief voor Groningen Adviescommissie 'Omgaan met risico's van geïnduceerde aardbevingen' 29th October 2015,
11. Eindadvies Handelingsperspectief voor Groningen Adviescommissie 'Omgaan met risico's van geïnduceerde aardbevingen' (Commissie-Meijdam), 14th December 2015
12. Letter to Parliament "Betreft Voortgang maatregelen gaswinningsbrief", 6 juni 2018, Minister of Economic Affairs and Climate Policy.

2 Production scenarios definition

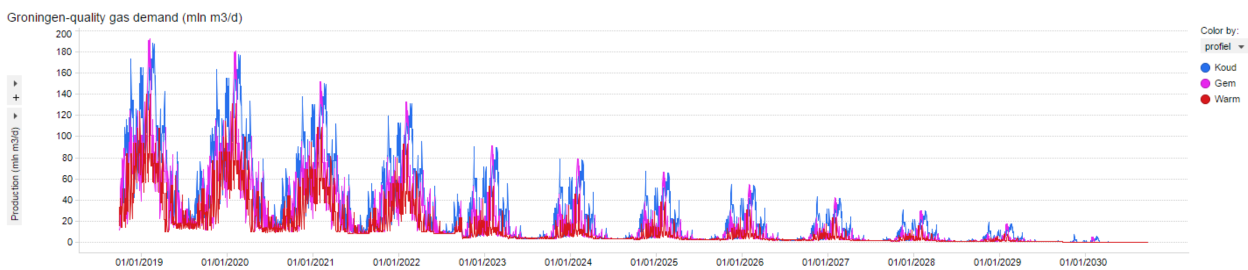
2.1 "Basispad Kabinet" for a Cold/Average/Warm temperature profile (Expectation Letter).

Total Groningen-quality gas demand in excess of the pseudo-Groningen gas

Detailed demand profiles (on a daily basis) were provided by the Ministry of Economic Affairs and Climate Policy (by means of an Expectation Letter) for the total Groningen-quality gas production in excess to the other L-gas supply sources, based on GTS studies, up to 30/9/2030 during either a cold, average or warm (gas)year[1], Figure 2-1.

These demand profiles assume an average of 85% utilisation of the GTS nitrogen blending plant, and do not distinguish between gas produced from Groningen field, UGS Norg or PGI Alkmaar nor the volumes required for injection in UGS Norg and PGI Alkmaar. These demand profiles were constructed by projecting historic temperature profiles for a cold (1985/1986), average (2011/2012) and a warm (2006/2007) gas-year on a L-gas market demand model including anticipated future demand reduction.

The "Basispad Kabinet" cold and warm production profiles give the extreme temperature end members from the past 31 years. Consecutive occurrence of 10 warm, average or cold years is highly unlikely.



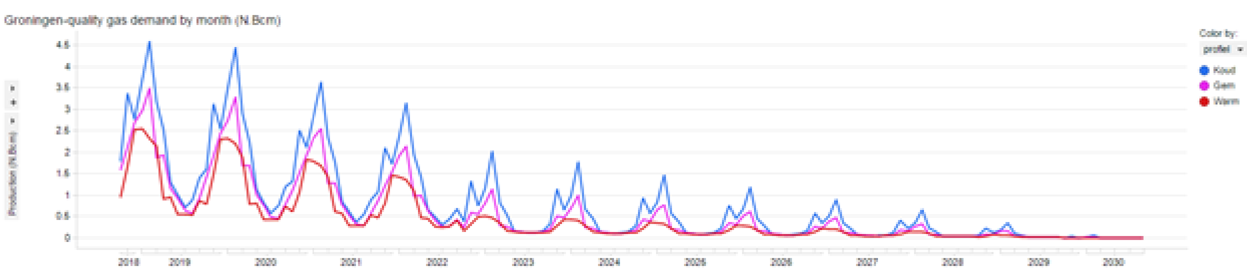


Figure 2-1 Groningen quality market demand in excess to the other L-gas supply sources for a sequence of cold, average and warm temperatures years. Top graph represents daily volume and bottom graph reflects monthly demand volume.

Groningen production

Both the Hazard and Risk Assessment as described in this document and the accompanying operational strategy have to be considered together. The Groningen gas field is part of the Groningen Production System. Here GasTerra[2] plays an important role, as they have knowledge on the L-gas market demand throughout the year and determine

1 Gas-year runs from 1 October to 30 September

2 The role of Gasterra in the operation of the Groningen System is addressed in the "Bouwstenen voor Operationele strategie Groningenveld 2018/2019", (Ref. 7).

the use of the L-gas resources in its portfolio and the deployment of the Groningen field to allow the L-gas market to function.

The dataset provided in the Expectation Letter has been worked by GasTerra to establish the utilisation of the Groningen System, and determine volumes produced from UGS Norg, PGI Alkmaar and Groningen field. It assumes the underground gas storages UGS Norg and PGI Alkmaar to be volume neutral over the gas-year, because it is filled with gas from the Groningen field in summer which gets produced during cold periods in winter. Furthermore it is assumed that the Alkmaar facility is filled with pseudo-G-gas, and can compensate for 0.5 N.Bcm/year of gas production from the Groningen field.

The applied methodology to determine the utilisation of Groningen system assets is based on perfect insight on future temperature profile (e.g. weather conditions are upfront known for every single day in future). This perfect insight assumption is a deterministically approach and is similar to the methodology applied by GTS. This Groningen system assets utilisation outcome is therefore to a degree theoretical, and does not cater for certain market uncertainties.

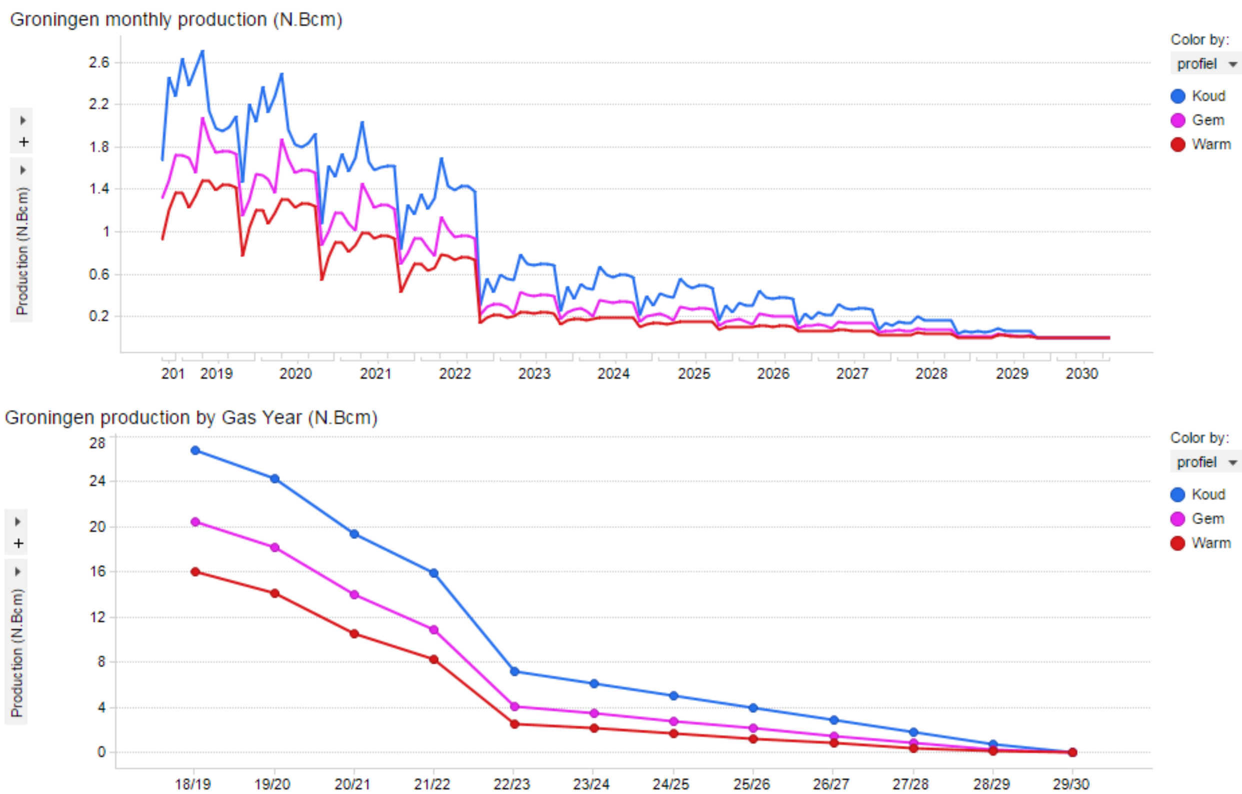


Figure 2-2 *Groningen field production profiles for cold, average and warm temperatures as outcome of GasTerra analysis. Top monthly production volumes, bottom annual production volumes.*

The requirement to fill Norg UGS in the summer has a flattening effect on the Groningen production profile, and actually leads to a seasonal production profile with higher production in summer than in winter for the average and warm production profiles, Figure 2-3.

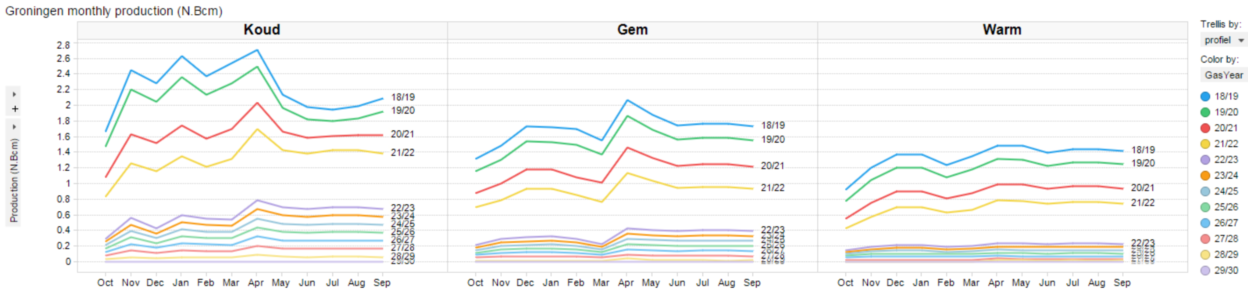


Figure 2-3 Monthly production fluctuation by gas-year for cold (left), average (middle) and warm (right) temperatures.

2.2 Spatial distribution of production

The Expectation Letter (Ref. 5) requires the distribution of production from the Groningen field to be reflecting the insights from NAM’s 2017 optimisation study (Ref. 4), whilst honouring the volume restrictions as advised by SodM in their report (Ref. 3) following the Zeerijp earthquake (8/1/2018).

> **Ad 1 Verwachtingen ten aanzien van de aanvullende Hazard & Risk Assessment**
>
> 2. Voor de verdeling van de productie over de verschillende clusters en regio’s wordt uitgegaan van NAM’s optimalisatiestudie uit december 2017, met dien verstande dat rekening wordt gehouden met volumebeperkingen die SodM naderhand in het “Zeerijp”-advies (1 februari 2018) heeft opgenomen (zie opsomming op p.2 van deze bijlage).

Excerpt from the Expectation Letter (Verwachtingenbrief aanvulling winningsplan Groningenveld 2016, 2/5/2018)

The results from NAM’s 2017 production optimisation study for seismicity are a function of the objective for which is optimised (e.g. event count, maxPGA, etc). However, all objective functions suggest prioritising production from the South-East of the field (Figure 2-4).

A further observation from the 2017 optimisation study is that production from the South-Western part of the field (clusters Kooipolder, Slochteren, Froombosch) seems to have a relatively strong non-linear effect on the analysed seismicity metrics. Consequently, production from this area should be minimized.

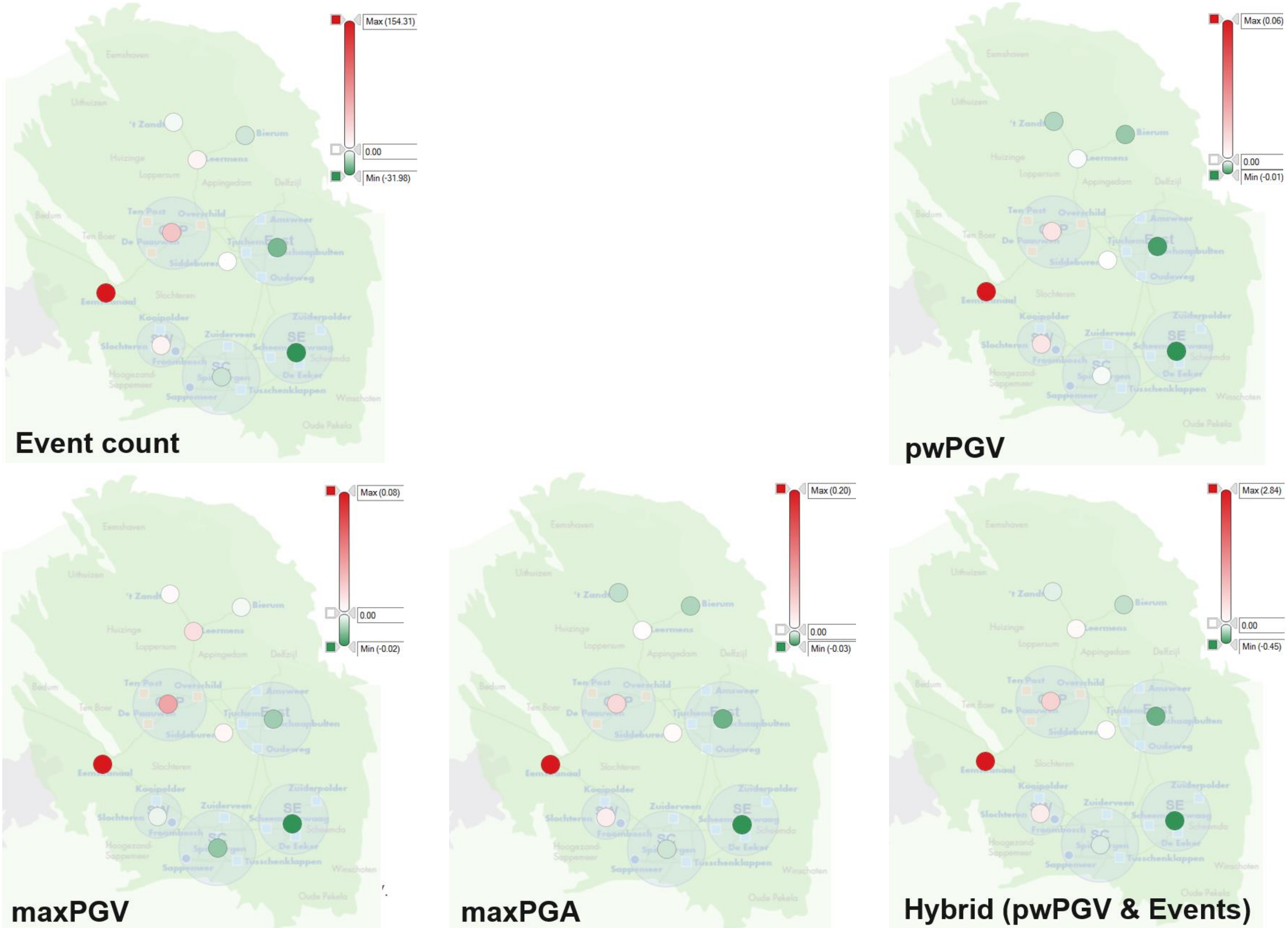


Figure 2-4: *Areal production optimization for various objective functions, based on partial dependence analysis on all objective functions. Increasing production from green coloured controls improves the response with respect to the objective function, red colours indicate deterioration, white colours indicate a neutral effect. After Figure 6-9 from Reference (Geurtsen & Valvatne, 1/12/2017)*

2.3 Production fluctuations

It was stated in the Expectation Letter that in addition to optimising production across the clusters and regions, the production should also reflect SodM's "Zeerijp-advies" to avoid production fluctuations.

> Productiefluctuaties conform advies SodM:
>
> - Beperking volumefluctuaties Bierum-cluster tot maximaal 20% per maand (met uitzondering van operationele omstandigheden, waaronder onderhoud en uitval)
> - Beperking regionale fluctuaties in de productie van de overige clusters tot het huidige niveau van +/- 50% per maand (behalve van het cluster EKL waarvoor een beperking tussen 0 – 150 mln m^3/maand geldt). De beperking van de fluctuaties van +/- 20% per maand voor de productie uit het gehele Groningenveld kan onder deze voorwaarde worden losgelaten.
> - Als referentie voor deze bandbreedtes in fluctuaties kan de gemiddelde productie over de afgelopen 12 maanden worden gehanteerd.

Excerpt from Expectation Letter (Verwachtingenbrief aanvulling winningsplan Groningenveld 2016, 2/5/2018)

The reduction of production fluctuations is addressed in the Building Block of the Operational Strategy (Ref. 7). In this document a probabilistic approach was used to analyse the utilisation of the Groningen system assets (Groningen field, UGS Norg and Alkmaar) for the gas-year 2018/2019, based on the 31 provided temperature profiles and the market demand model. The production fluctuations are related to temperature profile, yearly Groningen field volume offtake, spatial volume distribution over the field, UGS utilization and UGS work volume.

2.4 Model implementation

This section addresses the implementation of the spatial distribution and optimisation of production over the field as used in the modelling for the Hazard and Risk Assessment. The operational implementation in the Groningen field for gas-year 2018-2019 is addressed in the "Bouwstenen voor Operationele Strategie Groningenveld - 2018/2019" (Ref. 7).

In the Expectation Letter, the minister has depicted 5 regions (see table 2.1 and figure 2.5). To control the volume off-take for the regions (spatial distribution) a production cluster start-up sequence has been implemented in the model (see table 2.2). This is in line with both the request in the Expectation Letter to make use of the Optimisation Study results, as well as the operational strategy. The surface network model sequentially opens-up (groups of) clusters following the start-up sequence until the total required production demand is achieved. The Bierum production cluster (BIR) is kept at a constant offtake level and the Eemskanaal cluster (EKL) is assumed to produce at constant low rate from 1st October till 31st March and shut-in over summer. To reflect operational conditions (lower number of clusters in operation when low demand) and to optimise production within the cluster groups, further divisions have been introduced for the production clusters within regions East-Central and South-West, see table 2.2.

Region	Clusters
South-East	ZPD/SZW/EKR
East-Central	OWG/SCB/AMR/TJM/SDB
South-West	ZVN/SPI/ TUS-SAP/KPD/SLO-FRB
North	BIR
Eemskanaal	EKL

Table 2-1: Regions and cluster overview

Figure 2-5 Production regions as defined in the Expectation Letter

Start-up Priority	Region	Clusters
1	North	BIR (constant rate)
2	Eemskanaal	EKL (constant rate, winter only)
3	South-East	ZPD/SZW/EKR
4	East-Central (1)	OWG/SCB
5	South-West (1)	ZVN/SPI
6	East-Central (2)	AMR/TJM/SDB
7	South-West (2)	SAP/TUS
8	South-West (3)	KPD/SLO/FRB

Table 2-2: Production start-up list for achieving total required field production. Starting from the top of this list, groups of clusters are sequentially opened-up by the surface network model until the total required production can be achieved. The sequence was derived based on insights from the production optimisation study (see Fig. 2-4)

The second parameter to control volume off-take per region (spatial distribution) is the Load Factor. The Load Factor is the ratio of cluster production to its maximum capacity. It is calculated for each individual cluster at every timestep and a maximum value can be set as a constraint. A high maximum load factor will maximize volume withdrawal from clusters high in the start-up sequence, but at the same time also increase production fluctuations from clusters low in the start-up sequence (due to fluctuating demand).

It should be noted that, based on historic performance, the achieved load factor range is between 70% and 80%. A pre-set maximum load factor of 70% was found to be a good compromise between optimising production distribution while minimizing regional fluctuations. A maximum load factor of 90% was also tested and found to only give marginal improvements in seismic hazard and risk metrics.

2.5 References

1 Induced Seismicity in Groningen Assessment of Hazard, Building Damage and Risk – November 2017, NAM (Jan van Elk and Dirk Doornhof), November 2017.

2 Vertrouwen in de toekomst, Regeerakkoord 2017 – 2021 VVD, CDA, D66 en ChristenUnie, Section 3.3 Gaswinning, 10th October 2017.

3 Advies Groningen-gasveld n.a.v. aardbeving Zeerijp van 8 januari 2018, Staatstoezicht op de Mijnen, 1st February 2018.

4 Optimisation of the distribution of production over the Groningen field to reduce Seismicity, Leendert Geurtsen and Per Valvatne, December 2017.

5 Letter “Verwachtingenbrief aanvulling winningsplan Groningenveld 2016” to NAM, 2nd May 2018, Minister of Economic Affairs and Climate Policy.

6 Advies GTS leveringszekerheid middels scenario analyse, 27/3/2018, Gasunie Transport Services

7 Bouwstenen voor Operationele Strategie Groningenveld 2018/2019, NAM (with contributions from Gasterra and GTS transport Services, 2018.

3 Production scenario results

The production scenarios defined in Chapter 2 were simulated with the Groningen dynamic reservoir model (Ref. 1, 2 and 4). As described in Chapter 2, a proportional distribution of production per region is not a pre-described model constraint, but rather a result of the demand for Groningen gas that is a function of time and temperature profile. For every monthly timestep the model meets the demand through the use of the cluster start-up list (Table 2-2).

3.1 “Basispad Kabinet” – Average Temperature

Gas Production

The resulting production profile “Basispad Kabinet” for the average temperature outlook is given in Figure 3.1, split by production region[3]. Eemskanaal serves as a capacity provider, represented by continuous offtake of 2 mln m^3/d from 1 October till 31 March, and subsequently shut-in from October 2022. Bierum is assumed the be on continuous production of 6 mln m^3/d for gas-years 2018/19 and 2019/20, subsequently reduced to 4 mln m^3/d for 2020/21 and 2021/22, and shut-in from October 2022).

Between the various groups on the start-up list, South-East contributes the highest production share, some 30-40% prior to October 2022, and subsequently increasing to almost fully covering field production. The larger part of production demand is provided by the first four start-up groups (SE, CE1-2, SW1). The clusters close to Appingedam (CE2) are mainly required for the first 2 years only, and the clusters close to the city of Groningen (SW2-3) are required for capacity only.

[3] Production regions as defined in the Verwachtingenbrief, see Figure 2-5 of this report

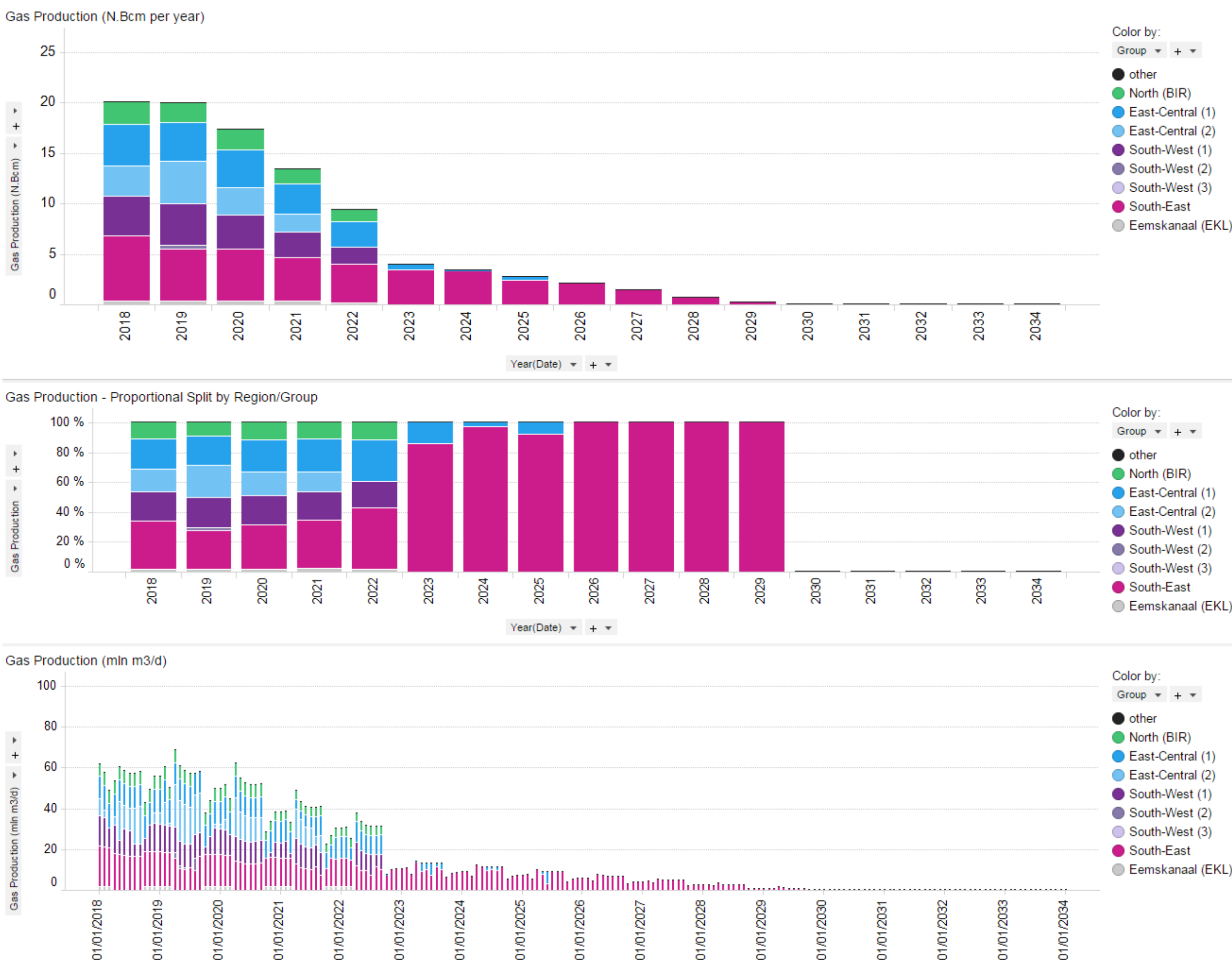


Figure 3-1: Production by region and start-up group (“Basispad Kabinet” – Average Temperature)

Reservoir pressure

The associated change in reservoir pressure in the direct vicinity of the production clusters is given in Figure 3.2 [4]. It can be observed that in the first few years the South-East clusters are most heavily utilized (steepest pressure decline and lowest overall reservoir pressure are observed in this area). Beyond 2021, the South-East production rates have decreased such that the effect of pressure equilibration across the entire reservoir becomes larger than the local depletion due to production. In other words, the gas flow from the higher pressure North-West of the field (Loppersum area) towards the more depleted South-East, becomes larger than the production from the South-East and the net effect is a stabilization and eventual increase of reservoir pressure in the entire South. The associated depletion in the Loppersum area is some 10 bar, following a relatively steady-state decline with no notable pressure fluctuations. The pressure fluctuations visible in the pressure response around the producing areas, due to production ramp-ups and cluster maintenance downtime, are fully dampened in the Loppersum area due to the distance from the producing clusters and the high compressibility of the gas.

Figure 3-3 shows a reservoir pressure map at 1/1/2018. The forecasted pressure decline over the next 5 years (1/1/2018 to 1/1/2023) is given in Figure 3.4. A consequence of the production distribution is that pressure decline is predominantly located in the South-East corner of the field. In the South-West corner of the field (clusters

4 Reservoir pressure is calculated by averaging the values in grid cells around the respective wells. The radius of this region is a function of permeability, but is typically in the order of a few hundred meters.

Kooipolder, Slochteren, Froombosch) a net increase in reservoir pressure of some 2-3 bar is observed. This is because the combined net influx from the North of the field and from the Eemskanaal block (both at higher pressures) is larger than the combined production (start-up group SW3 in Table 2-2) and outflux towards the South-East. Within the Eemskanaal block itself there is also a net pressure increase. This is the area of the Eemskanaal-13 well, which seized production in 2014. This area is now recharged by adjacent higher pressured blocks to the North and by the aquifer to the West of the field.

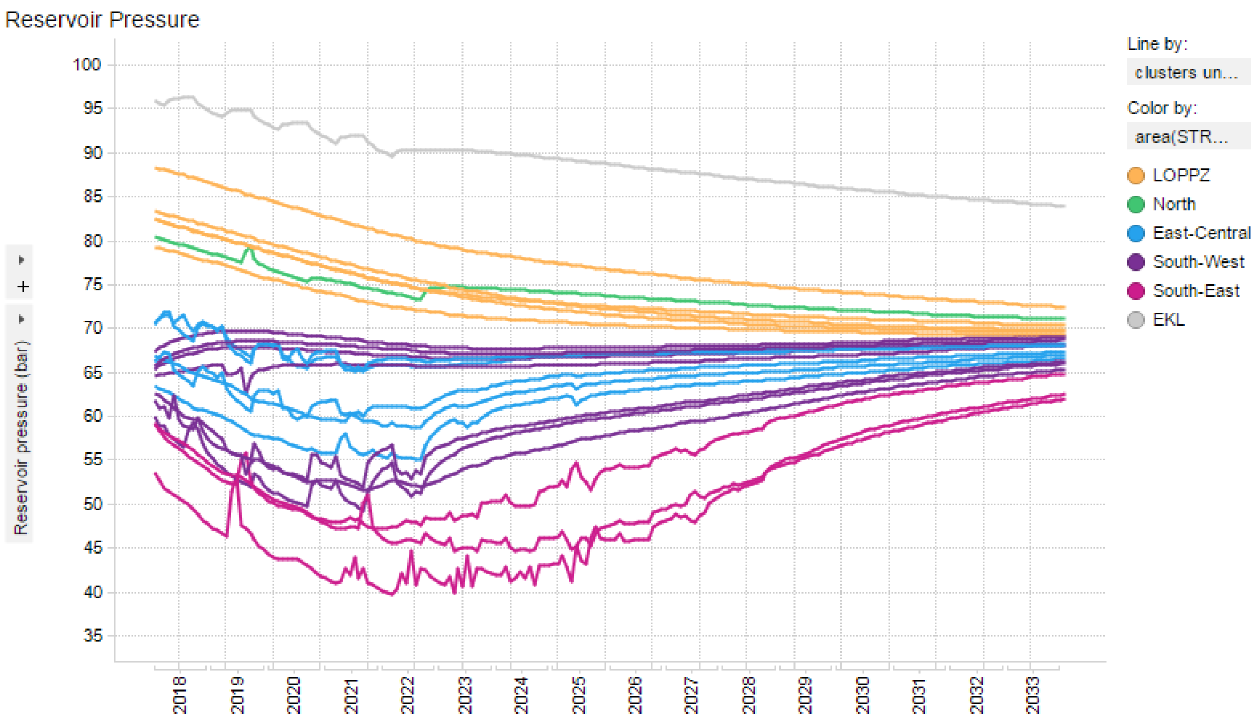


Figure 3-2: Reservoir pressure for “Basispad Kabinet” Average Temperature. Lines by production cluster, colours by production region.

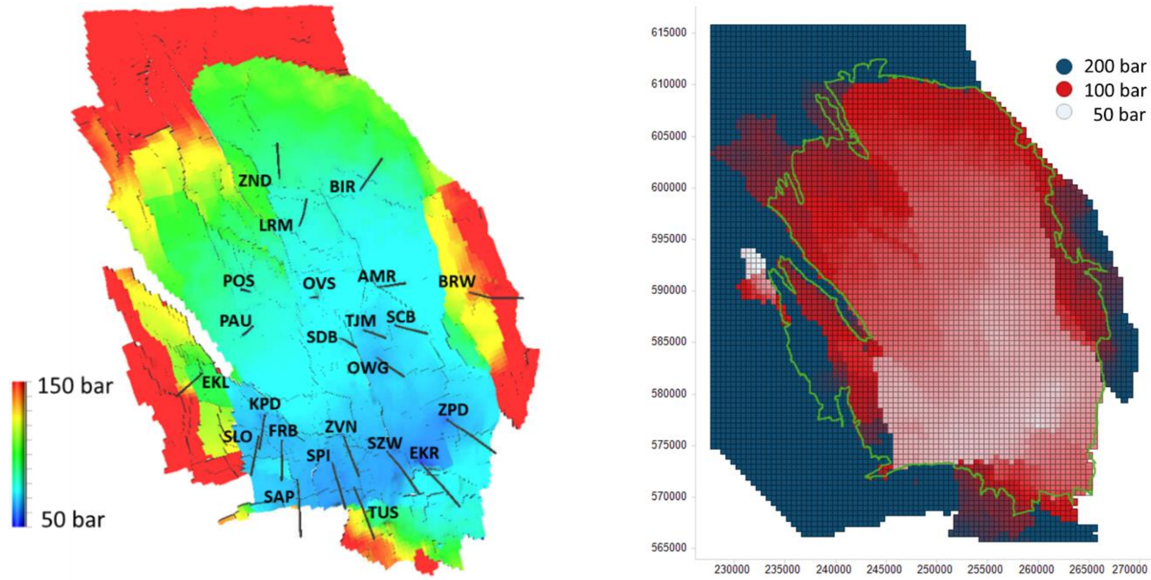


Figure 3-3: *Reservoir pressure at 1/1/2018. Both figures show the same data. On the left is the output from the reservoir simulator constrained to the Groningen field, while on the right is pressure used as input to the hazard and risk assessment.*

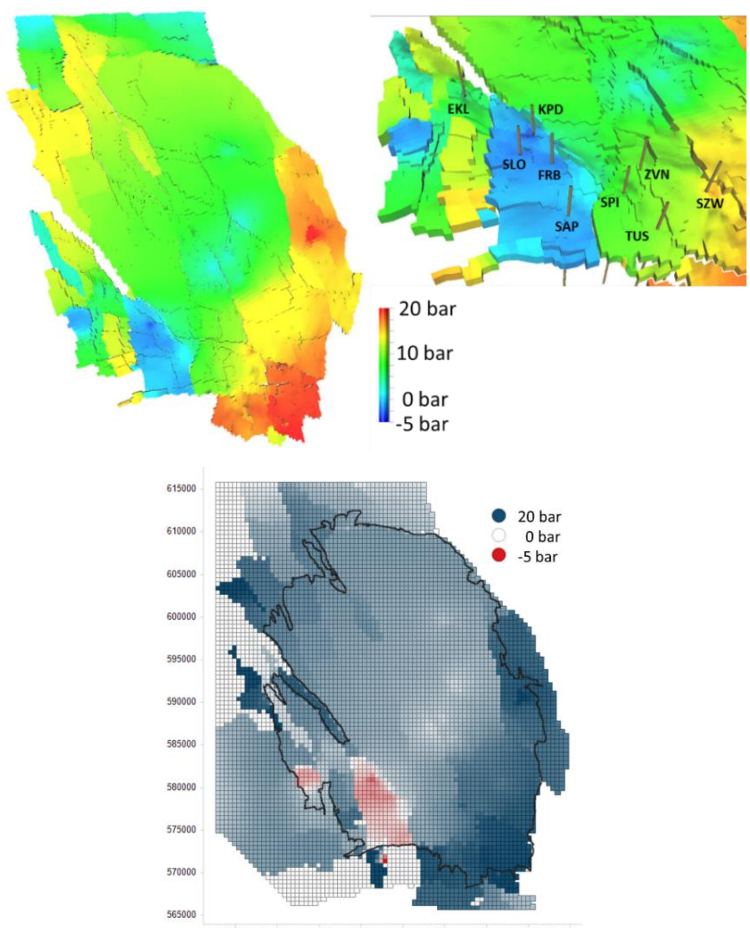


Figure 3-4 *Reservoir pressure decline from 1/1/2018 to 1/1/2023 for “Basispad Kabinet” – Average Temperature.*

Production capacity

Figure 3-5 compares the production to the available capacity in each region (under the unlikely assumption that all clusters remain available). The downward spikes in the region capacities are related to planned shutdowns of production clusters for maintenance and inspections, while the seasonal fluctuation in capacity is a reflection of the fact that the ambient temperature influences the efficiencies of the coolers and hence the total compressor efficiency. Another observation that can be made is that the production capacity is relatively constant through time for most regions. The South-East region shows a notable decline in capacity until 2022, after which the decline is halted and eventually capacity starts to increase again. This behaviour is a function of the reservoir pressure in the direct vicinity of the production clusters within each region. A declining reservoir pressure yields a declining production capacity, whereas an increasing reservoir pressure yields an increase in production capacity.

The associated load factors (fraction of total available capacity that is being produced) are given in Figure 3-6, reflecting the model implementation as outlined in section 2.4, with different start-up groups being ramped-up until overall field demand is met.

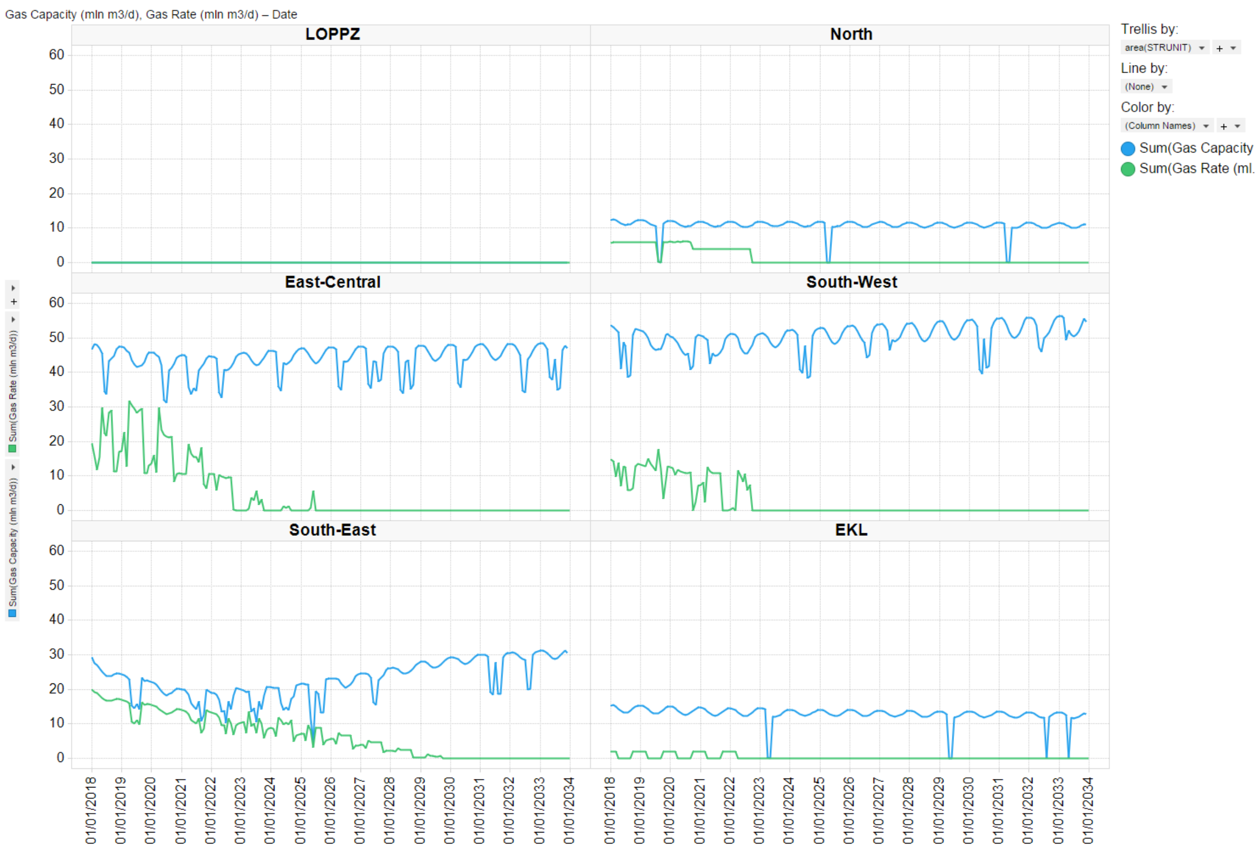


Figure 3-5: Forecasted production (green lines) and capacity (blue lines) per region for average temperature

Figure 3-6: Load Factor per region

3.2 "Basispad Kabinet" – Cold Temperature

The "Basispad Kabinet" cold and warm production profiles give the extreme temperature end members from the past 31 years. Consecutive occurrence of 10 warm, average or cold years is highly unlikely. However, analysing these end member profiles is useful to ensure that the operational philosophy is suitable to meet the demand, while minimizing seismic hazard and risk in periods of cold and warm temperature.

Gas Production

For the cold-temperature scenario, production volumes from the Bierum and Eemskanaal clusters were not increased compared to the average temperature base case. Figure 3.7 gives the regional break-down of the production profile, which now allocates more to the East-Central and South-West areas compared to the average temperature case. Due to being capacity constrained, the proportional share of the South-East clusters drops to about 20% in the years prior to the introduction of the nitrogen blending plant.

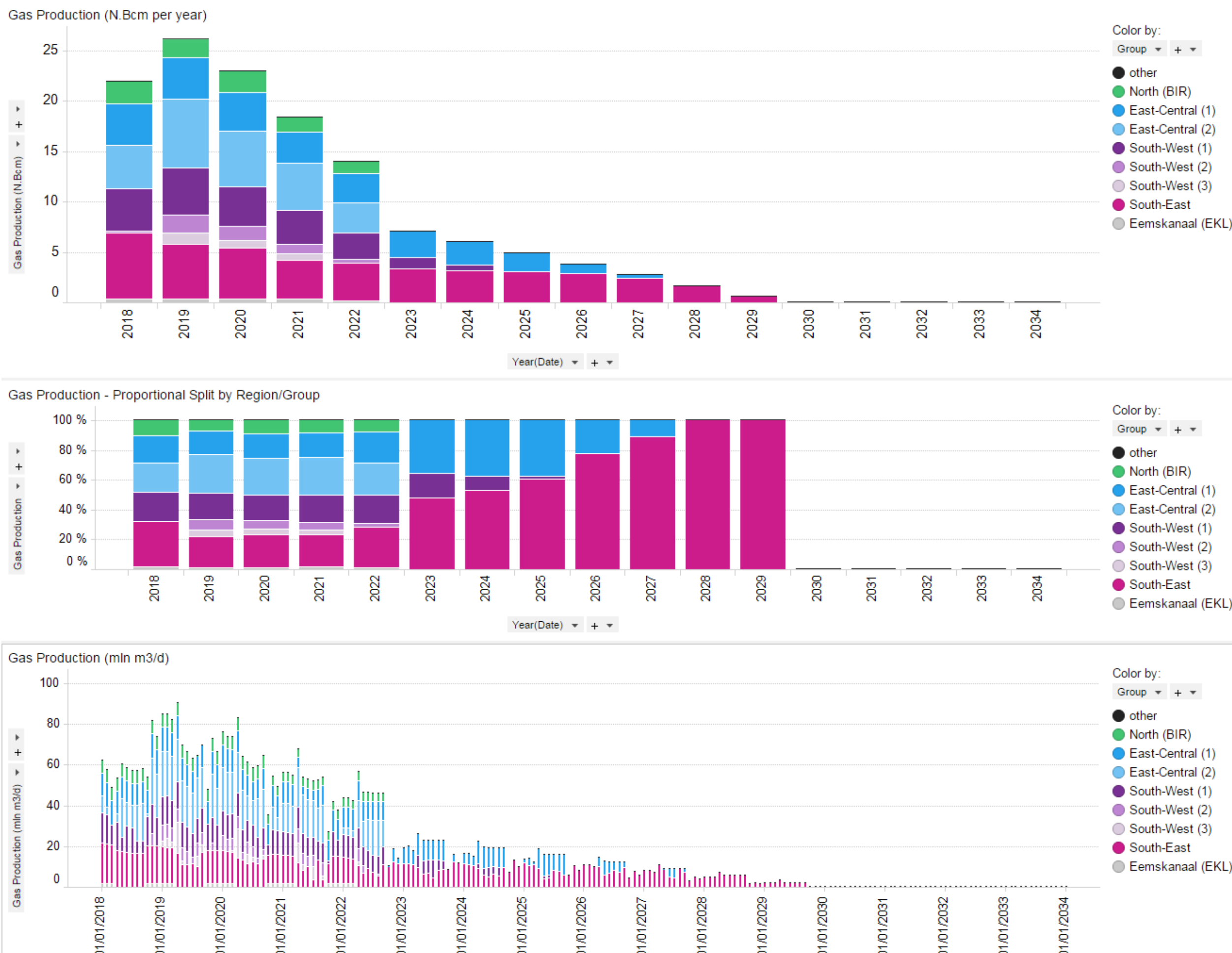


Figure 3-7 Production by region and start-up group ("Basispad Kabinet" – Cold Temperature) by calendar year

Reservoir pressure

Figure 3.8 gives the associated reservoir pressure in the direct vicinity of the production clusters, showing the impact of increased utilization of the South-West and East-Central regions.

Figure 3.9 highlights the incremental depletion relative to the Average temperature scenario over the next 5 years. The additional depletion in the South-West and East-Central regions is apparent, but does not exceed 10 bar. There is no large difference in the South-East, where clusters were already running on maximum Load-Factor in the Average temperature scenario. In the Loppersum region, the impact of the higher production within this five-year period is limited.

In a cold year a notable increase in pressure can be observed at the Eastern margin of the field, where the Borgsweer water disposal well is located. Given the higher production volumes associated with the lower average temperatures, compared to the average temperature case, more associated condensed water is produced from the Groningen clusters, and subsequently reinjected at Borgsweer.

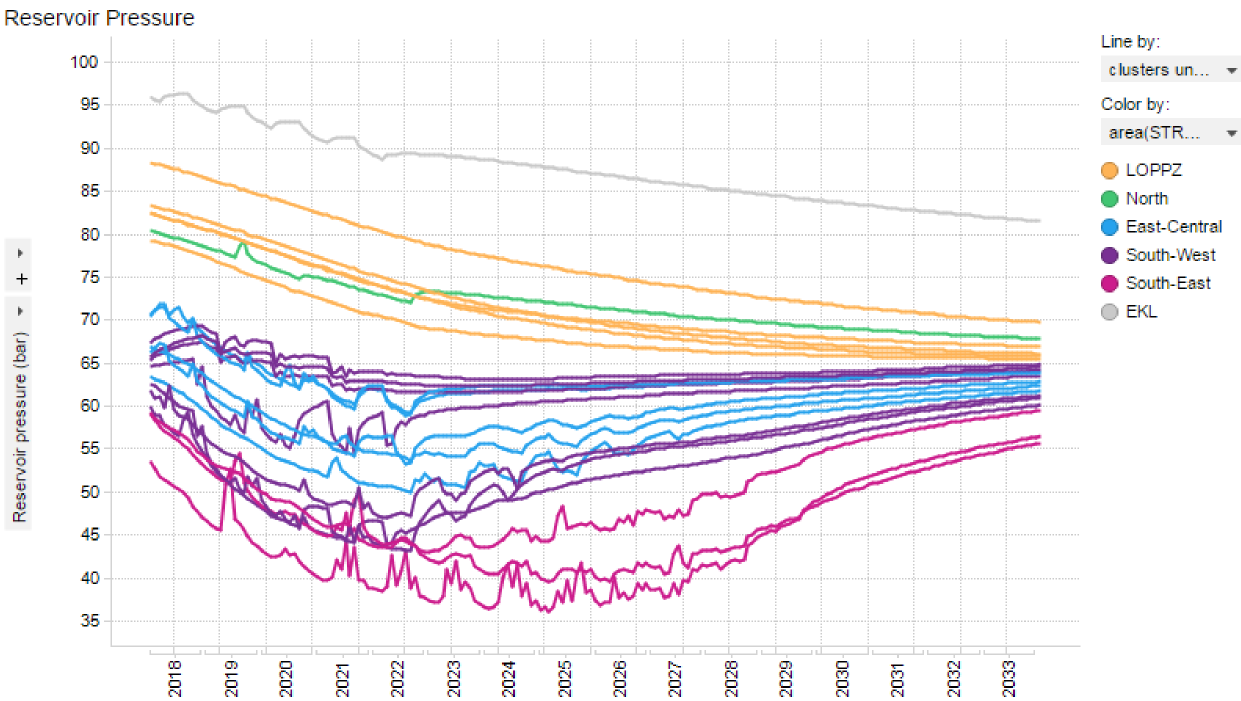


Figure 3-8: Reservoir pressure for “Basispad Kabinet” Cold Temperature. Lines by production cluster, colours by production region.

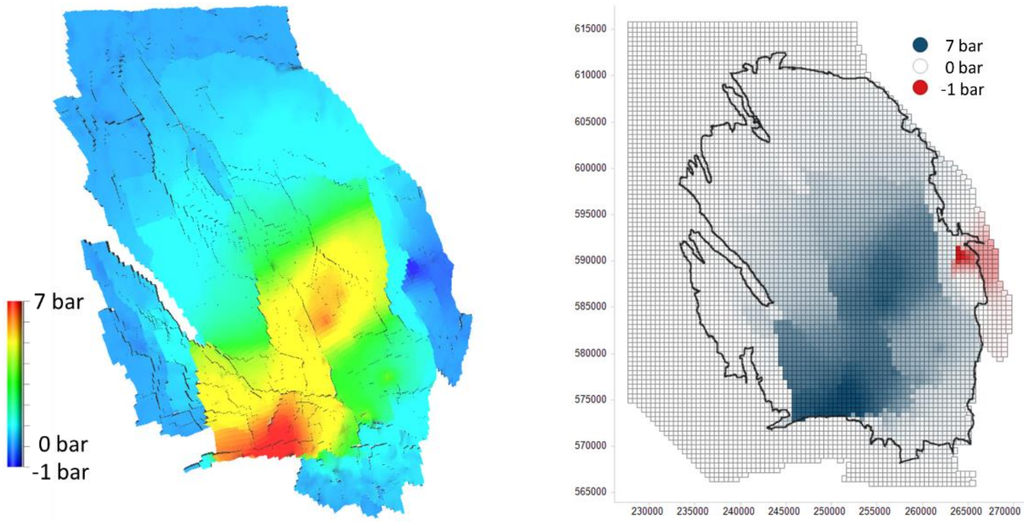


Figure 3-9: Incremental reservoir pressure decline for Cold scenario as compared to the Average temperature scenario, between 1/1/2018 and 1/1/2023.

Production capacity

The higher utilization of South-West and East-Central is also evident from Figure 3-10 and 3.11. The East-Central clusters initially produce at full capacity (within the Load Factor restriction). Note that the maximum Load Factor was increased from 0.7 to 0.75 in order to meet periods of peak gas demand during the first few years. Some spare capacity remains available towards the South-West (EKL, SW2-3).

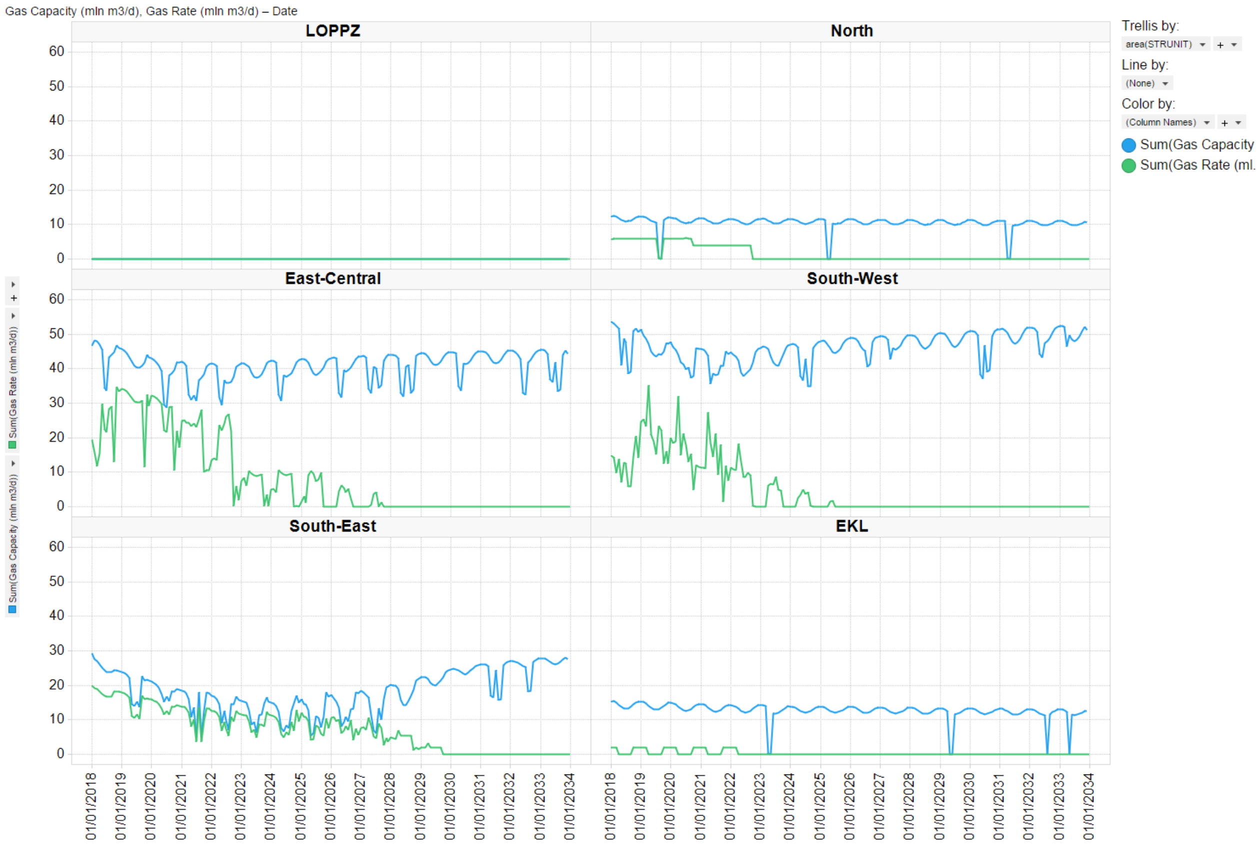


Figure 3-10: Forecasted production (green lines) and capacity (blue lines) per region for cold temperature

Figure 3-11: Load Factor per region and start-up group.

3.3 “Basispad Kabinet” – Warm Temperature

The “Basispad Kabinet” cold and warm production profiles give the extreme temperature end members from the past 31 years. Consecutive occurrence of 10 warm, average or cold years is highly unlikely. However, analysing these end member profiles is useful to ensure that the operational philosophy is suitable to meet demand, while minimizing seismic hazard and risk in periods of cold and warm temperature.

Gas Production

Figure 3.12 gives the regional break-down of the production profile for the warm temperature scenario. Bierum and Eemskanaal are again operated as per the average temperature case. The South-East region can now carry a larger proportional share (some 35-55% prior to the nitrogen blending plant), and from 2023 onwards it can provide the required production volumes on its own. Only a modest volume is required from the South-West.

The larger part of the production demand can be met by the first three start-up groups (SE, CE1, SW1).

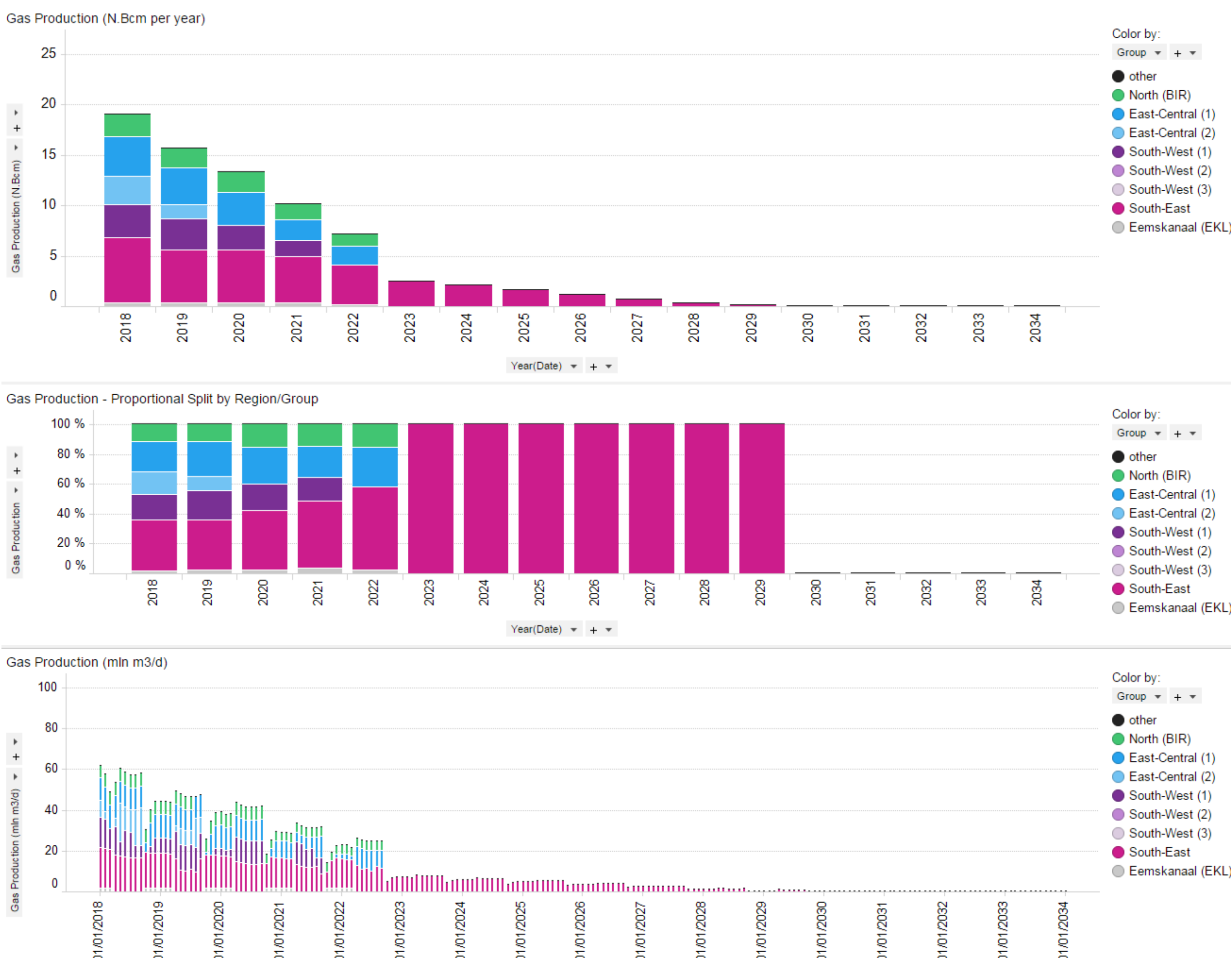


Figure 3-12: Production by region and start-up group (“Basispad Kabinet” – Warm Temperature)

Reservoir pressure

Figure 3.13 and Figure 3.14 show the impact of the reduced production volumes in the Warm scenario on reservoir pressure. The depletion in the South and East of the field is up to about 10 bar less than in the average temperature case. Again, there is only limited impact on the Loppersum region for the five-year period shown in Figure 3.14. For this production case there is a slight reduction in pressure in the Borgsweer area due to less water injected.

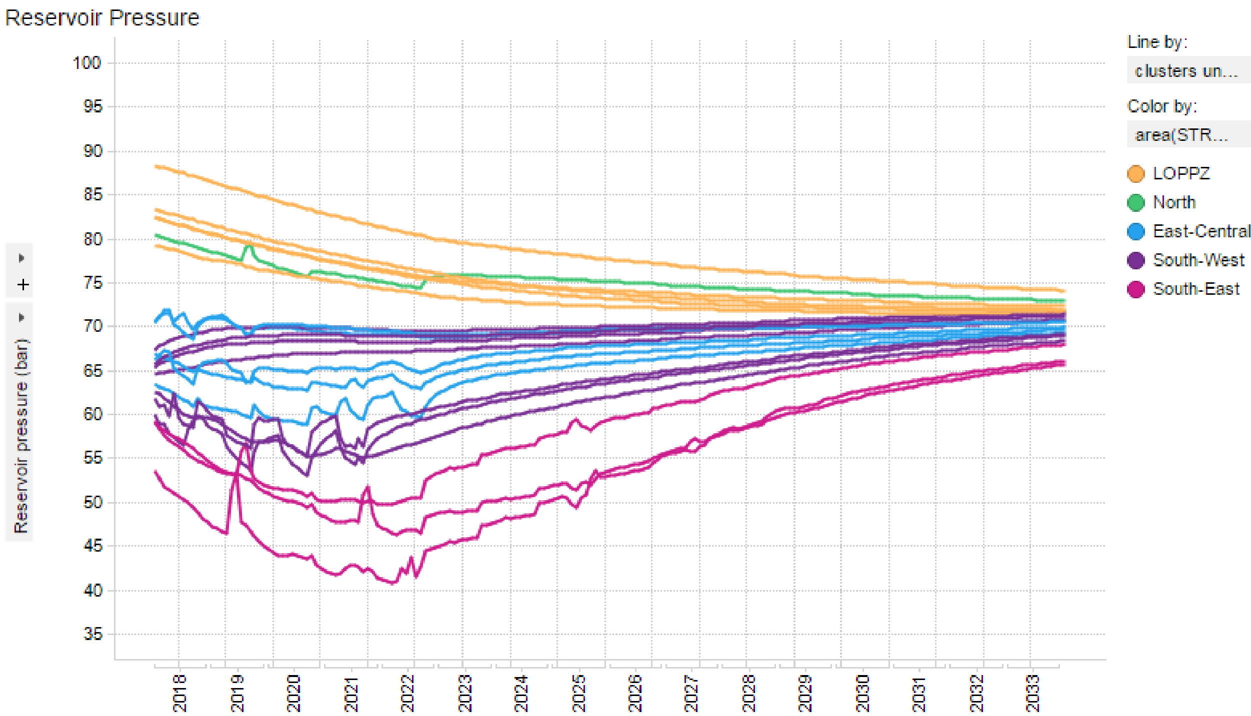


Figure 3-13: *Reservoir pressure for "Basispad Kabinet" Average Temperature. Lines by production cluster, colours by production region.*

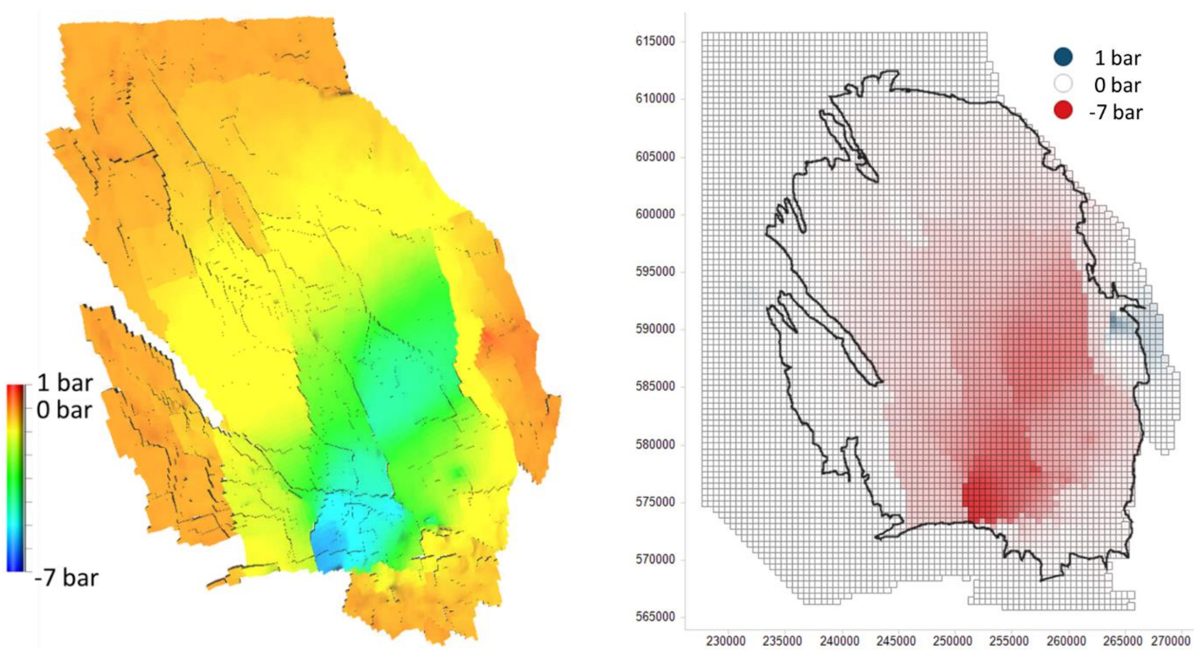


Figure 3-14: *Incremental reservoir pressure decline for Warm scenario as compared to the Average temperature scenario, between 1/1/2018 and 1/1/2023.*

Production and capacity

The production and capacity curves are shown in Figure 3.15, and the resulting Load Factors shown in Figure 3-16. The effect of the additional nitrogen blending plant (onstream as per gas-year 2022/2023) is clearly evident from the Load Factor graph, with the Load Factor in the South-East showing a big drop as the total gas demand becomes less than the available capacity in the South-East alone.

Figure 3-15: Forecasted production (green lines) and capacity (blue lines) per region for warm temperature

Figure 3-16: Load Factor per region and start-up group

3.4 Comparing scenarios

Some further comparisons between the various scenarios are given in Figure 3-17 to Figure 3-19. Figure 3-17 compares the production by region, Figure 3-18 the reservoir pressure (in the vicinity of a selected production cluster within each region), and Figure 3-19 the Load Factor by region. The compared properties are averaged over the year for clarity.

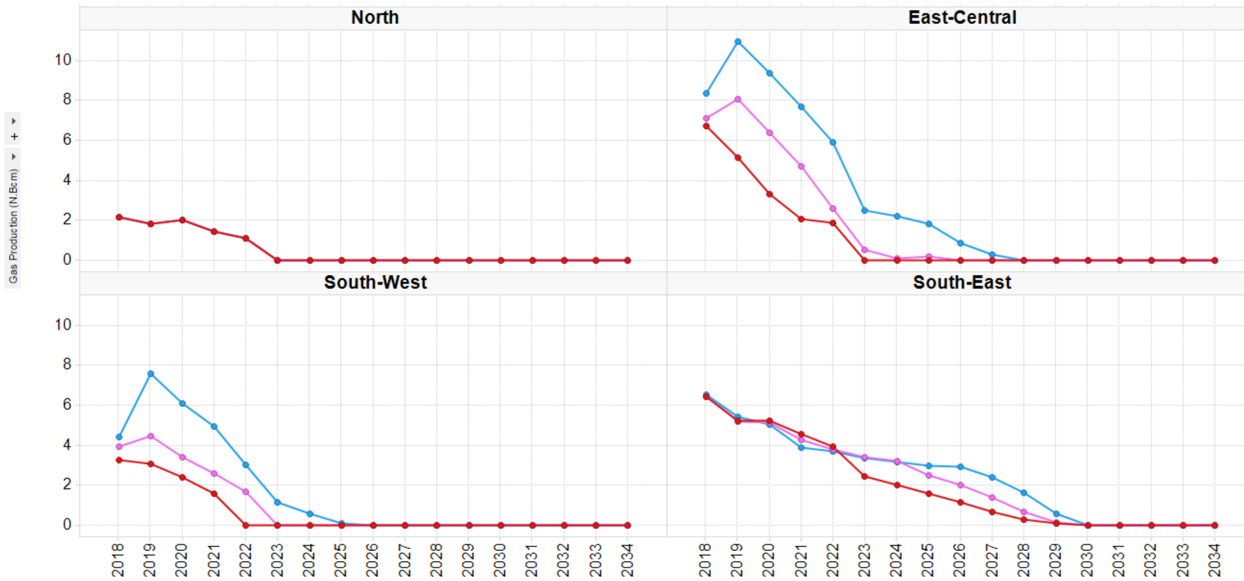


Figure 3-17: Comparison between production scenarios of the Gas Production by region. Cold temperature scenario given in blue, Average in magenta, Warm in red.

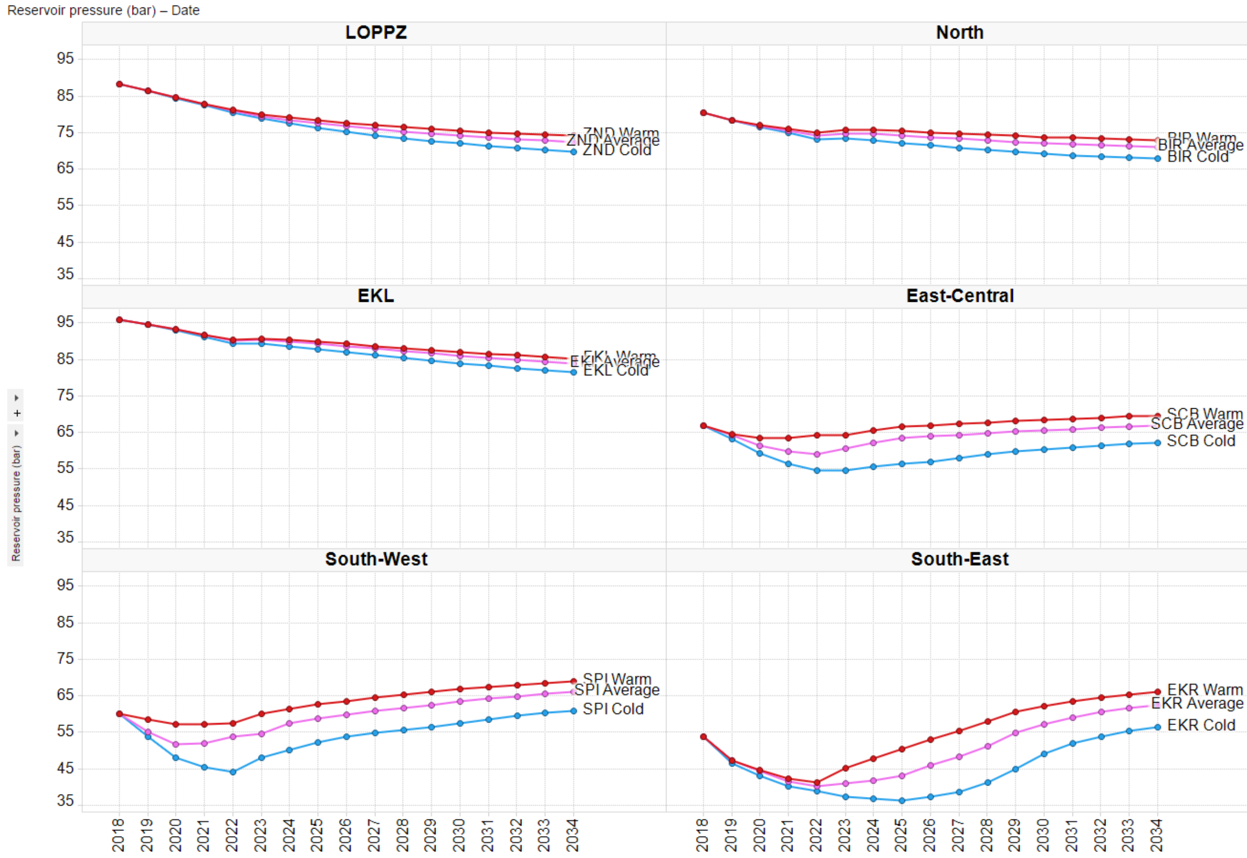


Figure 3-18: Comparison between production scenarios of the reservoir pressure in the vicinity of a selected production cluster for each region.

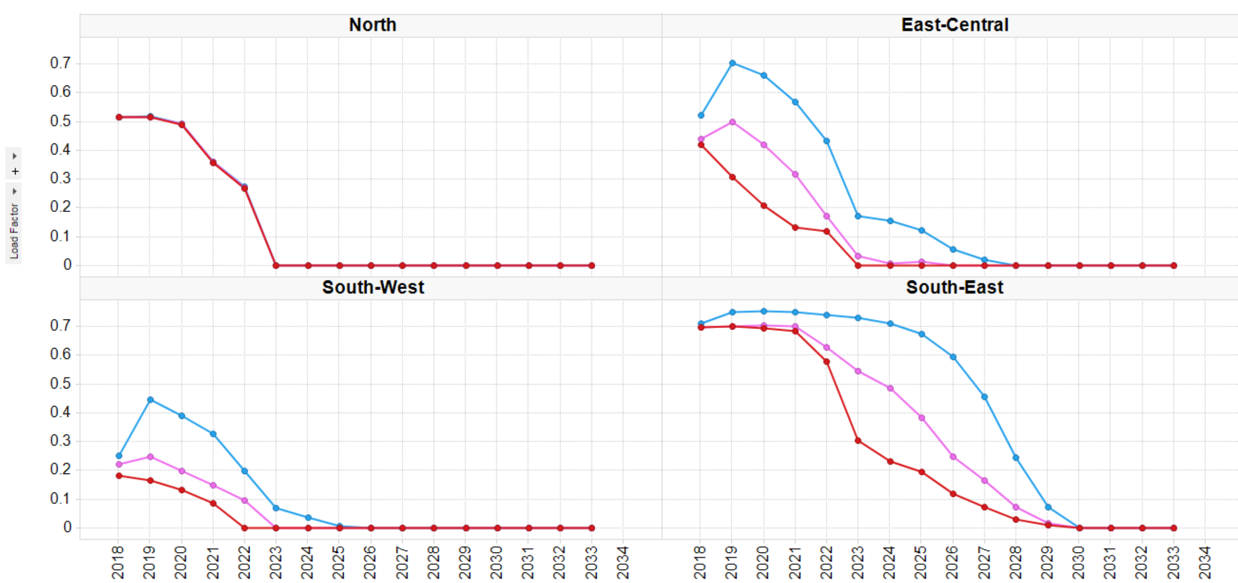


Figure 3-19: Comparison between production scenarios of the Load Factor by region. Cold temperature scenario given in blue, Average in magenta, Warm in red.

3.5 Impact of cold and warm temperature on HRA

The "Basispad Kabinet" cold and warm production profiles give the extreme temperature end members from the past 31 years. Reflecting the fact that it is unlikely to only have consecutive extreme cold (or warm) years, it was deemed more realistic[5] to evaluate seismic hazard and risk on production profiles that follow the average, but include an outstep to the extreme temperature profile for one single gas-year. An example where gas-year 2019-2020 follows the cold temperature profile is shown in Figure 3-20.

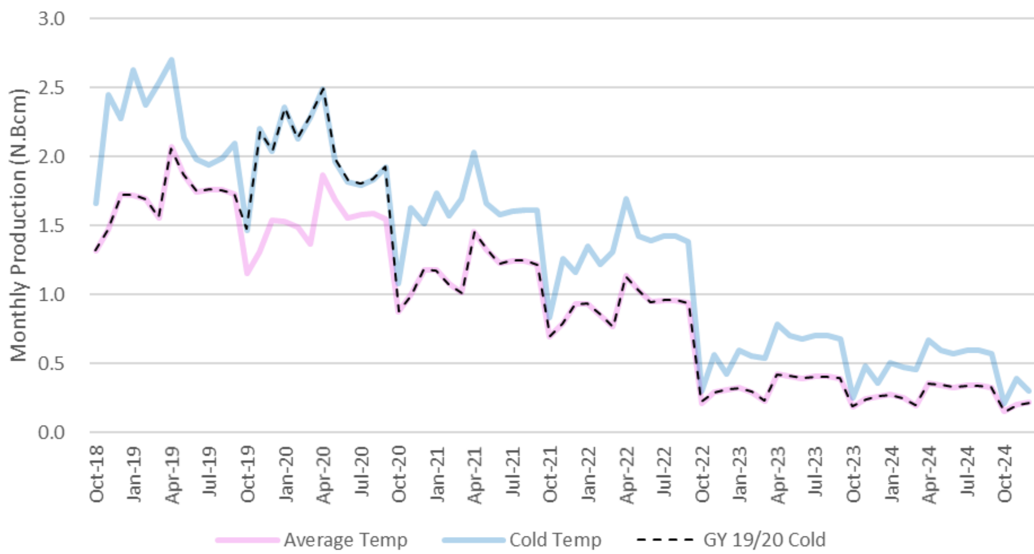


Figure 3-20: Groningen field production profiles for average and cold temperatures along with the profile used where a single year follows the cold temperature profile, in this case gas-year 2019-20.

In terms of regional production distribution etc. these outstep profiles typically lie close to the cold or warm temperature profile for the single year in question. The example of gas-year 2019-20 being cold is given in Table 3-1 in terms of regional production fractions.

Region	Average Temperature	Cold Temperature	GY 2019-20 Cold
South-East	29%	22%	22%
East-Central	36%	41%	42%
South-West	21%	27%	25%
BIR	12%	9%	9%
Eemskanaal	2%	1%	1%

Table 3-1: Production fractions per region for gas-year 2019-20; comparing the single year outstep profile to the average and cold temperature profiles.

[5] Similar to rolling a dice, the odds of only throwing 6 in a set of rolls is progressively getting smaller when increasing the sampling set, the expectation value is 3.5

3.6 References

1. Groningen Dynamic Model Update 2017, NAM Reservoir Engineering Team: Henk van Oeveren, Per Valvatne and Leendert Geurtsen, September 2017.
2. Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017, NAM (Jan van Elk and Dirk Doornhof), November 2017.
3. Seismic risk assessment for a selection of seismic risk production scenarios for the Groningen field - Addendum to: Induced Seismicity in Groningen Assessment of Hazard, Building Damage and Risk (November 2017), Jan van Elk, Assaf Mar-Or, Leendert Geurtsen, Per Valvatne, Eddy Kuperus and Dirk Doornhof, March 2018.
4. Groningen Dynamic Model Update 2017 – V5, Quint de Zeeuw, Leendert Geurtsen, September 2017.

4 Event Rate and Hazard Assessment

4.1 Event Rate Forecasting

Based on the production scenarios "Basispad Kabinet", the number of earthquakes with a magnitude larger than or equal to M=1.5 have been forecasted. Figure 4-1 shows the annual number of earthquakes forecasted until 2032 for Groningen field volume offtake for the "Basispad Kabinet" average temperature profile. After an initial plateau of about 16 – 19 earthquakes per year until 2021, the seismic activity rate starts to decline. This is a consequence of the decreasing gas production after the new nitrogen blending plant comes on stream.

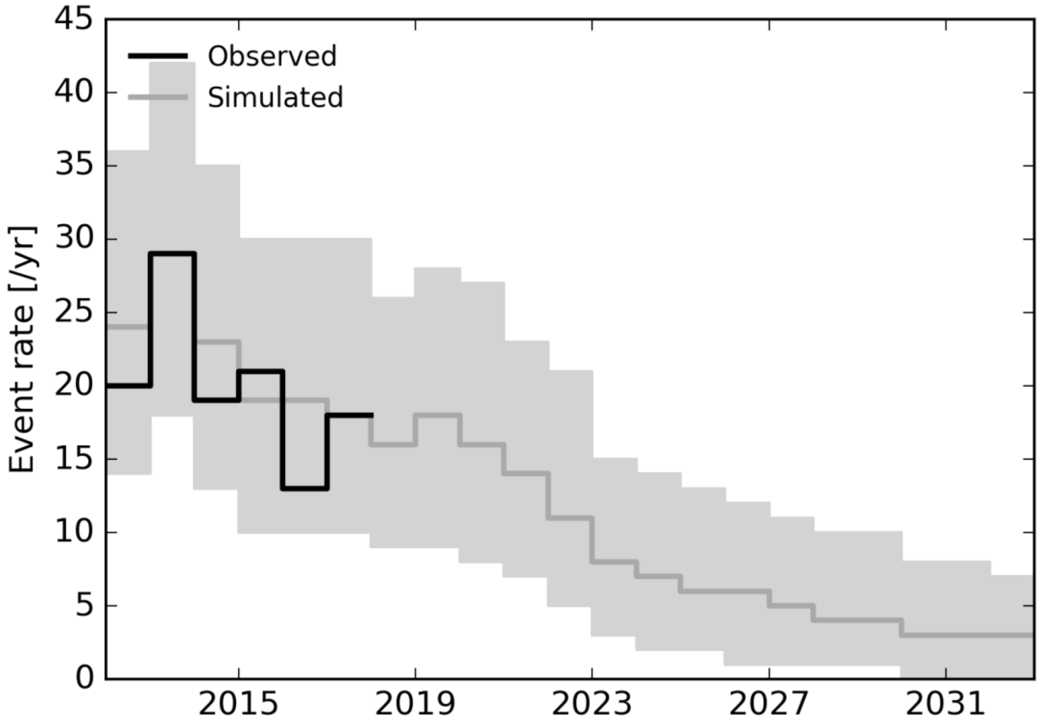


Figure 4-1 *Seismic Activity Rate of earthquakes for the period 2012 to 2032 ("Basispad Kabinet – Average Temperature"). The dark grey line indicates the expected number of earthquakes in each year and the grey area the uncertainty band.*

The seismic activity rate declines to an expected 3 earthquakes per year in 2032, with an uncertainty range of 0 to 8 earthquakes per year. The seismic activity rate beyond 2025 is primarily driven by the pressure equilibration in the field, between the high-pressure area North-West of Loppersum and the lower-pressure area South-East of the field (Ref. 1).

The expected impact of temperature uncertainty is within the uncertainty band for event rate of the average temperature scenario. In Figure 4-2 the seismic activity rate for three scenarios is shown; the average temperature scenario, an average temperature scenario with gas-year 2018-2019 a cold year and an average temperature scenario with gas-year 2018-2019 a warm year. Especially in calendar year 2019 the activity rate is higher for the cold year scenario (20 earthquakes) than for the average temperature scenario (18 earthquakes) and lower for the warm year scenario (15 earthquakes).

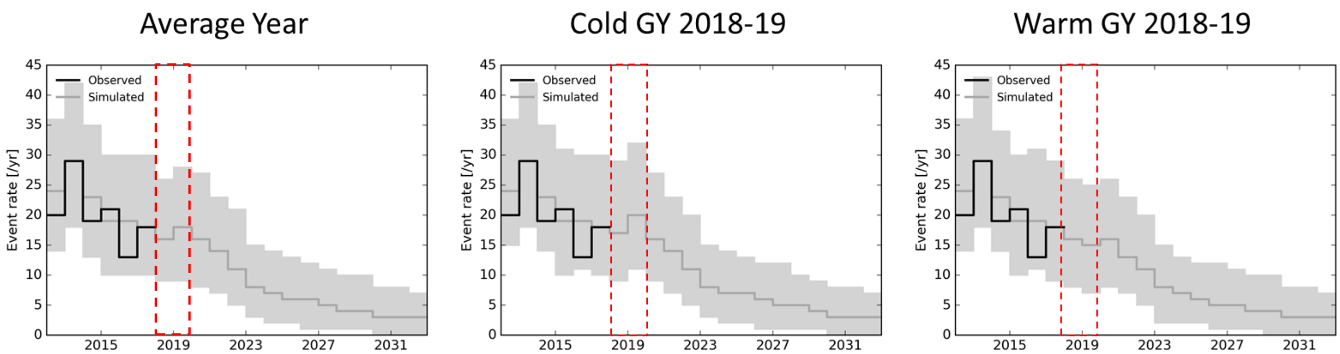


Figure 4-2 *The seismic activity rate for three production scenarios; (left) the average temperature scenario, (middle) an average temperature scenario with gas-year 2018-2019 a cold year and (right) an average temperature scenario with gas-year 2018-2019 a warm year.*

These differences in seismic activity rate between the weather scenarios are smaller than the uncertainty band for the average weather scenario.

The seismological model is used to forecast the seismicity in terms of the number, location and magnitude of future earthquakes. The probability of an earthquake with a magnitude exceeding a given magnitude can be assessed. In table 4.1 the annual probability of an earthquake occurring with a magnitude exceeding the specified magnitude is given. For instance, the probability of an earthquake occurring in 2018 with a magnitude exceeding M_L=3.6 (the magnitude of the Huizinge earthquake) is equal to 13%.

Year	P(M>=3.6)	P(M>=4.0)	P(M>=4.5)	P(M>=5.0)
2018	13.4%	5.5%	1.4%	0.3%
2019	14.5%	5.8%	1.3%	0.3%
2020	13.4%	5.4%	1.3%	0.3%
2021	12.2%	4.9%	1.1%	0.3%
2022	10.0%	4.0%	1.0%	0.3%
2023	7.0%	2.6%	0.7%	0.2%
2024	6.2%	2.5%	0.6%	0.2%
2025	6.0%	2.5%	0.6%	0.1%
2026	5.3%	2.2%	0.6%	0.1%
2027	4.6%	1.7%	0.4%	0.1%

Table 4.1 *Table with annual probabilities for occurrence of earthquakes exceeding a set magnitude.*

For comparison, the equivalent table in the “Hazard, Building Damage and Risk Assessment – November 2017” (Ref. 2) is reproduced as table 4.2. This Hazard Assessment was based on a 24 Bcm/year scenario. A reduction of the event rate for the “Basispad Kabinet” production scenario compared to the event rate for the 24 Bcm/year scenario can be observed. For instance, the chance of an earthquake in 2019, with a magnitude $M_L \geq 3.6$ (the magnitude of the Huizinge earthquake in 2012), was in the report from November 2017 (Ref. 2) assessed to be 17%, based on a 24 Bcm/year production scenario. Based on “Basispad Kabinet” production scenario this chance has reduced to 14.5%.

More importantly, as a result of the declining production in the “Basispad Kabinet” scenario the chance of an earthquake with a magnitude exceeding M_L=3.6 (or other magnitude) is declining throughout the next 10 years.

Year	P(M>=3.6)	P(M>=4.0)	P(M>=4.5)	P(M>=5.0)
2018	16.0%	6.6%	1.6%	0.4%
2019	17.0%	7.0%	1.6%	0.4%
2020	17.8%	7.5%	1.8%	0.4%
2021	19.3%	8.0%	1.9%	0.5%
2022	20.2%	8.7%	2.2%	0.6%

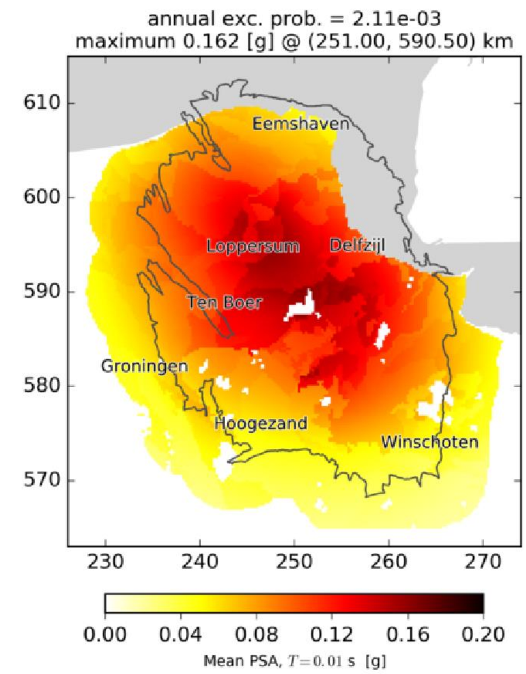
Table 4.2 Table with annual probabilities for occurrence of earthquakes exceeding a set magnitude Taken from “Hazard, Building Damage and Risk Assessment – November 2017” (Ref. 2).

4.2 Hazard Assessment

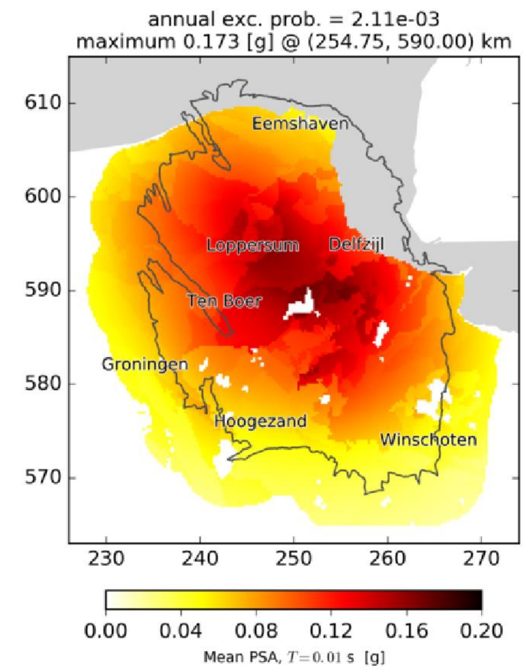
Hazard maps have been prepared for each year of the next ten calendar years and for the next three 5-year periods. Separate hazard maps are available for the “Basispad Kabinet” at average temperature profile, cold temperature profile and warm temperature profile.

The hazard map for the average temperature weather scenario for each year of the period 2018 to 2027 is shown in figure 4.3 a, b, c. The hazard is, as expected based on the declining gas production profile, also decreasing over this period. The trend in the largest PGA in these annual hazard maps is shown in figure 4.4. However, this reduction is not evenly spread over all areas of the field. In the later years, the hazard is primarily located in the area North-West of Loppersum. This is consistent with the equilibration of reservoir pressures during these later years. The gas from the higher-pressure area to the North-West of Loppersum will continue to flow to the lower pressure South-Eastern area, causing a continued decrease of pressure in the former area. This effect of gas flow within the reservoir due to equilibration of pressure differences is referred to as the “remweg” effect. In theoretical remweg production scenarios this effect (Ref. 1) has also been demonstrated.

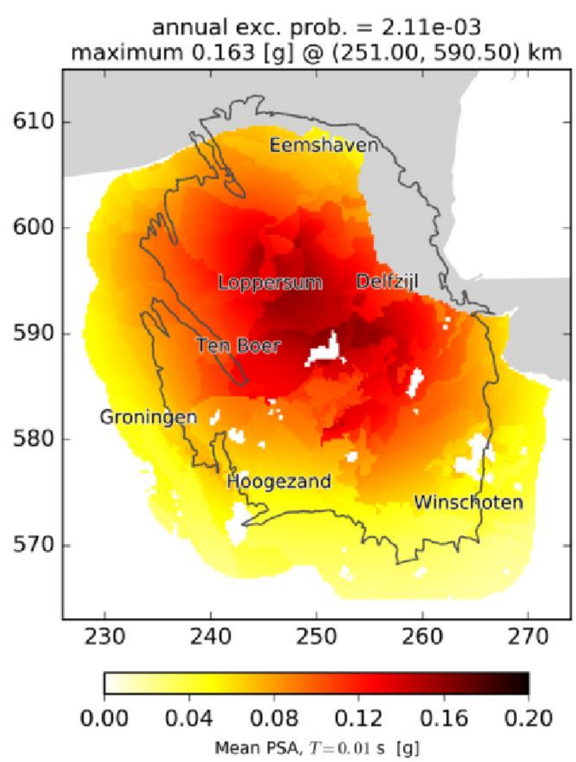
The effect can also be seen in Figure 4-5, showing in the upper row the hazard maps of the “Basispad Kabinet” production scenario for the next three 5-year periods. The lower row shows the hazard maps for the 24 Bcm/year scenario of November 2017 for the next two 5-year periods for comparison. In Figure 4-6 the Hazard map for the 5-year period 2018 to 2022 is shown in larger format.



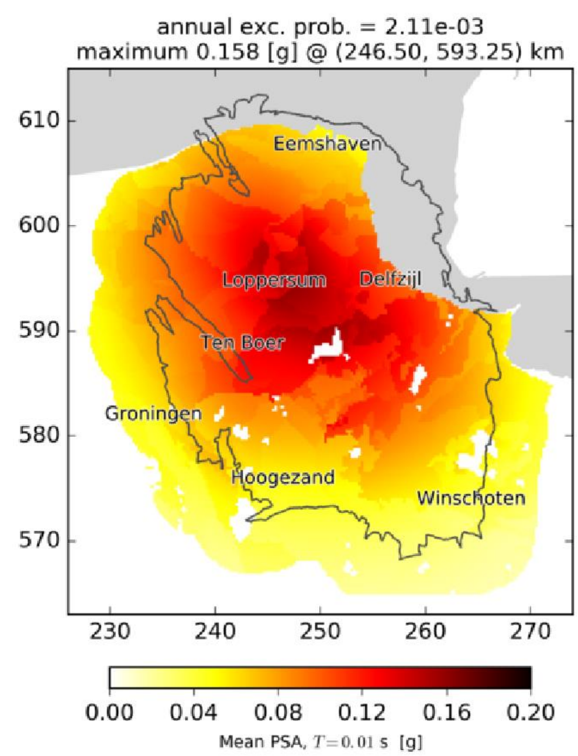
2018



2019

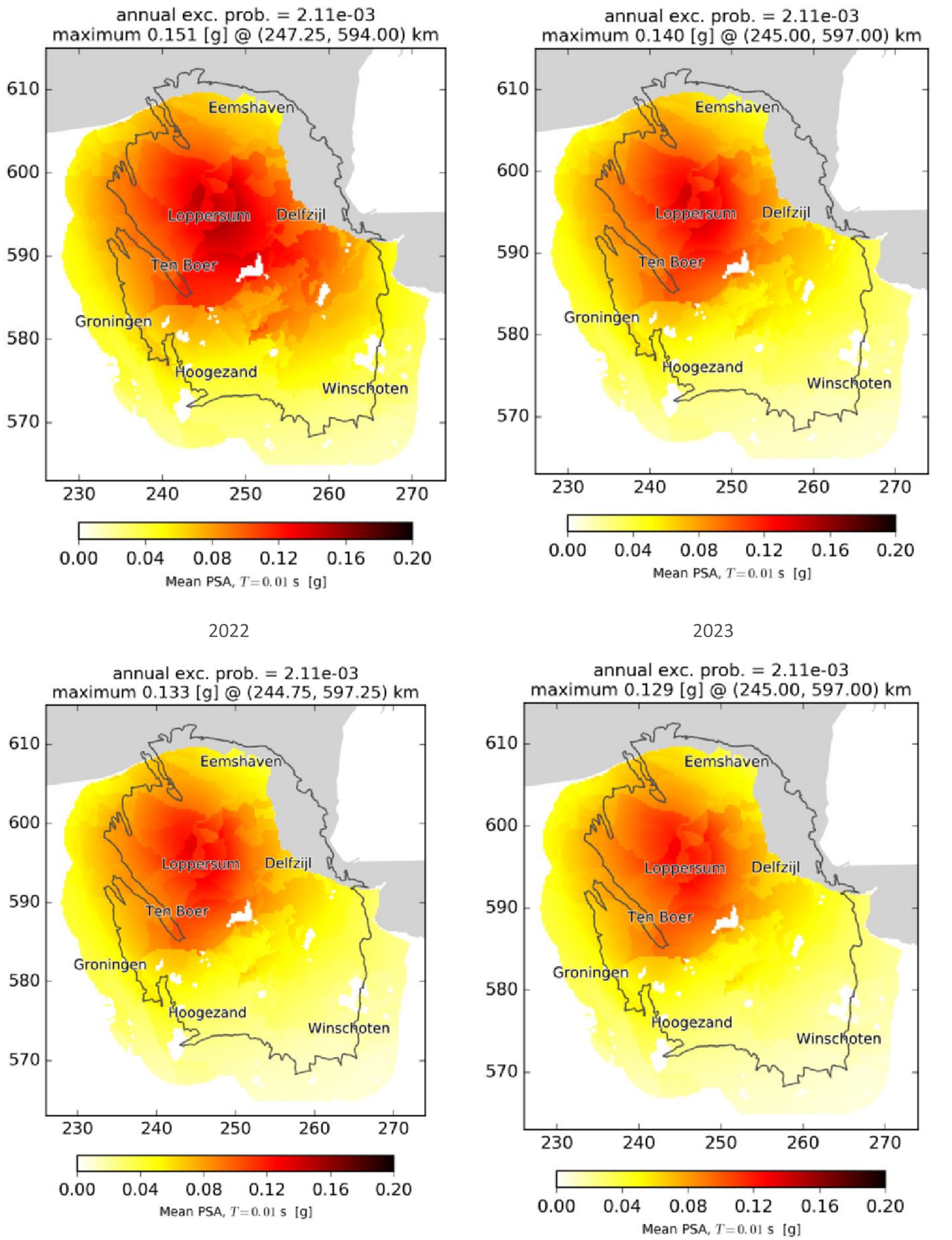


2020



2021

Figure 4.3a *Hazard Maps for the average temperature weather scenario for the years 2018 (top – left), 2019 (top – right), 2020, (bottom – left) and 2021 (bottom – right).*



2024 2025

Figure 4.3b *Hazard Maps for the average temperature weather scenario for the years 2022 (top – left), 2023 (top – right), 2024, (bottom – left) and 2025 (bottom – right).*

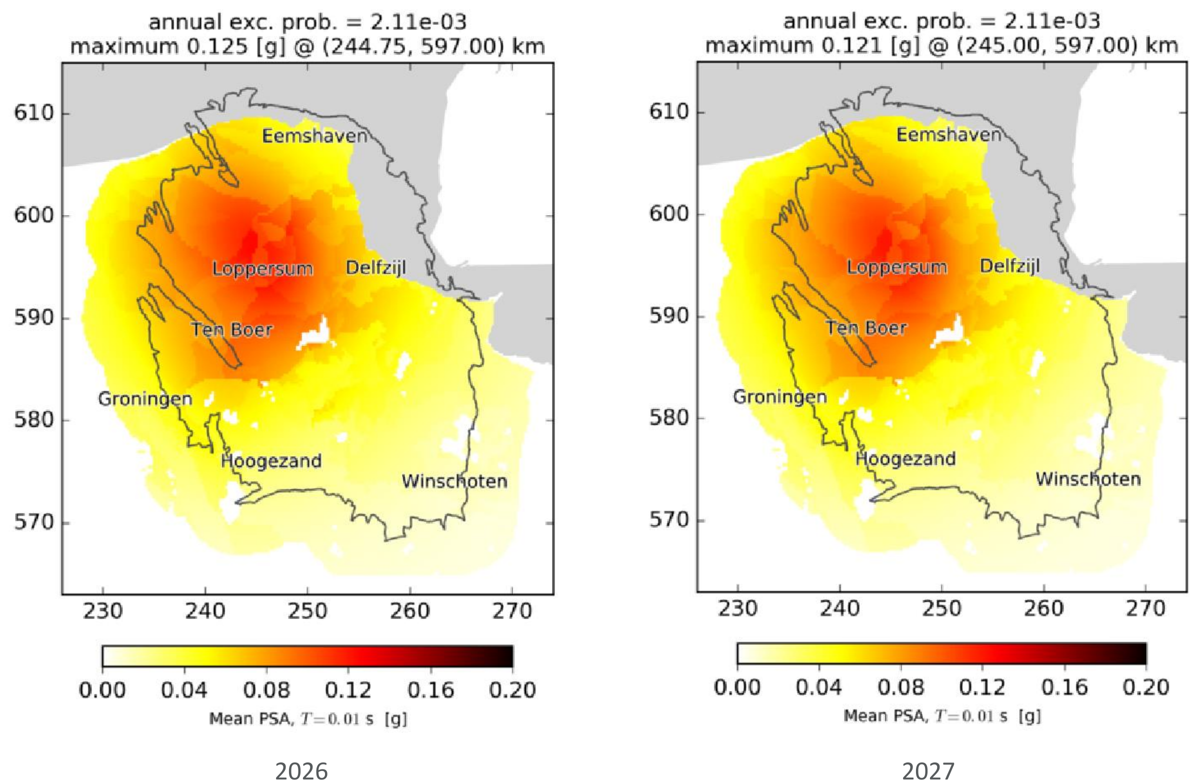


Figure 4.3c *Hazard Maps for the average temperature weather scenario for the years 2026 (left) and 2027 (right).*

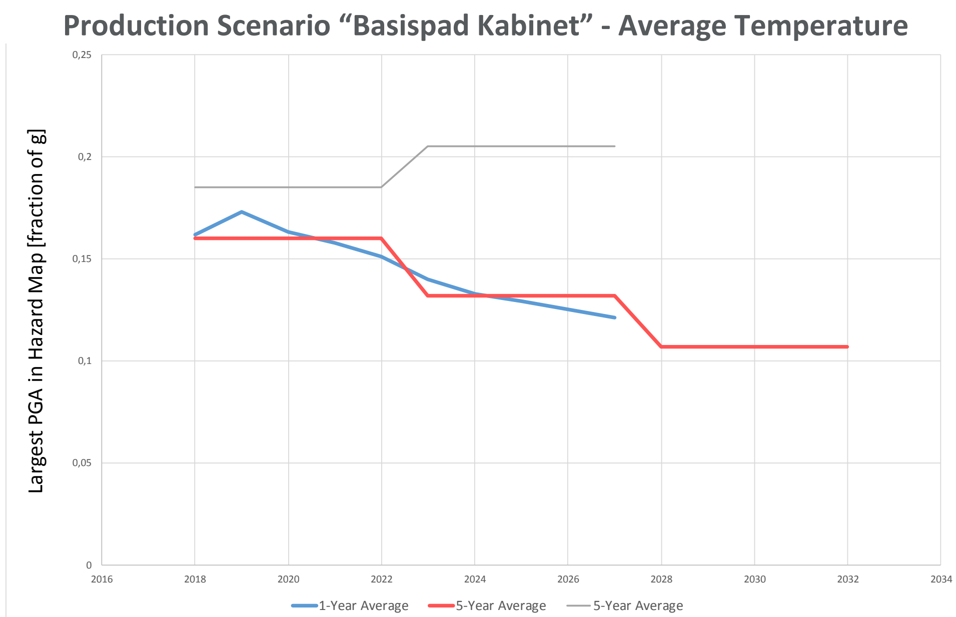


Figure 4.4 *Development over time of the largest PGA in the hazard maps.*
The grey line denotes the largest PGA in the two 5-year hazard maps of the 24 Bcm/year scenario.
The red line denotes the largest PGA in the three 5-year hazard maps of the “Basispad Kabinet” scenario.
The blue line denotes the largest PGA in the ten 1-year hazard maps of the “Basispad Kabinet” scenario.

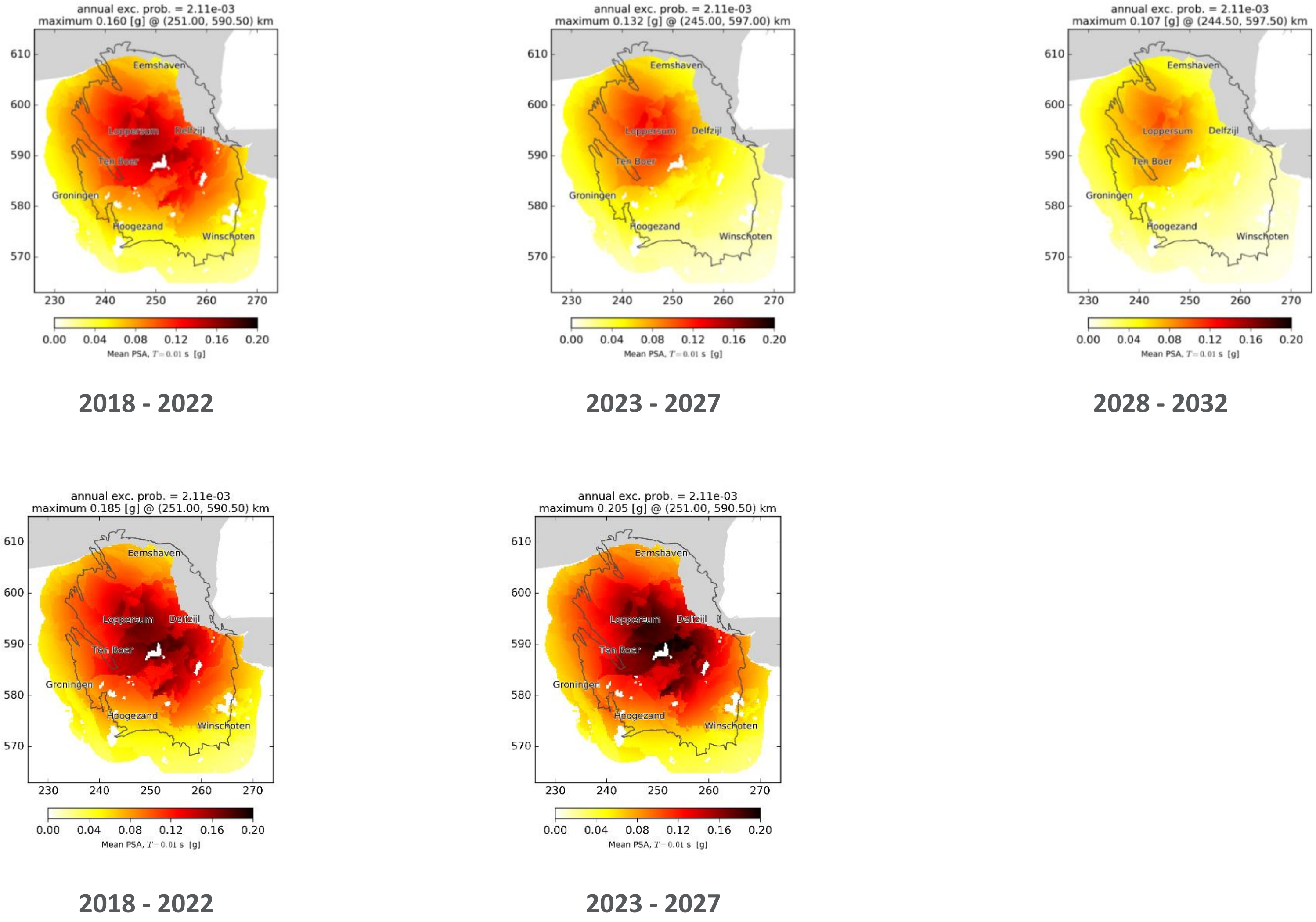


Figure 4.5 *The three 5-year hazard maps for the average weather “Basispad Kabinet” scenario (top) and the two 5-year hazard maps for the average weather 24 Bcm/year scenario (bottom).*

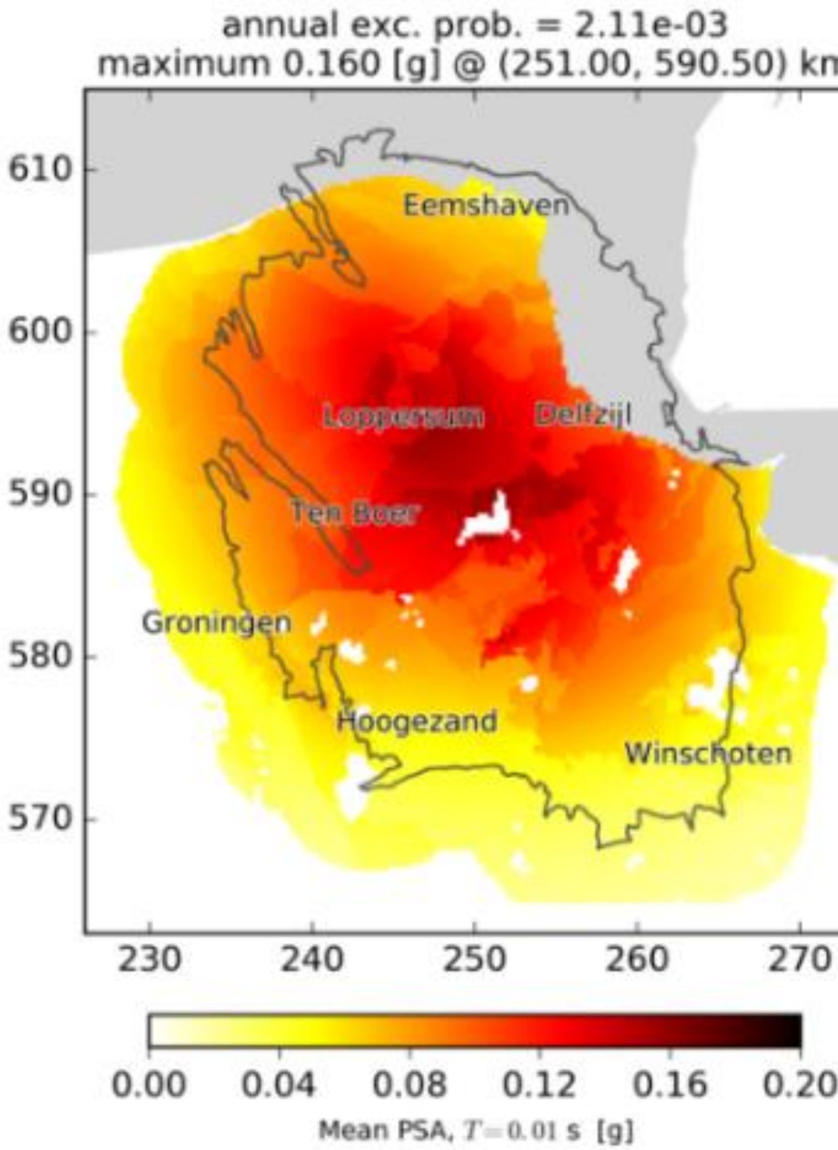


Figure 4.6 The 5-year hazard map (period 2018 – 2023) for the average weather "Basispad Kabinet" scenario.

Figure 4-7 compares the annual (calendar year) hazard maps of the average temperature profile to the sensitivity runs for cold temperature. As in the cold and warm weather scenarios the cold (or warm year) is preceded and followed by years with an average temperature. For this reason, preparing the hazard maps for the cold and warm weather scenario, required a dedicated assessment for each year in these weather scenarios.

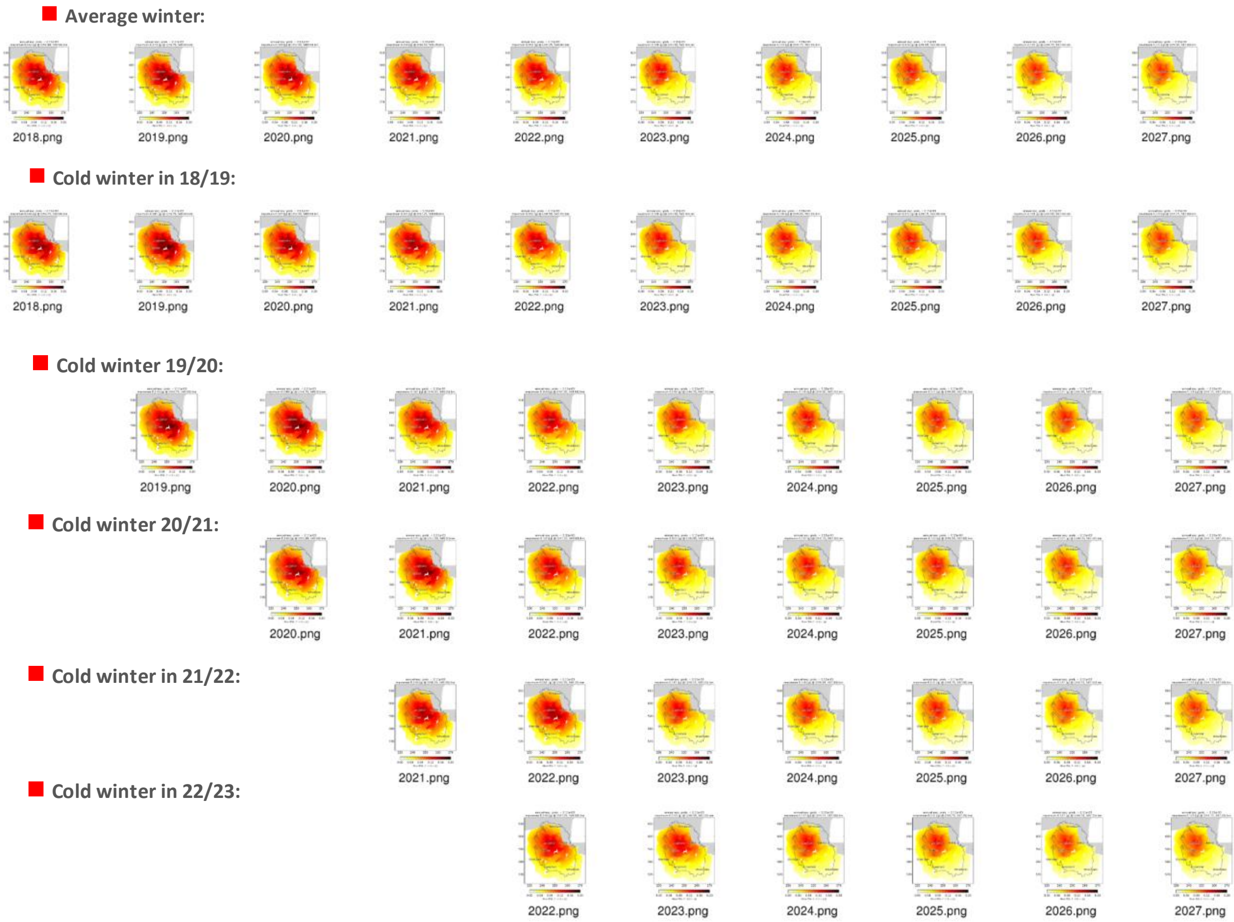
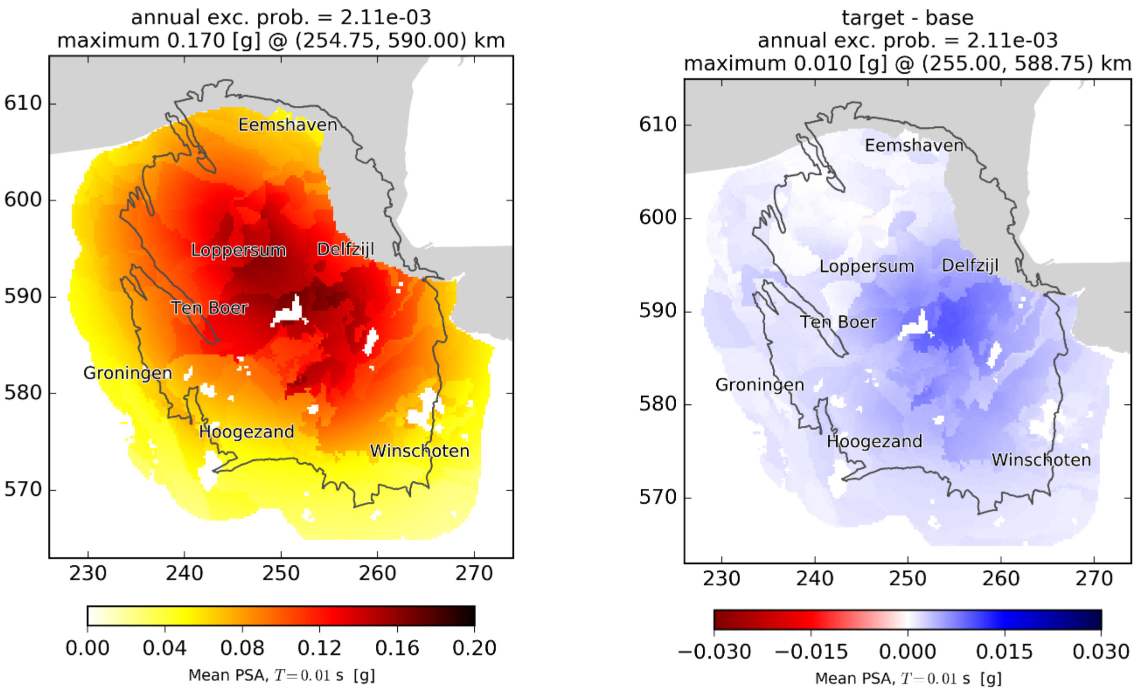


Figure 4-7 *Hazard maps for the average winter weather scenario (top) followed by the different cold weather cases making up de cold weather scenario. Gas-year 2018/2019 as a cold year followed by average temperature years (second line). Gas-year 2019/2020 as a cold year followed by average temperature years (third line). Following lines start with cold year followed by average temperature years.*

Figures 4-8 and 4-9 show, respectively, the annual hazard maps for the cold- and warm-temperature scenarios together with the difference w.r.t. the corresponding hazard for the average-temperature scenario. As can be observed, these differences are within the range of ±0.03g at peak (corresponding to a relative difference of 15% to 30%).

2018



2020

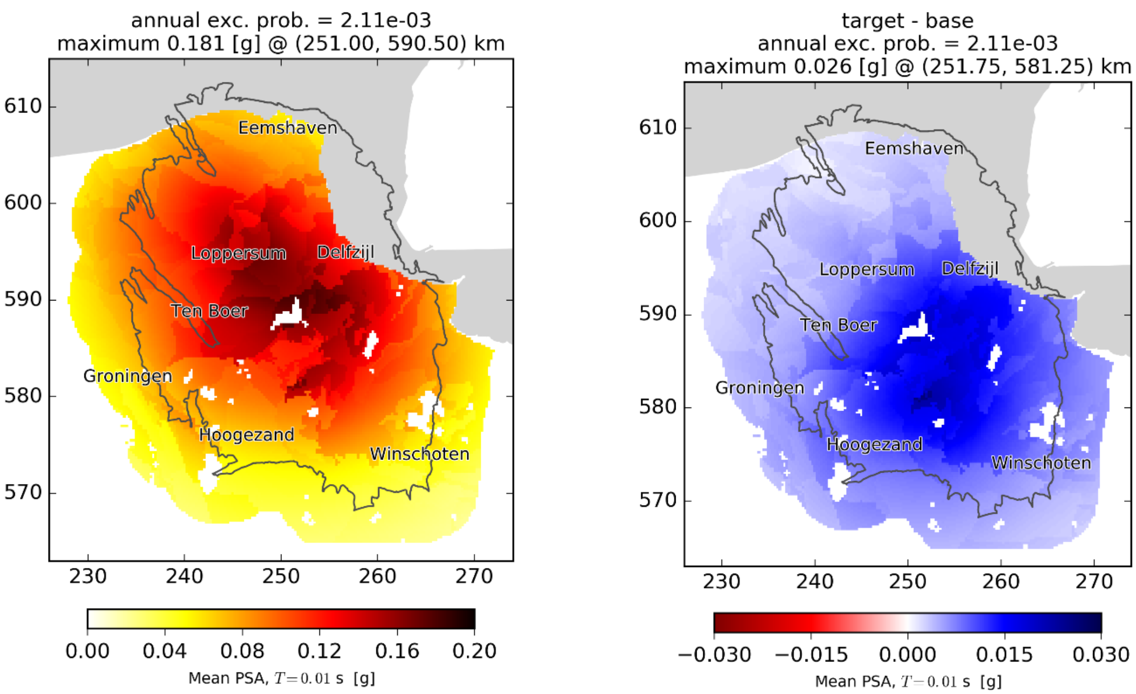
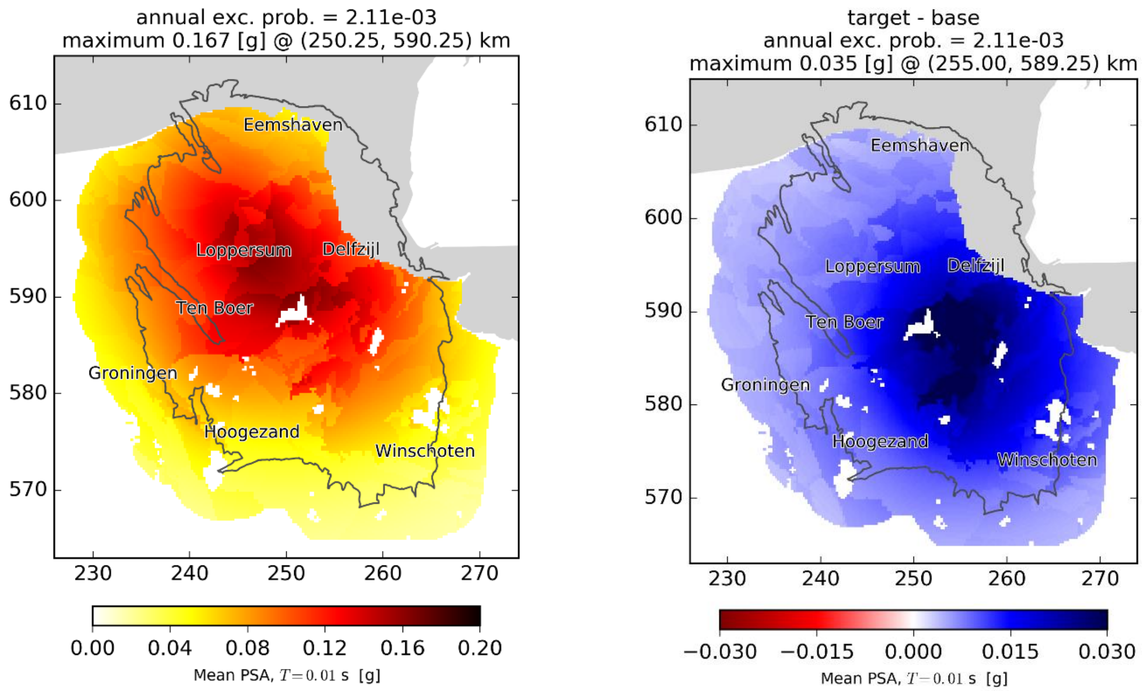


Figure 4-8a Cold-temperature scenario -- annual hazard plots (left) and difference w.r.t. corresponding average-temperature scenario hazard (right)

2022



2024

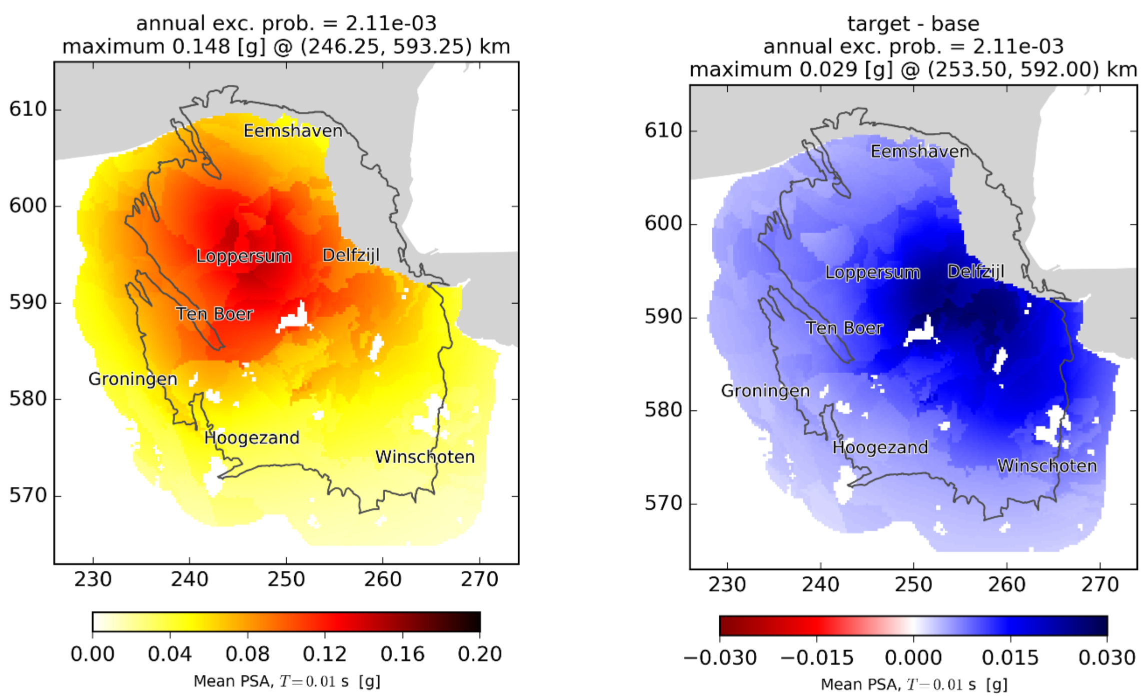


Figure 4-8b Cold-temperature scenario -- annual hazard plots (left) and difference w.r.t. corresponding average-temperature scenario hazard (right)

2026

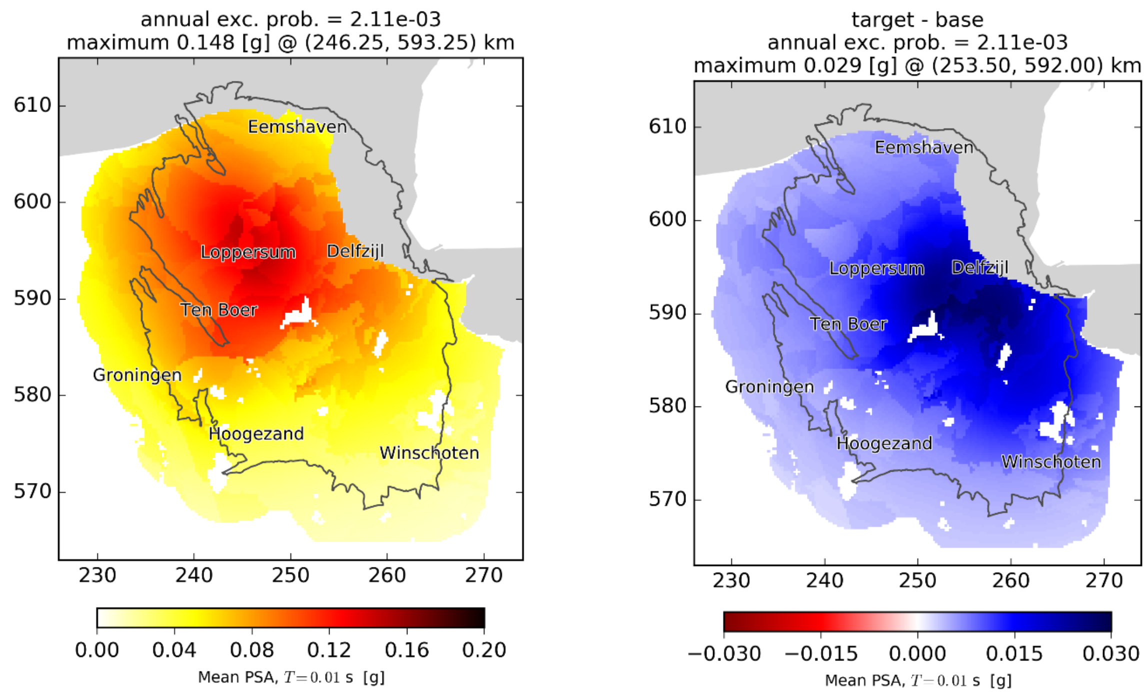
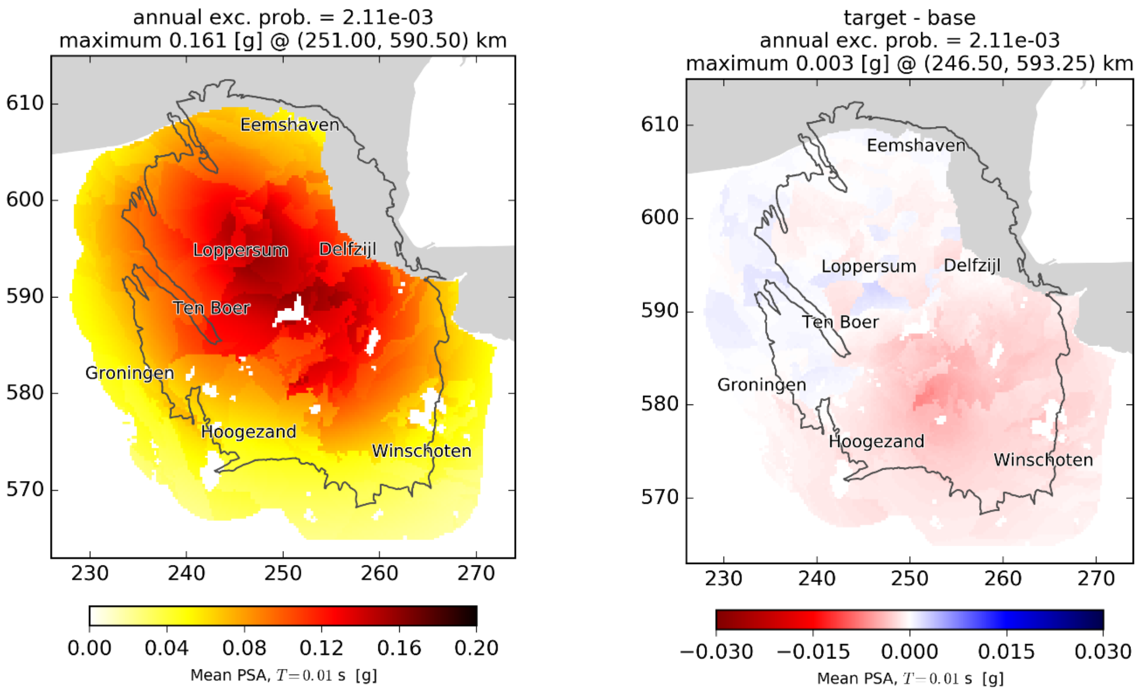


Figure 4-8c Cold-temperature scenario -- annual hazard plots (left) and difference w.r.t. corresponding average-temperature scenario hazard (right)

2018



2020

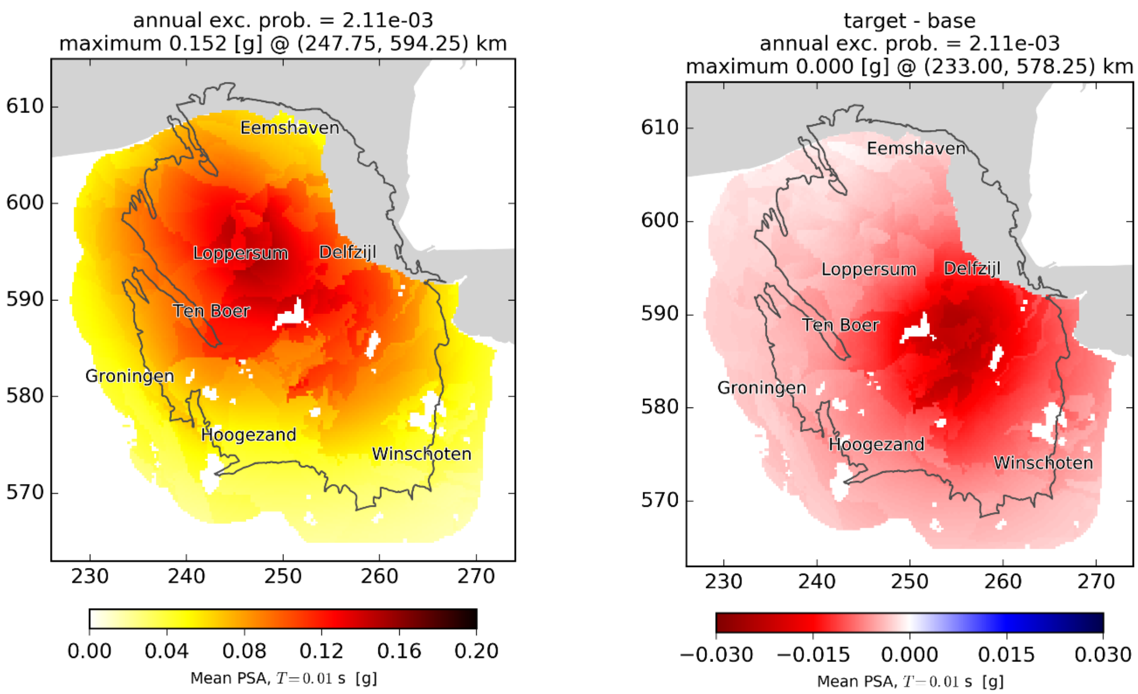
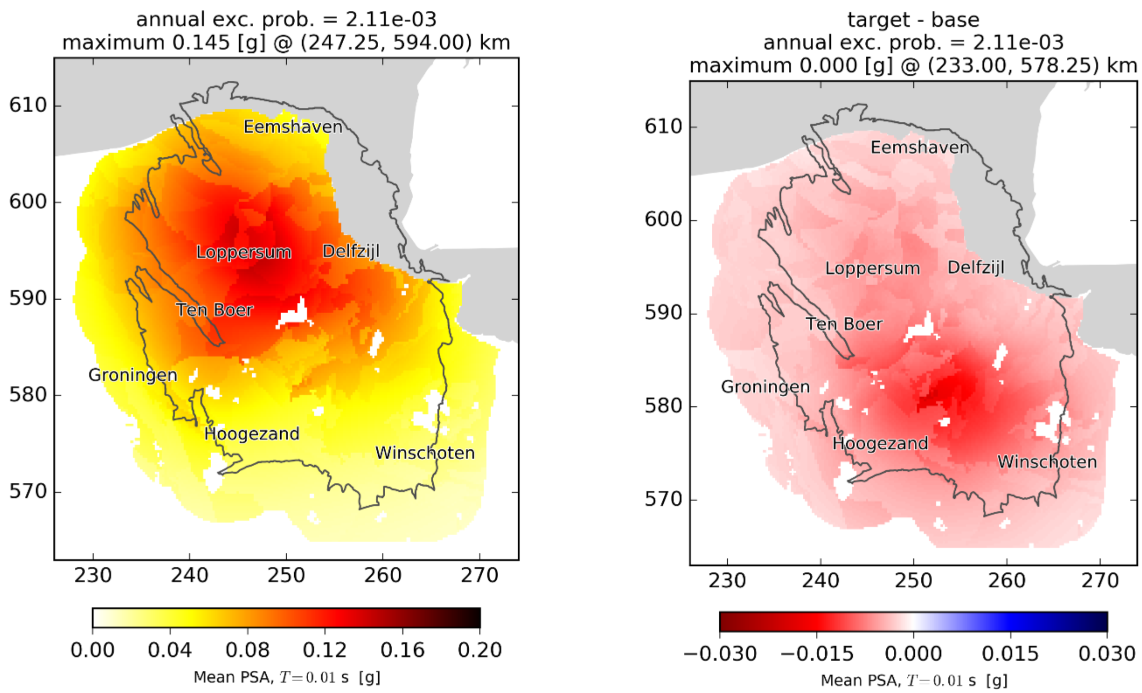


Figure 4-9a Warm-temperature scenario -- annual hazard plots (left) and difference w.r.t. corresponding average-temperature scenario hazard (right)

2022



2024

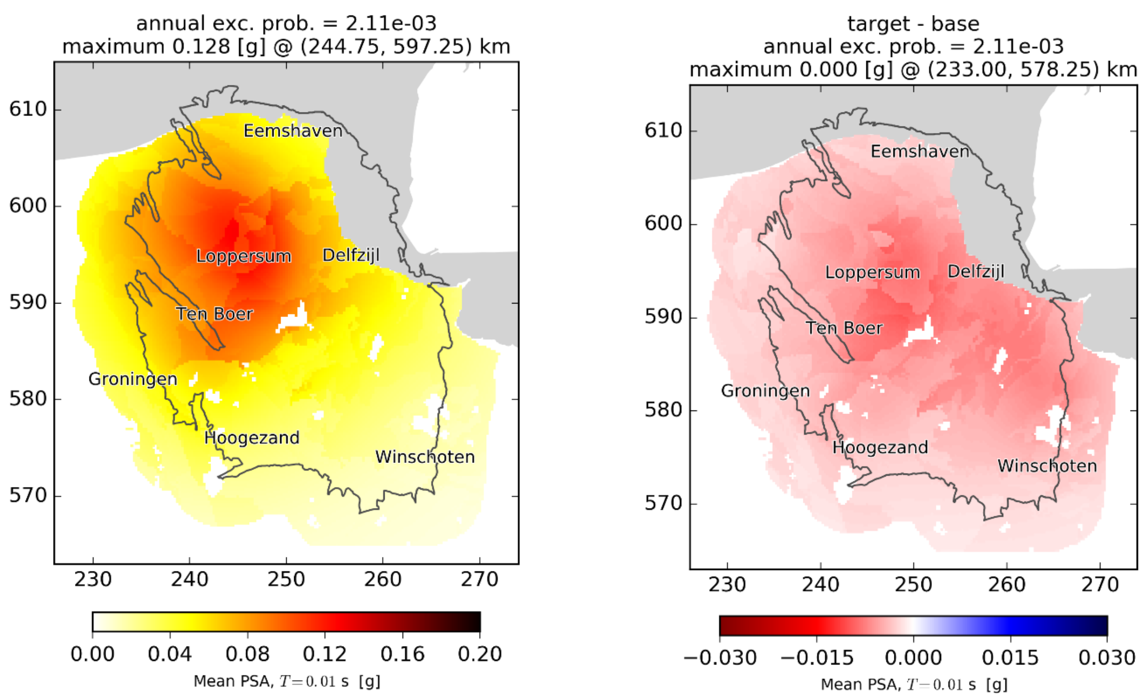


Figure 4-9b Warm-temperature scenario -- annual hazard plots (left) and difference w.r.t. corresponding average-temperature scenario hazard (right)

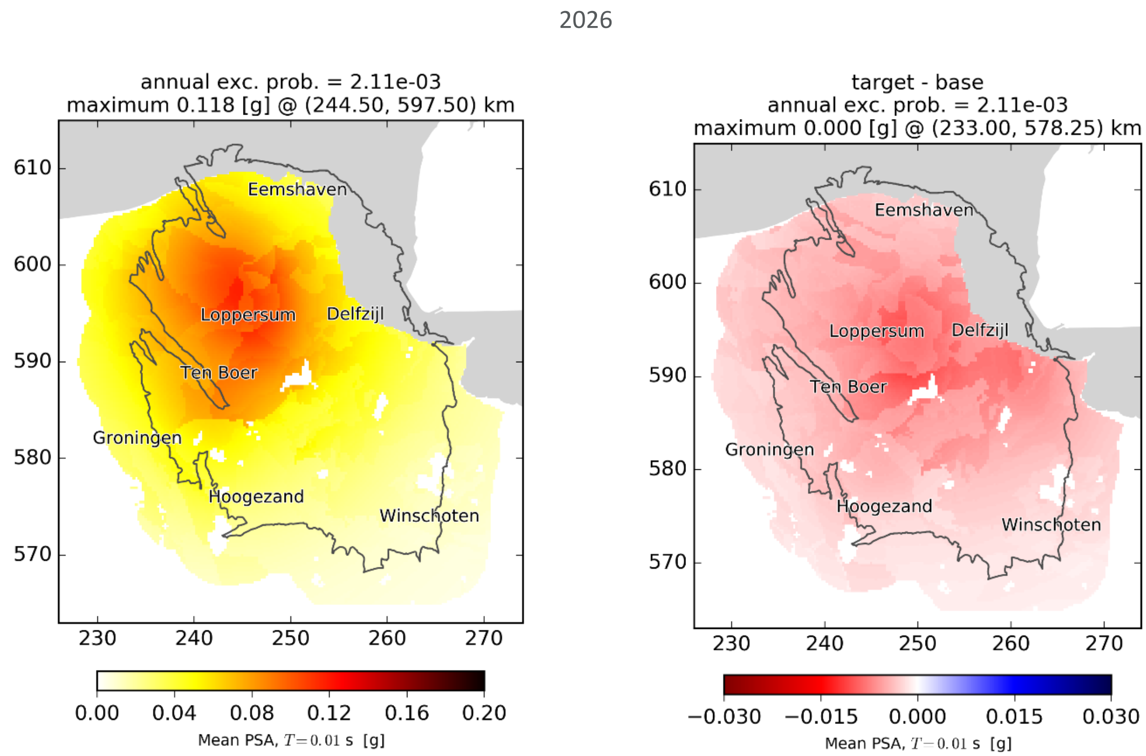


Figure 4-9c Warm-temperature scenario -- annual hazard plots (left) and difference w.r.t. corresponding average-temperature scenario hazard (right)

4.3 References

1. Seismic risk assessment for a selection of seismic risk production scenarios for the Groningen field - Addendum to: Induced Seismicity in Groningen Assessment of Hazard, Building Damage and Risk (November 2017), Jan van Elk, Assaf Mar-Or, Leendert Geurtsen, Per Valvatne, Eddy Kuperus and Dirk Doornhof, March 2018.
2. Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017, NAM (Jan van Elk and Dirk Doornhof), November 2017.

5 Risk Assessment

5.1 Local Personal Risk

The Minister of Economic Affairs and Climate Policy has confirmed that he has adopted the Meijdam Norm for Groningen gas production related risks, this norm states that buildings should meet the same 10^{-5}/year level as is generally used in the Netherlands, but that for a transition period a level of 10^{-4}/year should apply. This report shows the number of houses where the risk exceeds one of these two levels, without addressing which of the two levels applies for an individual house, as such is the domain of the NCG who currently directs the strengthening effort.

Figures 5.1a and 5.1b show the number of buildings exceeding a mean annual Local Personal Risk (LPR) for each year of the 10-year period 2018 to 2027. The grey bands in these LPR-graphs indicate the uncertainty range. Figure 5-2 shows the LPR-graphs for the three five-year periods 2018 to 2022, 2023 to 2027 and 2028 to 2032. The impact of the buildings already strengthened to date has not been incorporated in this assessment.

The development of the mean LPR for the Groningen building stock over the period 2018 to 2027 is shown in figure 5.3. The number of buildings exceeding the Meijdam norm of mean LPR 10^{-5}/year shows a declining trend from 2021 onwards. This is particularly evident for the years 2021 to 2024 the number of buildings exceeding this norm declines noticeably, as a result of the decline in gas production when the nitrogen blending plant comes on stream. For each year in the period 2018 to 2027, tables 5-1a and 5-1b, show the number of buildings for three different probabilistic assessments:

- MeanLPR_1e5 is the number of buildings with LPR exceeding the 10^{-5}/year level
- MeanLPR_1e4 is the number of buildings with LPR exceeding the 10^{-4}/year level

During the period 2021 to 2023, the number of buildings where the 10^{-5}/year norm is not met is assessed to decrease from just over 1,100 in 2021 to about 250 in 2023 and less than one hundred in 2024.

The data captured in tables 5-1a and 5-1b is also shown in figures 5-4 and 5-5. In figure 5-4 shows number of buildings where the LPR exceeds the 10^{-4}/year and 10^{-5}/year, for different scenarios. The average temperature scenario and several cold and warm weather scenarios are shown. For instance, the cold temperature scenario for the gas-year 2018/2019 is shown with all following years being average temperate years. Cold and warm temperature scenarios for other gas-years are also shown. For comparison the results for the 24 Bcm/year scenario from November 2017 are also shown.

In figure 5-5, the cold and warm temperature scenario as specified in the Expectation Letter are shown. The cold temperature (and the warm temperature) scenarios are based on the individual year being cold (or warm), but all preceding years and following years being average temperature years.

The LPR results can be disaggregated to show the separate contributions of the different building typologies (shown in figure 5-6d) as well as their collapse states to the LPR. Collapse State 1 refers for most typologies to partial collapse of façade walls, typically out-of-plane and generally to the outside of the building. Collapse State 2 and 3 are typically more severe, with collapse State 3 leading to global collapse of a significant part of the building. The measures required to strengthen the building will depend on the collapse state that contributes most to the LPR for each building typology.

The numbers of buildings (for each building typology) exceeding a given average annual collapse rate for collapse states 1, 2 and 3 are shown in figure 5-6 (a-c). The building typologies with the highest average annual collapse rate for global collapse (i.e. collapse state 3) across the field are predominantly terraced buildings with large openings at the ground floor (URM4L), precast reinforced concrete buildings (PC4M) and barns (W2L).

We note that the second paragraph of the above text is only valid for the 2022, 2024 and 2026 plots if the same three building typologies are highest on the y axis.

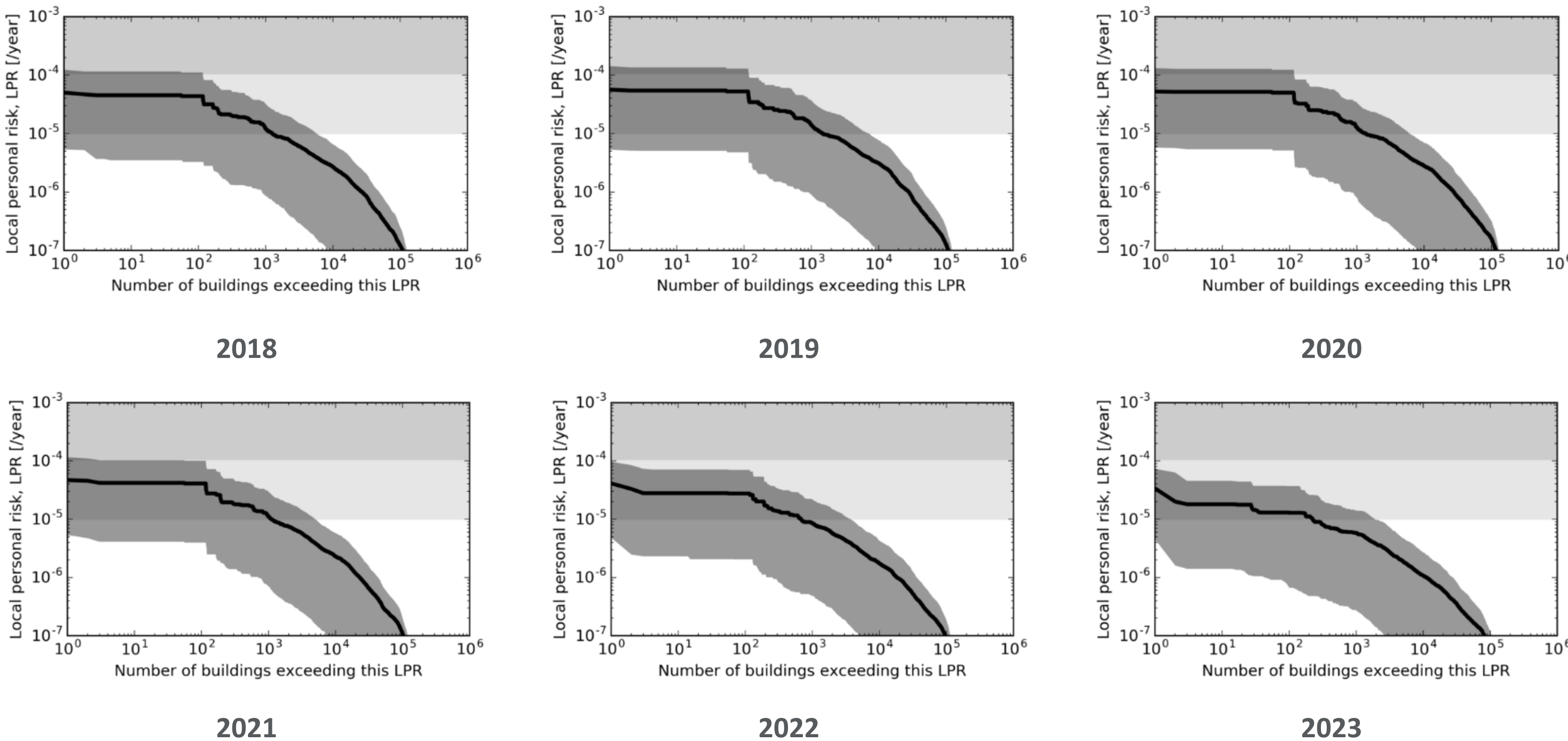
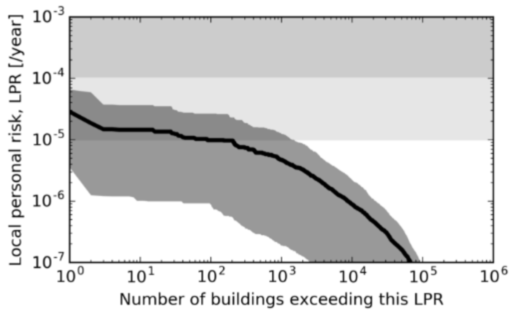
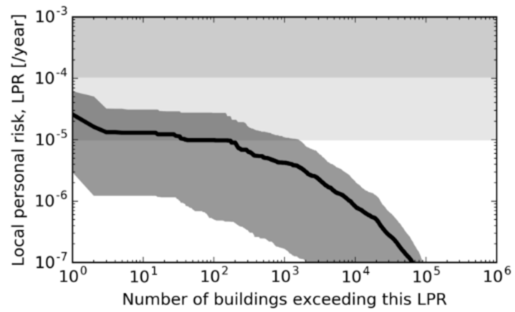


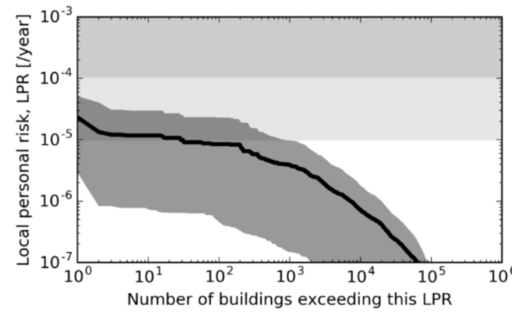
Figure 5.1a *Local Personal Risk graphs for the years 2018 to 2023. These show the number of houses that are exposed to a LPR. The black lines denote the mean and the dark grey areas the uncertainty bands. The two horizontal bands in light grey denote the LPR levels of the Meijdam-Norm.*



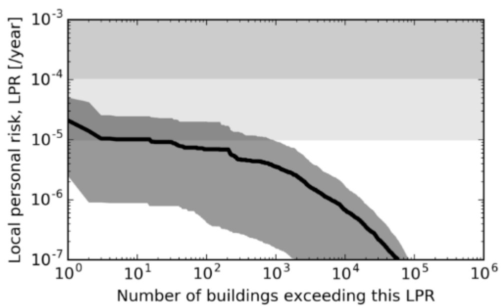
2024



2025



2026



2027

Figure 5.1b *Local Personal Risk graphs for the years 2024 to 2027. These show the number of houses that are exposed to a LPR. The black lines denote the mean and the dark grey areas the uncertainty bands. The two horizontal bands in light grey denote the LPR levels of the Meijdam-Norm.*

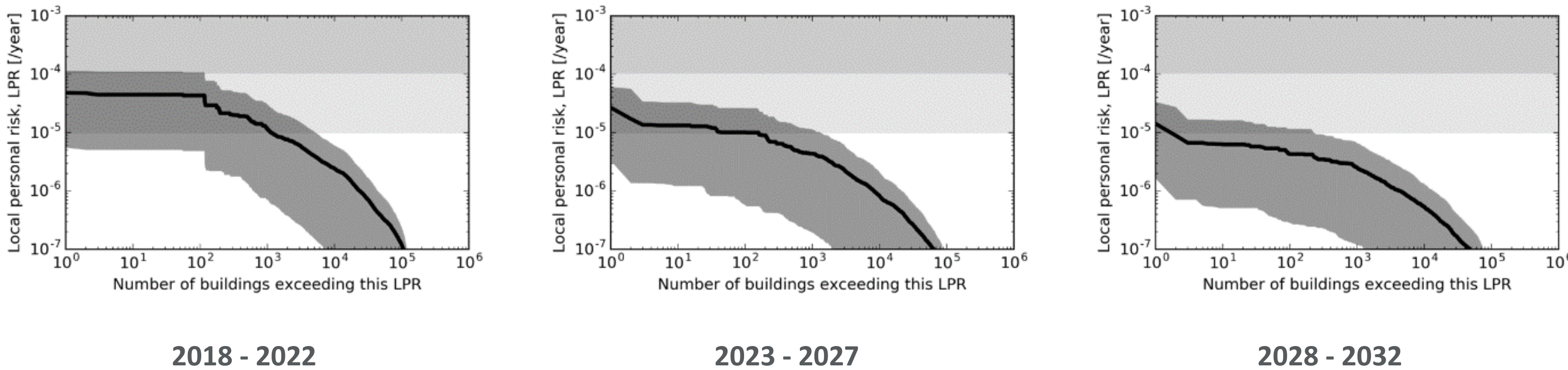


Figure 5.2 *Local Personal Risk graphs for the three 5-year periods (2018 to 2023, 2024 to 2028 and 2029 to 2033). These show the number of houses that are exposed to a LPR. The black lines denote the mean and the dark grey areas the uncertainty bands. The two horizontal bands in light grey denote the LPR levels of the Meijdam-Norm.*

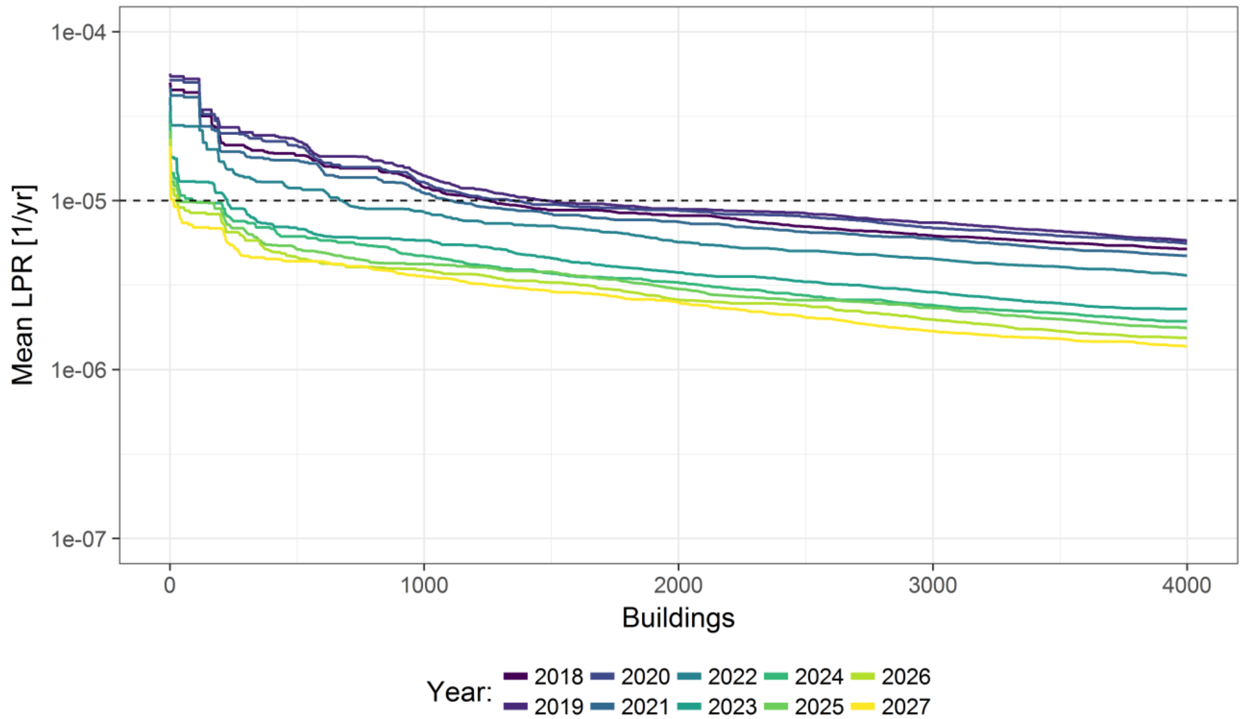


Figure 5.3 *Mean Local Personal Risk graphs for the years 2018 to 2027. These show the number of buildings that are exposed to a LPR. The uncertainty bands have been left out of this graph, but are shown in figures 5.1a and 5.1b. The years are colour coded.*
Note that the number of buildings exceeding the mean LPR norm of 10^{-5}/year decreases over time.

Production Scenario	Weather	Year	Mean LPR 10^{-5} /year	Mean LPR 10^{-4} /year
Basispad Kabinet	Average Year	2018	1256	0
Basispad Kabinet	Average Year	2019	1478	0
Basispad Kabinet	Average Year	2020	1354	0
Basispad Kabinet	Average Year	2021	1109	0
Basispad Kabinet	Average Year	2022	678	0
Basispad Kabinet	Average Year	2023	225	0
Basispad Kabinet	Average Year	2024	88	0
Basispad Kabinet	Average Year	2025	40	0
Basispad Kabinet	Average Year	2026	28	0
Basispad Kabinet	Average Year	2027	15	0
ReferenceCase (24 Bcm/year)	Average Year	2018	2138	0
ReferenceCase (24 Bcm/year)	Average Year	2019	2545	0
ReferenceCase (24 Bcm/year)	Average Year	2020	2859	0
ReferenceCase (24 Bcm/year)	Average Year	2021	3044	0
ReferenceCase (24 Bcm/year)	Average Year	2022	3391	0
ReferenceCase (24 Bcm/year)	Average Year	2023	3228	0
ReferenceCase (24 Bcm/year)	Average Year	2024	3894	1
ReferenceCase (24 Bcm/year)	Average Year	2025	4020	1
ReferenceCase (24 Bcm/year)	Average Year	2026	4414	115
ReferenceCase (24 Bcm/year)	Average Year	2027	4761	115

Table 5.1a *Number of buildings exceeding 10^{-5}/year and 10^{-4}/year level for LPR, for different production and temperature scenarios. See main text for further explanation. These are shown for each year of the period 2018 to 2027 for the production scenario "Basispad Kabinet" for an average weather year and the reference case of 24 Bcm/year.*

Production Scenario	Weather	Year	Mean LPR 10^{-5} /year	Mean LPR 10^{-4} /year
Basispad Kabinet	Cold Year	2018	1660	0
Basispad Kabinet	Cold Year	2019	2521	0
Basispad Kabinet	Cold Year	2020	2164	0
Basispad Kabinet	Cold Year	2021	1726	0
Basispad Kabinet	Cold Year	2022	1197	0
Basispad Kabinet	Cold Year	2023	466	0
Basispad Kabinet	Cold Year	2024	349	0
Basispad Kabinet	Cold Year	2025	172	0
Basispad Kabinet	Cold Year	2026	38	0
Basispad Kabinet	Cold Year	2027	27	0
Basispad Kabinet	Warm Year	2018	1210	0
Basispad Kabinet	Warm Year	2019	1074	0
Basispad Kabinet	Warm Year	2020	916	0
Basispad Kabinet	Warm Year	2021	781	0
Basispad Kabinet	Warm Year	2022	640	0
Basispad Kabinet	Warm Year	2023	91	0
Basispad Kabinet	Warm Year	2024	62	0
Basispad Kabinet	Warm Year	2025	31	0
Basispad Kabinet	Warm Year	2026	20	0
Basispad Kabinet	Warm Year	2027	2	0

Table 5.1b *Number of buildings exceeding 10^{-5}/year and 10^{-4}/year norm for LPR, for different production and temperature scenarios. See main text for further explanation. These are shown for each year of the period 2018 to 2027 for the production scenario “Basispad Kabinet” for cold weather and warm weather years.*

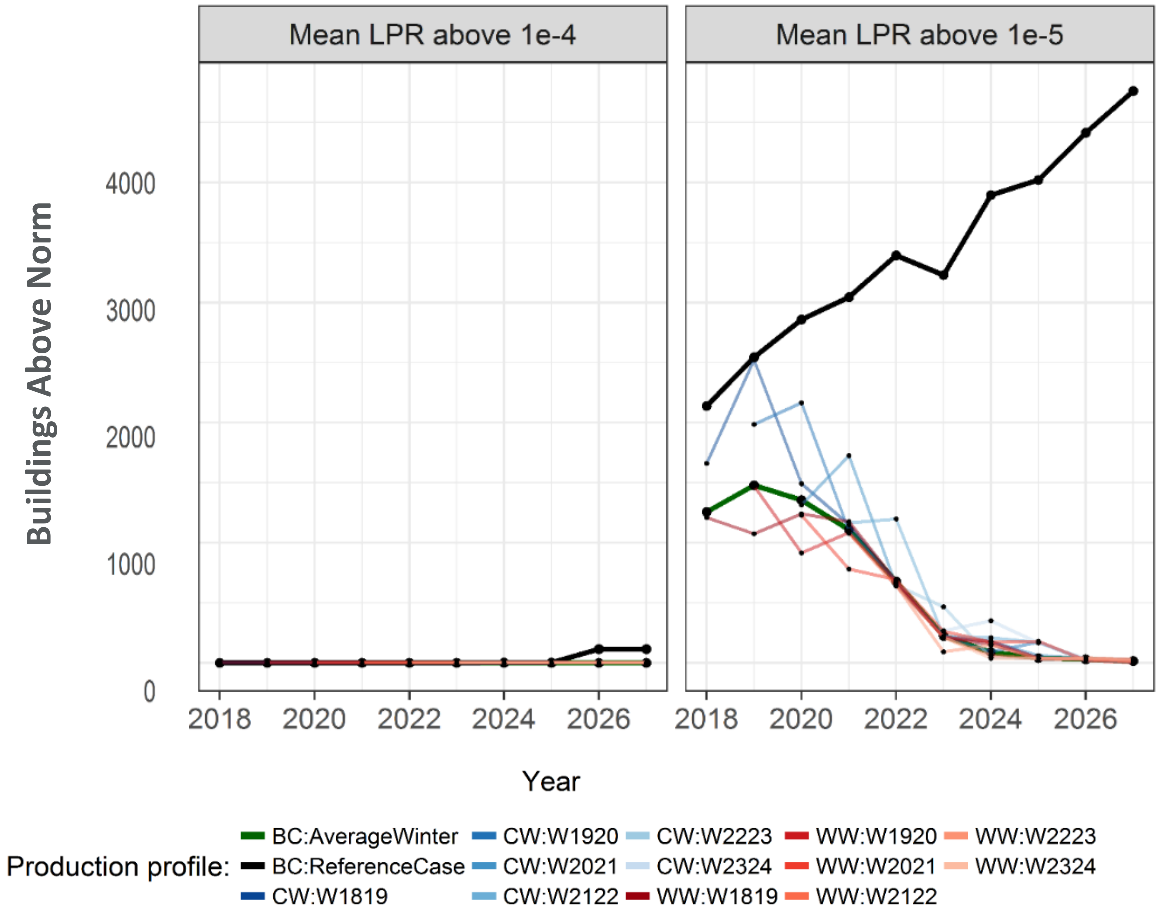


Figure 5.4 *Graphs show the Local Personal Risk associated with the production scenario "Basispad Kabinet" for average (green), cold weather and warm weather years, and the Reference Scenario (24 Bcm/year) (black), and for the period 2018 to 2027. Each cold (blue) and warm (red) year is followed by average temperature years.*

Right graph: *number of buildings exceeding the norm mean LPR larger than 10^{-5}/year*

Left graph: *number of buildings exceeding the norm mean LPR larger than 10^{-4}/year*

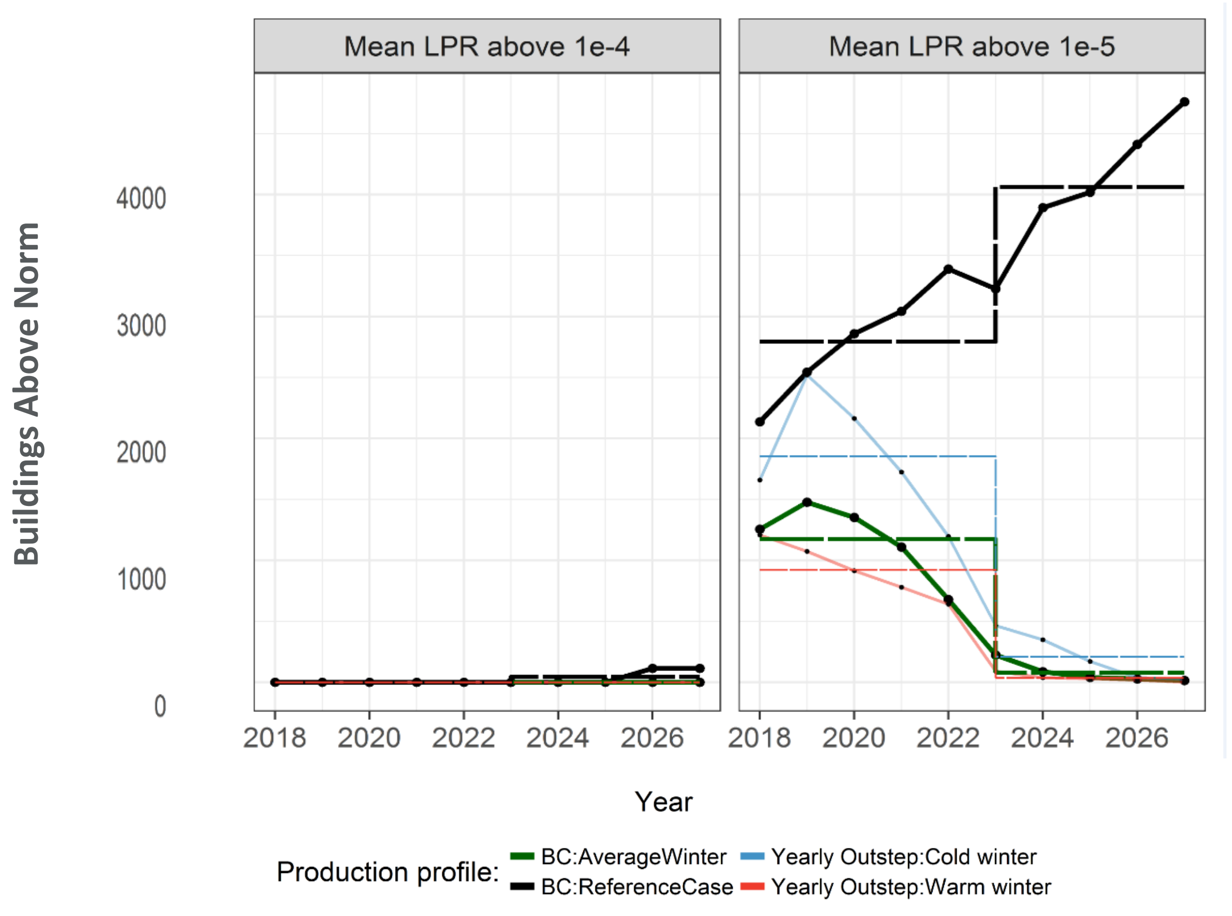
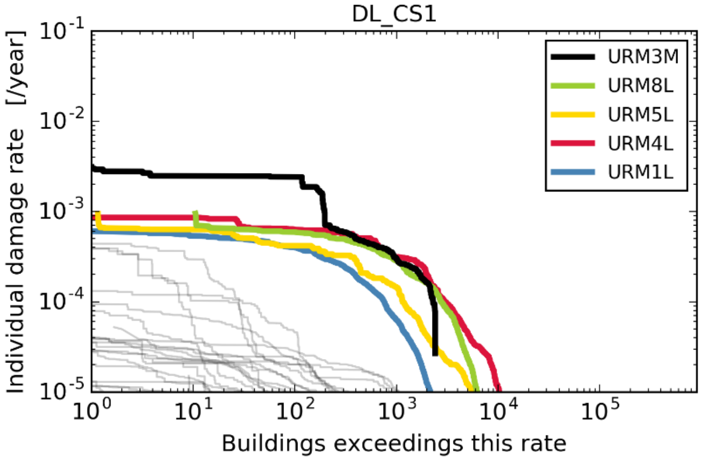


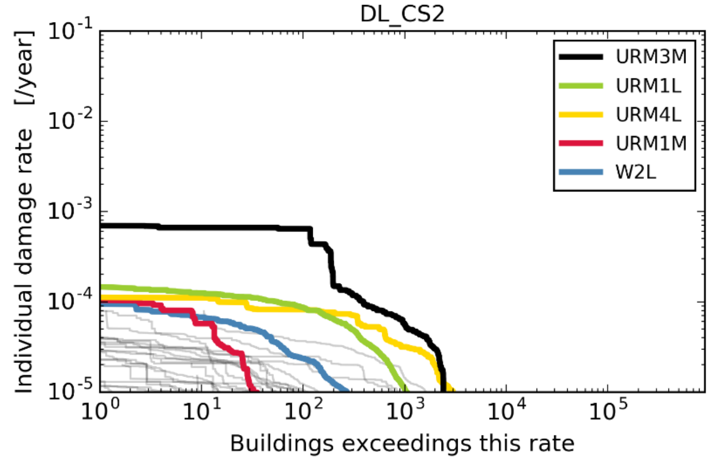
Figure 5.5 *Graphs show the Local Personal Risk associated with the production scenario "Basispad Kabinet" for average (green), cold weather and warm weather years, and the Reference Scenario (24 Bcm/year) (black), and for the period 2018 to 2027. The cold and warm weather years have been gathered as the blue and red line respectively.*

Right graph: *number of buildings exceeding the norm mean LPR larger than 10^{-5}/year*

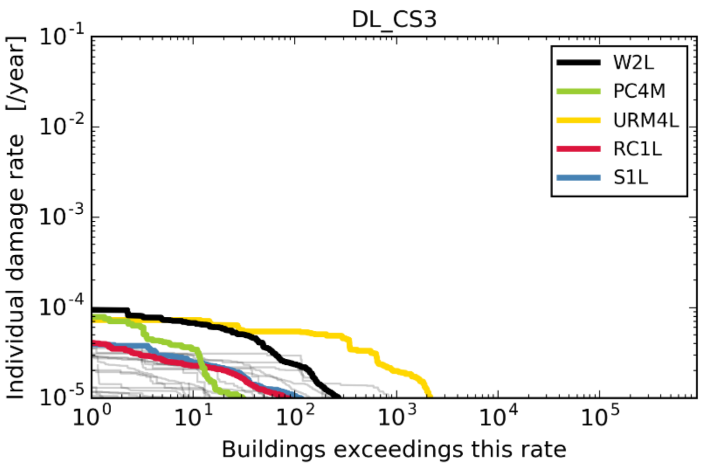
Left graph: *number of buildings exceeding the norm mean LPR larger than 10^{-4}/year*



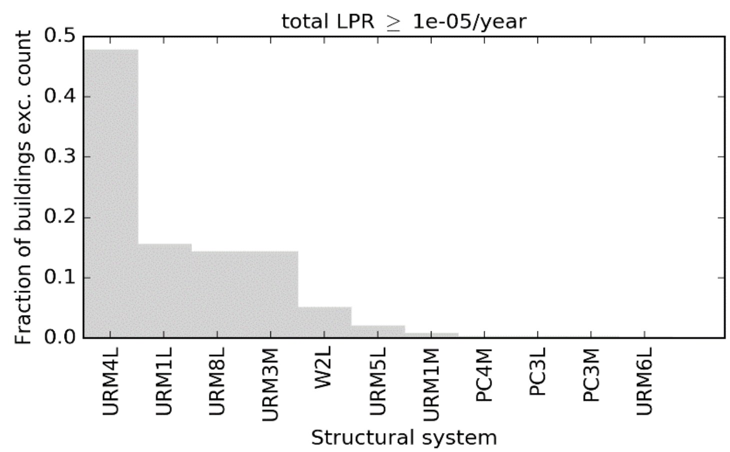
2020, CS1



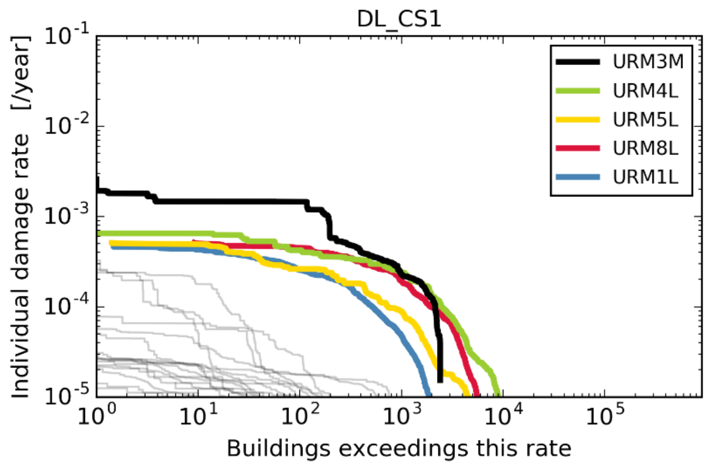
2020, CS2



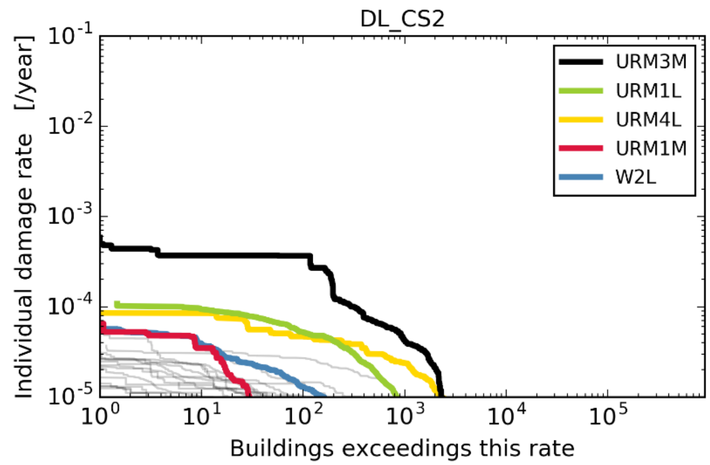
2020, CS3



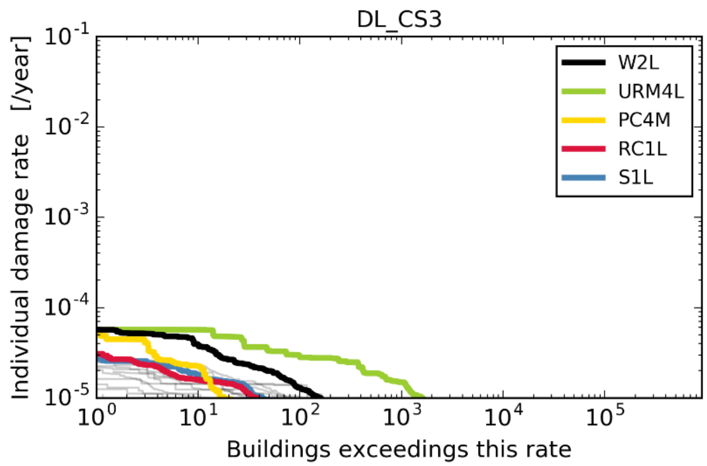
2020



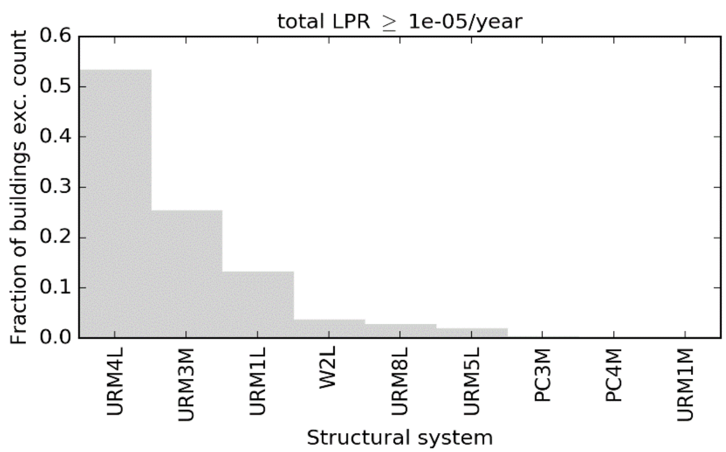
2022, CS1



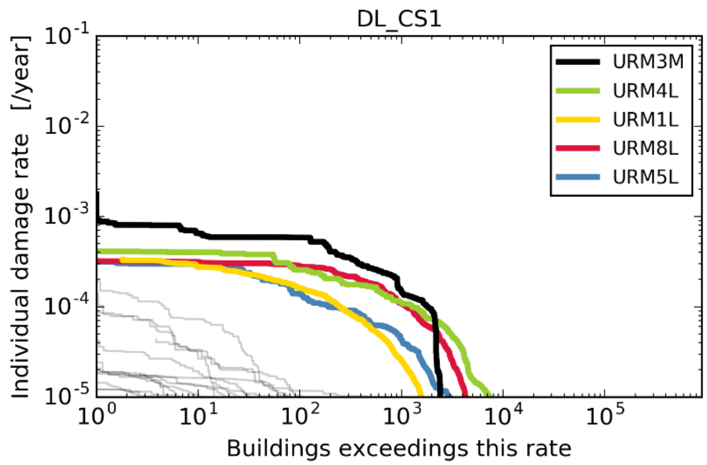
2022, CS2



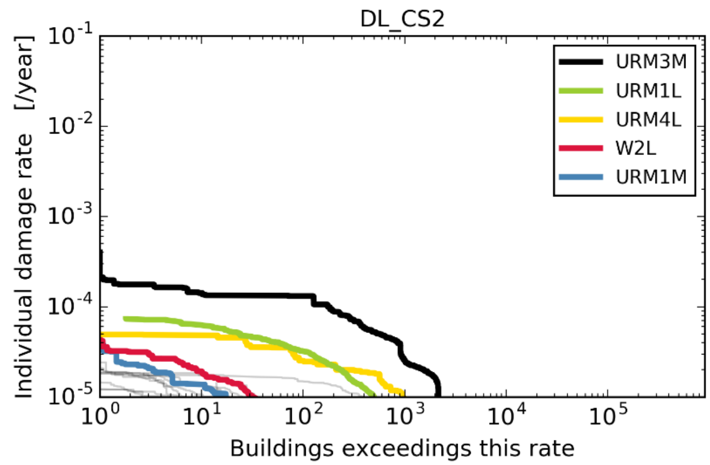
2022, CS3



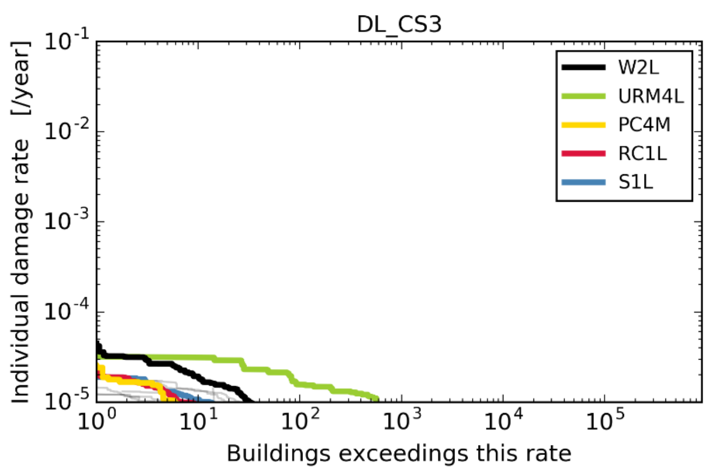
2022



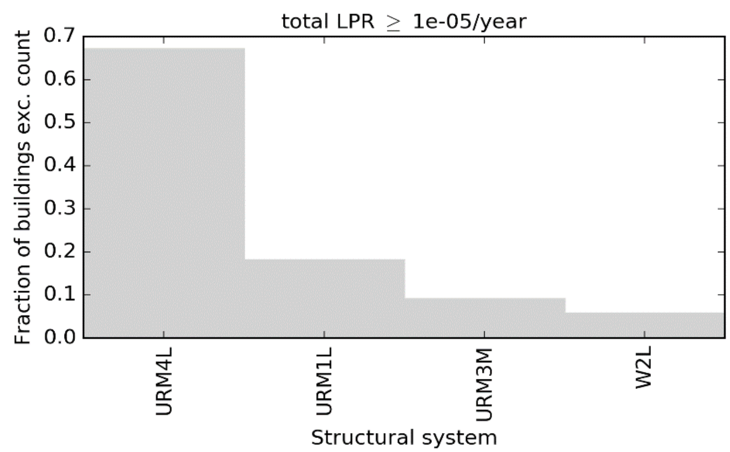
2024, CS1



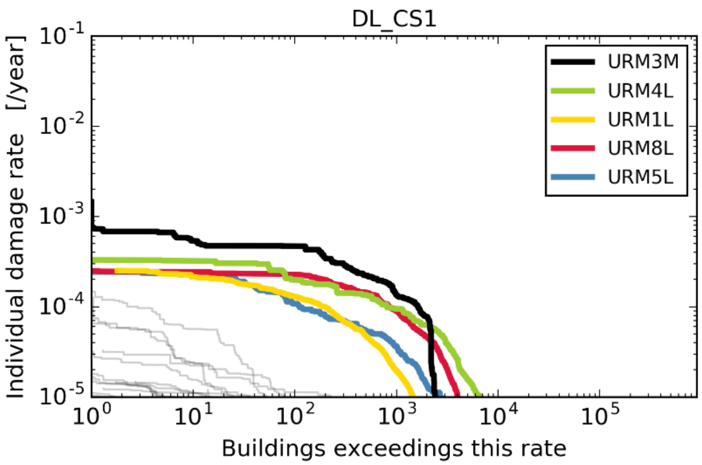
2024, CS2



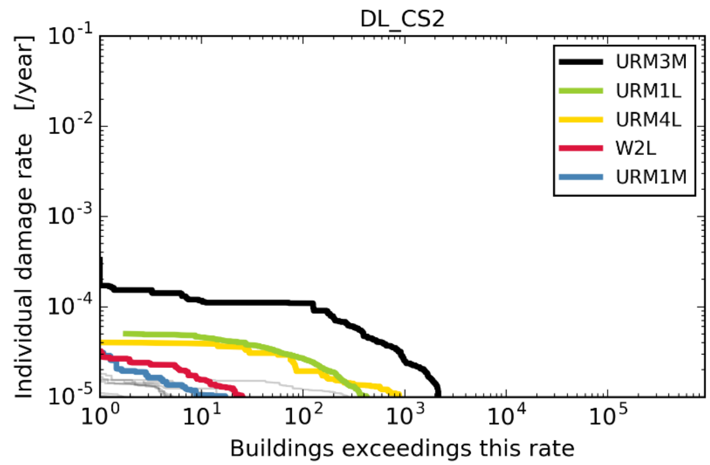
2024, CS3



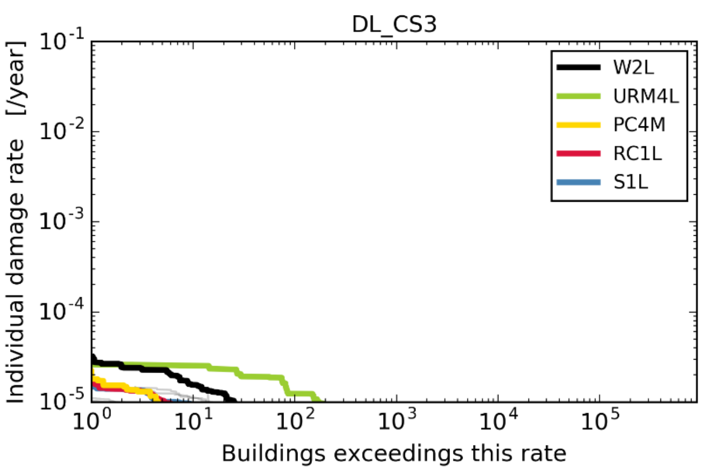
2024



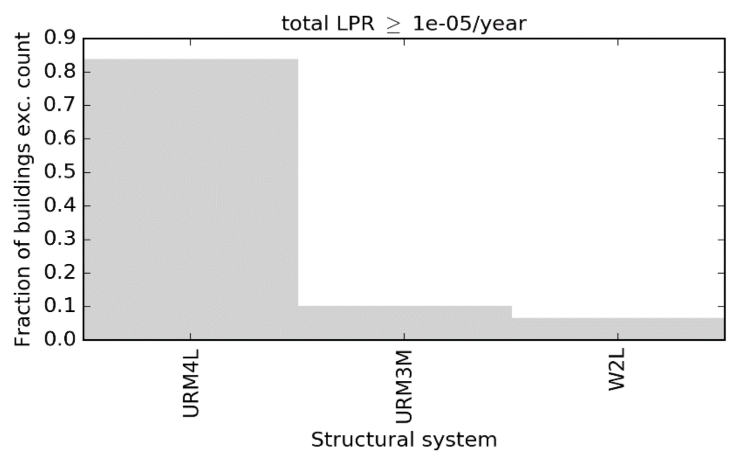
2026, CS1



2026, CS2



2026, CS3

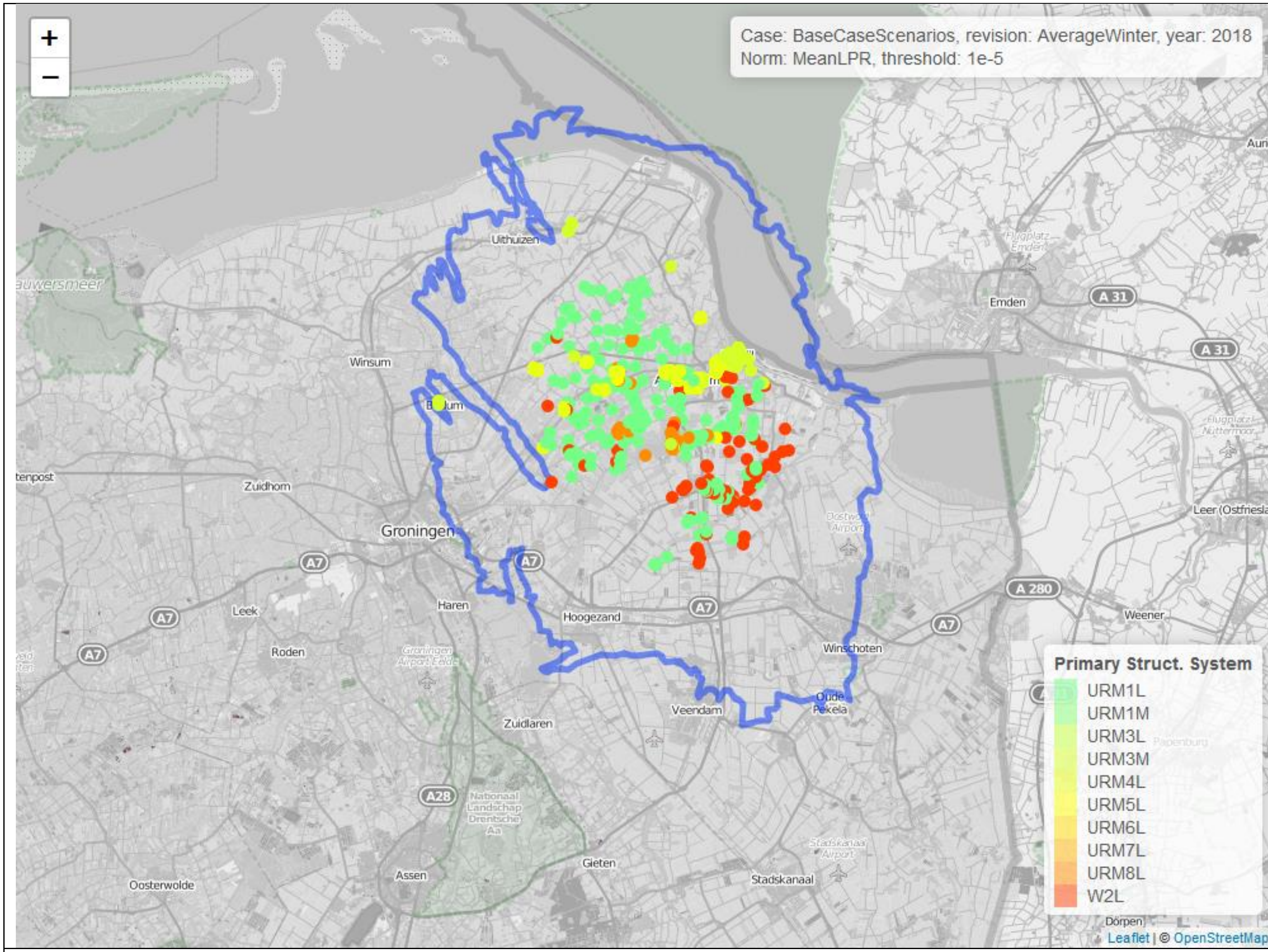


2026

Figure 5-6 *Graphs showing the number of buildings exceeding a given average annual collapse rate for CS1 (top left), CS2 (top right), and CS3 (bottom left), for the “Basispad Kabinet” production scenario for the assessment periods years 2020, 2022, 2024 and 2026. The named structural systems denote the top-five ranked according to the number of buildings with a collapse rate of at least 10^{-5}/year. Breakdown of the structural systems (bottom right) contributing to LPR over the 10^{-5}/year threshold for the assessment periods years 2020, 2022, 2024 and 2026 for the “Basispad Kabinet” scenario.*

5.2 Maps of Buildings compared to the Meijdam-Norm Risk Levels

The maps of figure 5.7 show all buildings exceeding mean LPR>10^{-5}/year for the years between 2018 and 2027. Different colours represent different dominant building typologies. For the purpose of this risk assessment, the Groningen building stock has not been adjusted for the ongoing strengthening operations.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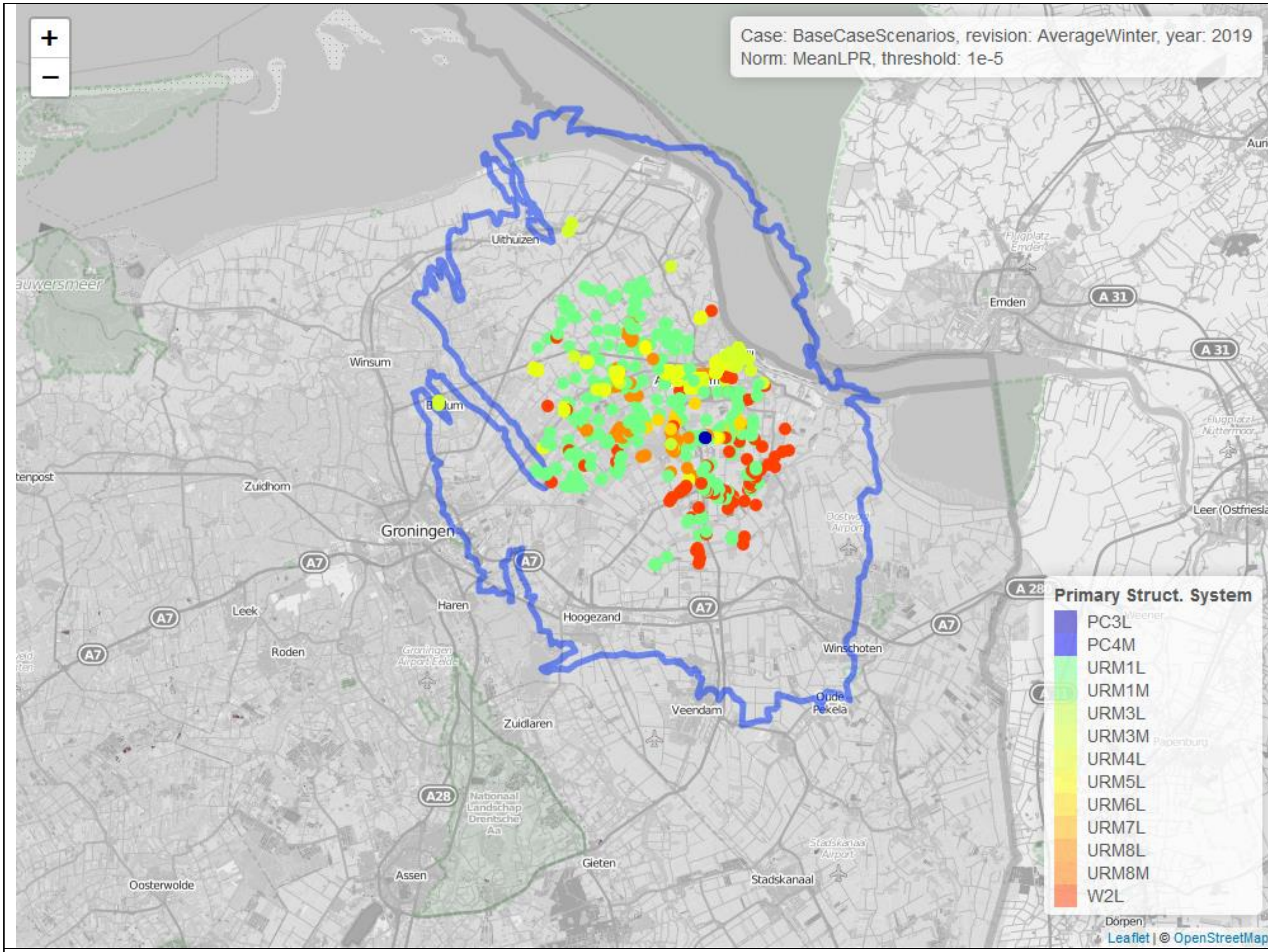
Primary Struct. System
URM1L
URM1M
URM3L
URM3M
URM4L
URM5L
URM6L
URM7L
URM8L
W2L
Uithuizen
Winsum
Zuidhorn
Groningen
Emden
Haren
Hoogezand
Leek
Roden
Winschoten
Veendam
Zuidlaren
Assen
Gieten
Stadskanaal
Oosterwolde
Weener
Leer (Ostfriesland)
Oude Pekela
Dörpen
Leaflet | © OpenStreetMap

2018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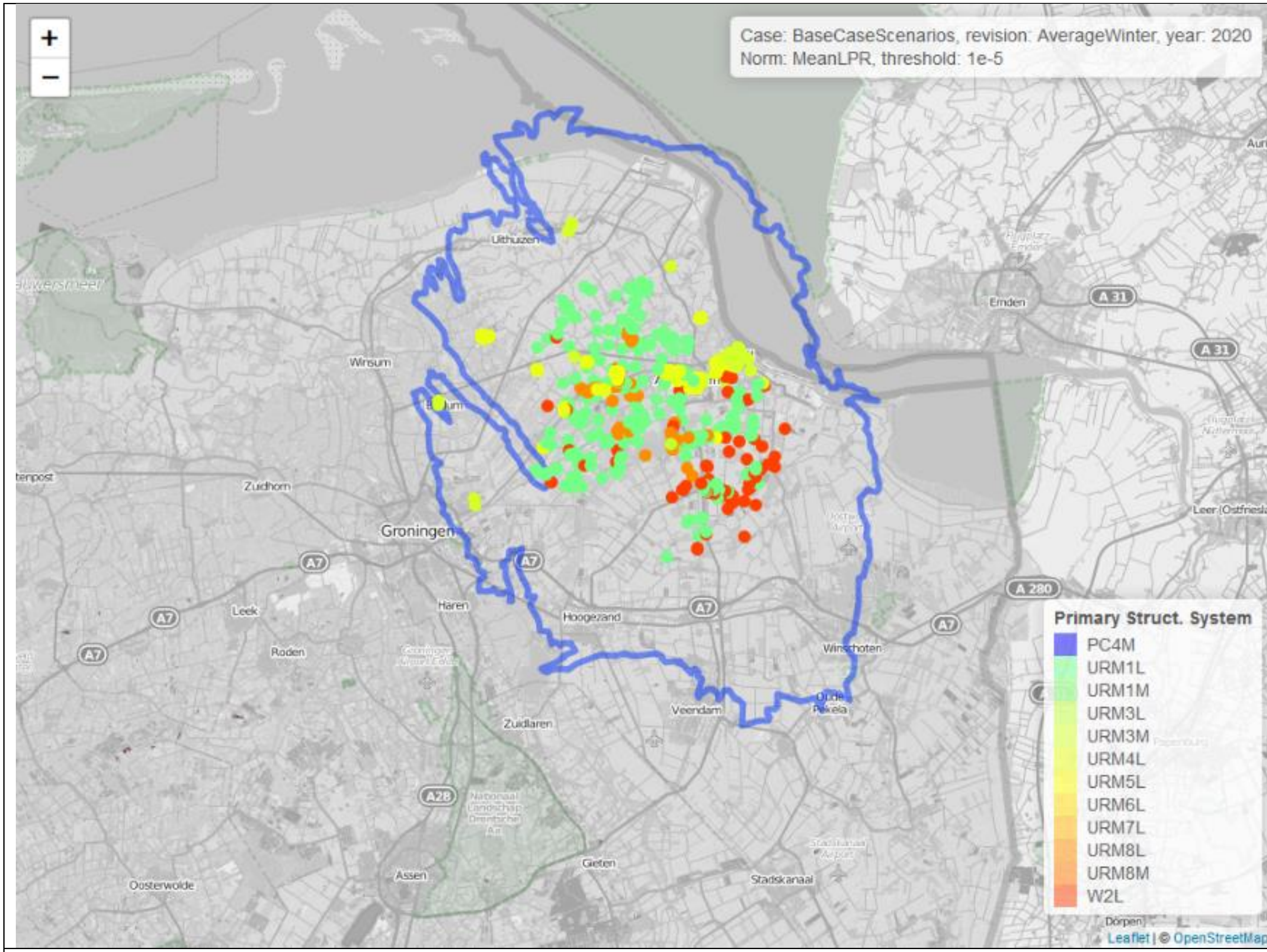
Primary Struct. System
PC3L
PC4M
URM1L
URM1M
URM3L
URM3M
URM4L
URM5L
URM6L
URM7L
URM8L
URM8M
W2L
Uithuizen
Winsum
Groningen
Zuidhorn
Leek
Roden
Haren
Hoogezand
Veendam
Winschoten
Zuidlaren
Assen
Gieten
Stadskanaal
Oosterwolde
Emden
Leer (Ostfriesland)
Leaflet | © OpenStreetMap

2019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PC4M
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URM1M
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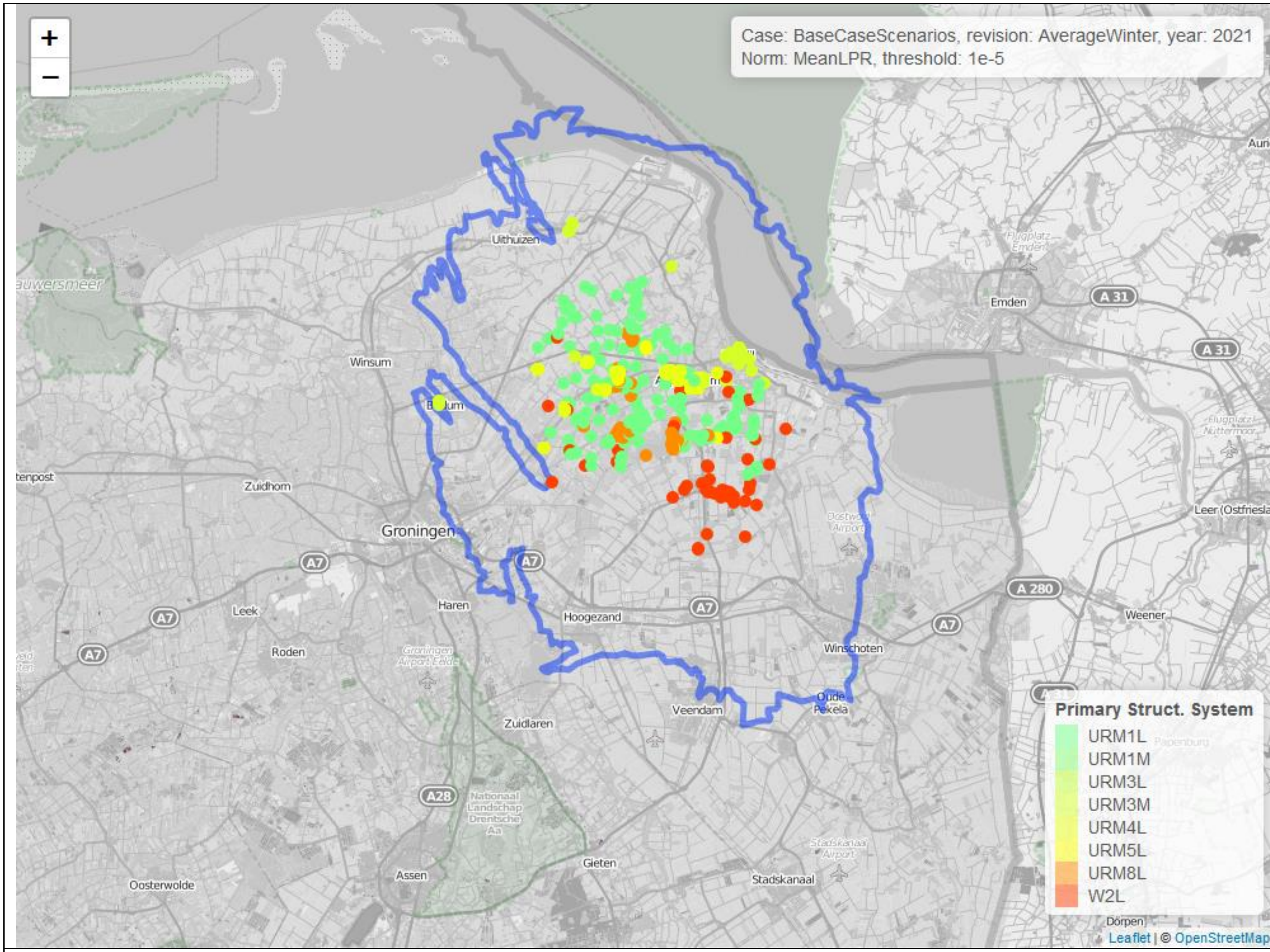
URM3M
URM4L
URM5L
URM6L
URM7L
URM8L
URM8M
W2L
Uithuizen
Winsum
Zuidhorn
Groningen
Emden
Leek
Roden
Haren
Hoogezand
Winschoten
Veendam
Zuidlaren
Assen
Gieten
Stadskanaal
Oosterwolde
Leaflet | © OpenStreetMap

2020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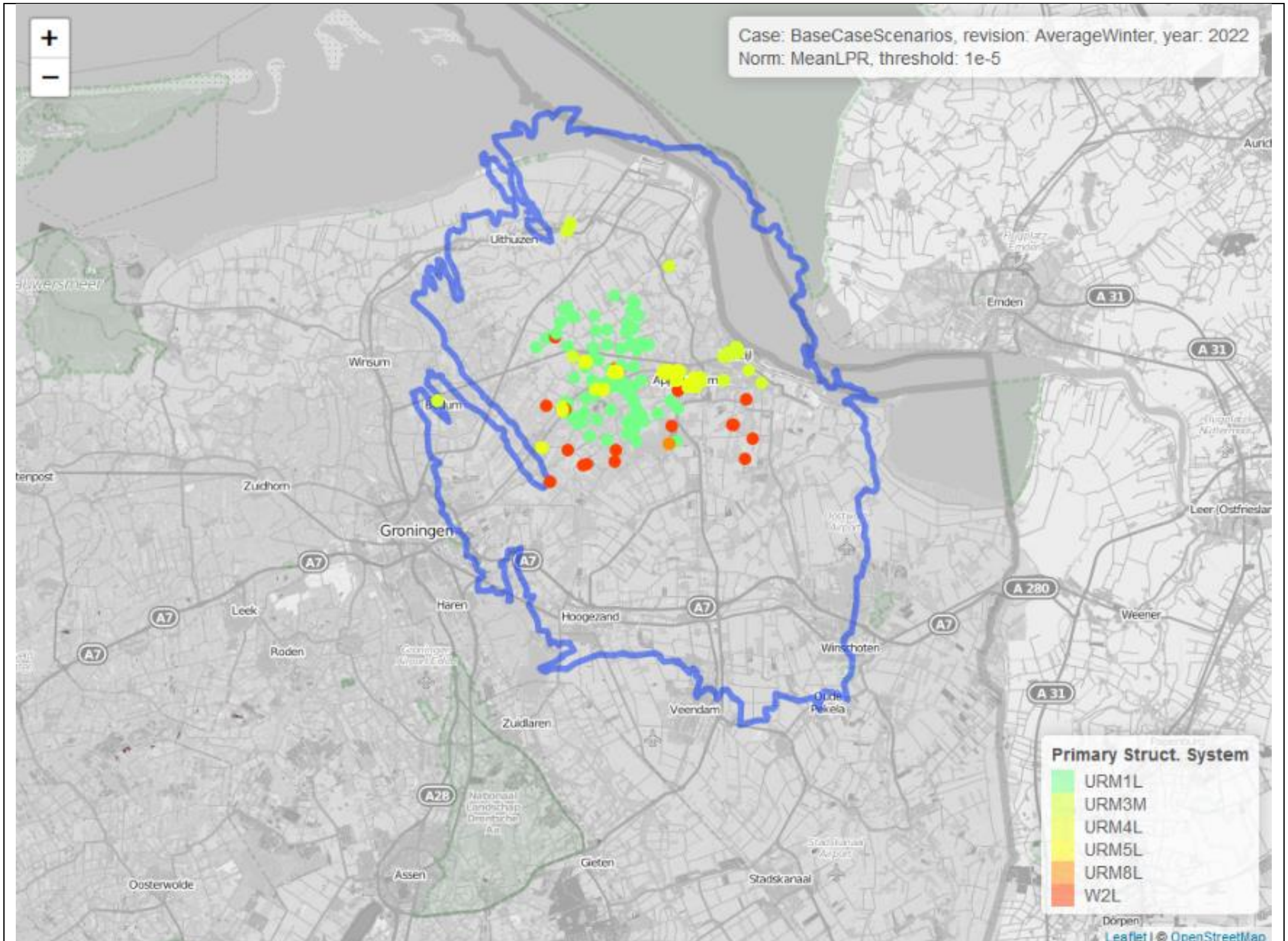
URM1M
URM3L
URM3M
URM4L
URM5L
URM8L
W2L
Uithuizen
Winsum
Groningen
Zuidhorn
Haren
Hoogezand
Leek
Roden
Zuidlaren
Veendam
Winschoten
Emden
Weener
Assen
Gieten
Stadskanaal
Oosterwolde
Leaflet | © OpenStreetMap

2021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URM4L
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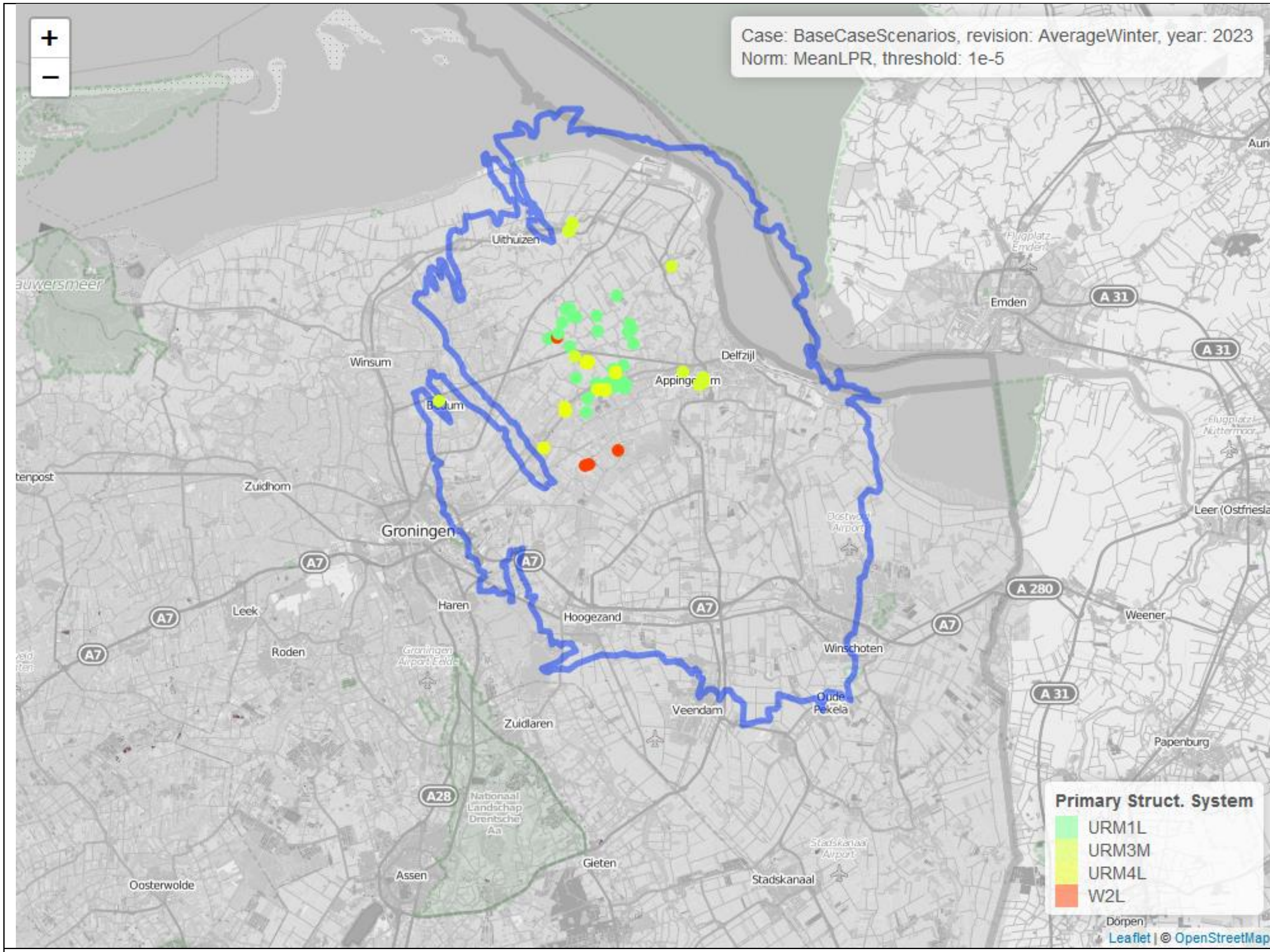
URM8L
W2L
Groningen
Uithuizen
Winsum
Zuidhorn
Leek
Roden
Haren
Hoogezand
Veendam
Winschoten
Zuidlaren
Assen
Gieten
Stadskanaal
Oosterwolde
Emden
Weener
Leer (Ostfriesland)
A7
A28
A31
A280
Leaflet | © OpenStreetMap

2022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URM3M
URM4L
W2L
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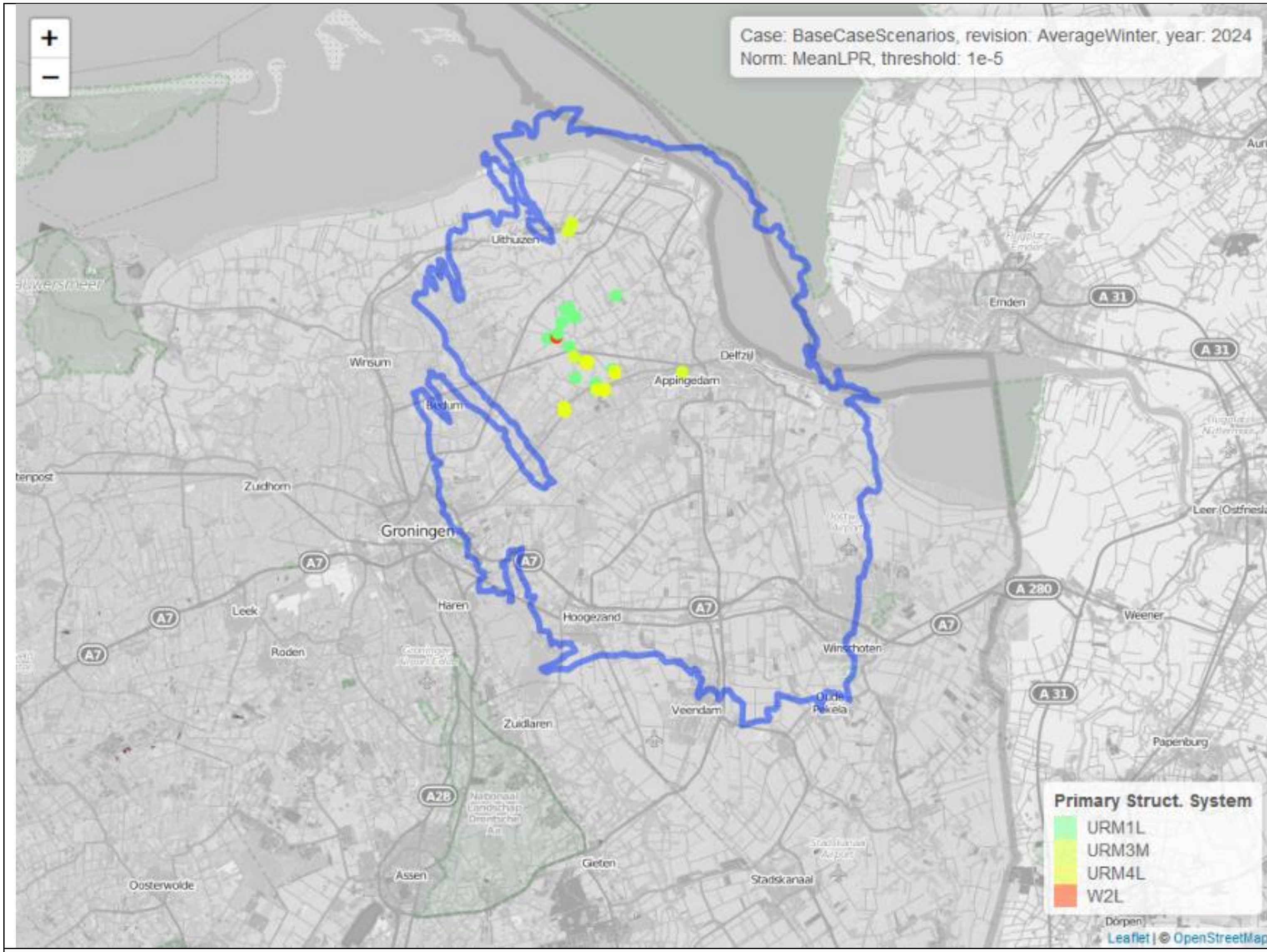
Delfzijl
Winsum
Groningen
Zuidhorn
Leek
Roden
Haren
Hoogezand
Zuidlaren
Veendam
Winschoten
Oude Pekela
Assen
Gieten
Stadskanaal
Oosterwolde
Emden
Weener
Papenburg
Leer (Ostfriesland)
Leaflet | © OpenStreetMap

2023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URM3M
URM4L
W2L
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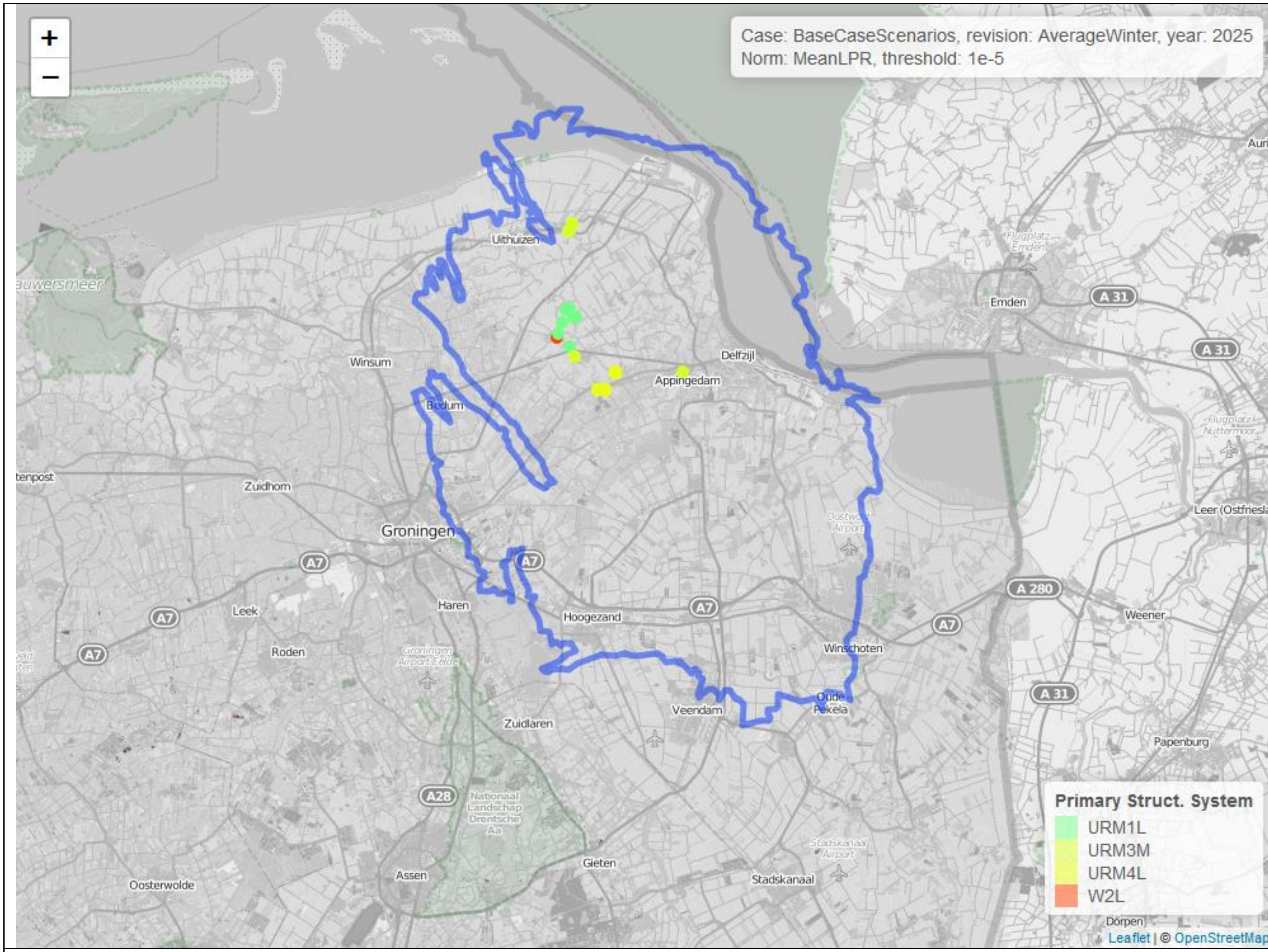
Winsum
Delfzijl
Appingedam
Bedum
Zuidhorn
Groningen
Emden
Leek
Haren
Hoogezand
Roden
Winschoten
Veendam
Oude Pekela
Zuidlaren
Weener
Papenburg
Leer (Ostfriesland)
Assen
Gieten
Stadskanaal
Oosterwolde
Leaflet | © OpenStreetMap

2024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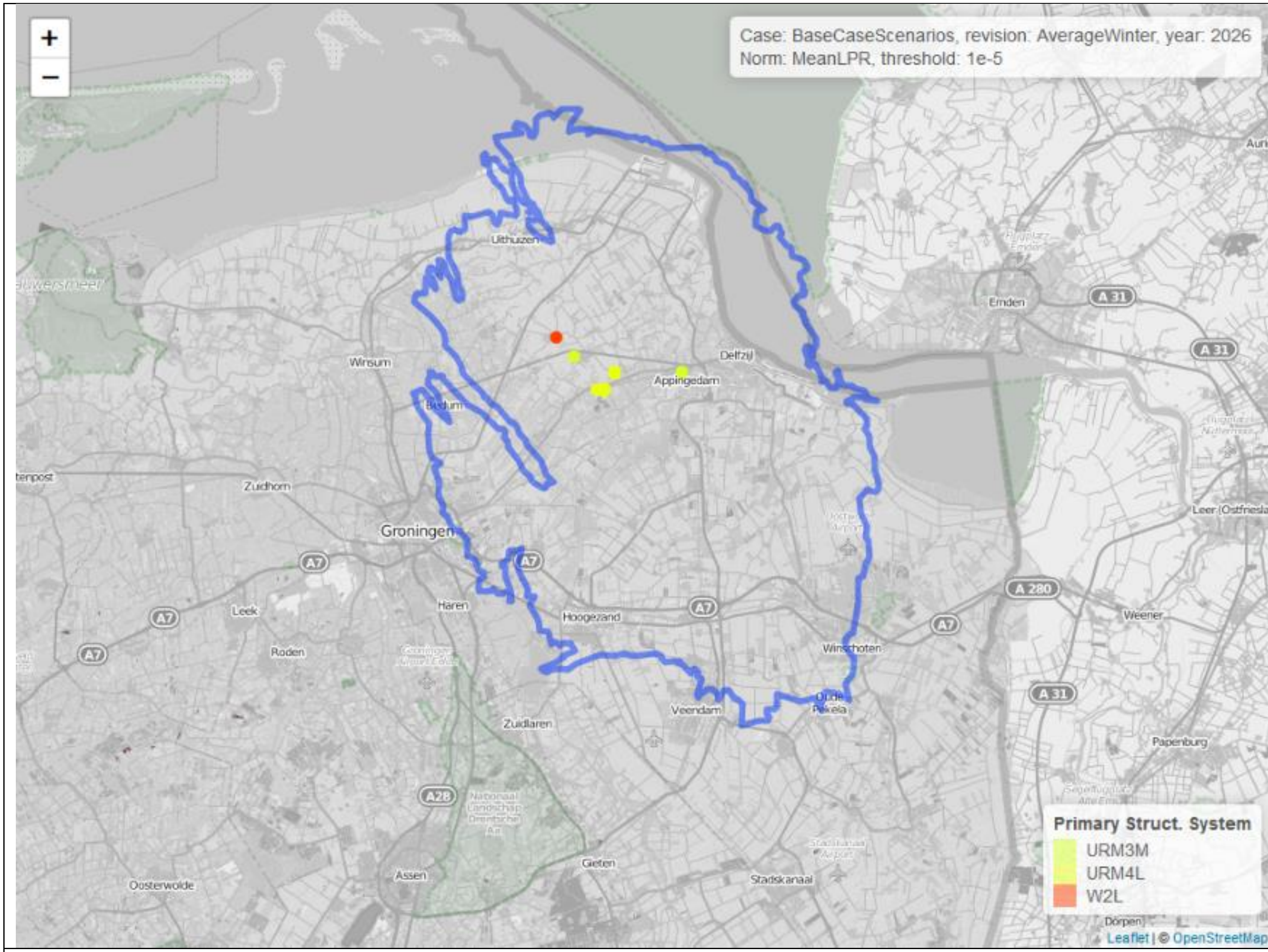
Norm: MeanLPR, threshold: 1e-5
Primary Struct. System
URM1L
URM3M
URM4L
W2L
Uithuizen
Winsum
Delfzijl
Appingedam
Bedum
Zuidhorn
Groningen
Emden
Haren
Leek
Roden
Hoogezand
Winschoten
Veendam
Oude Pekela
Zuidlaren
Assen
Gieten
Stadskanaal
Oosterwolde
Weener
Papenburg
Leer (Ostfriesland)
Leaflet | © OpenStreetMap

2025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Norm: MeanLPR, threshold: 1e-5
Primary Struct. System
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URM4L
W2L
Uithuizen
Winsum
Delfzijl
Appingedam
Bedum
Zuidhorn
Groningen
Haren
Leek
Roden
Hoogezand
Winschoten
Veendam
Oude Pekela
Zuidlaren
Assen
Gieten
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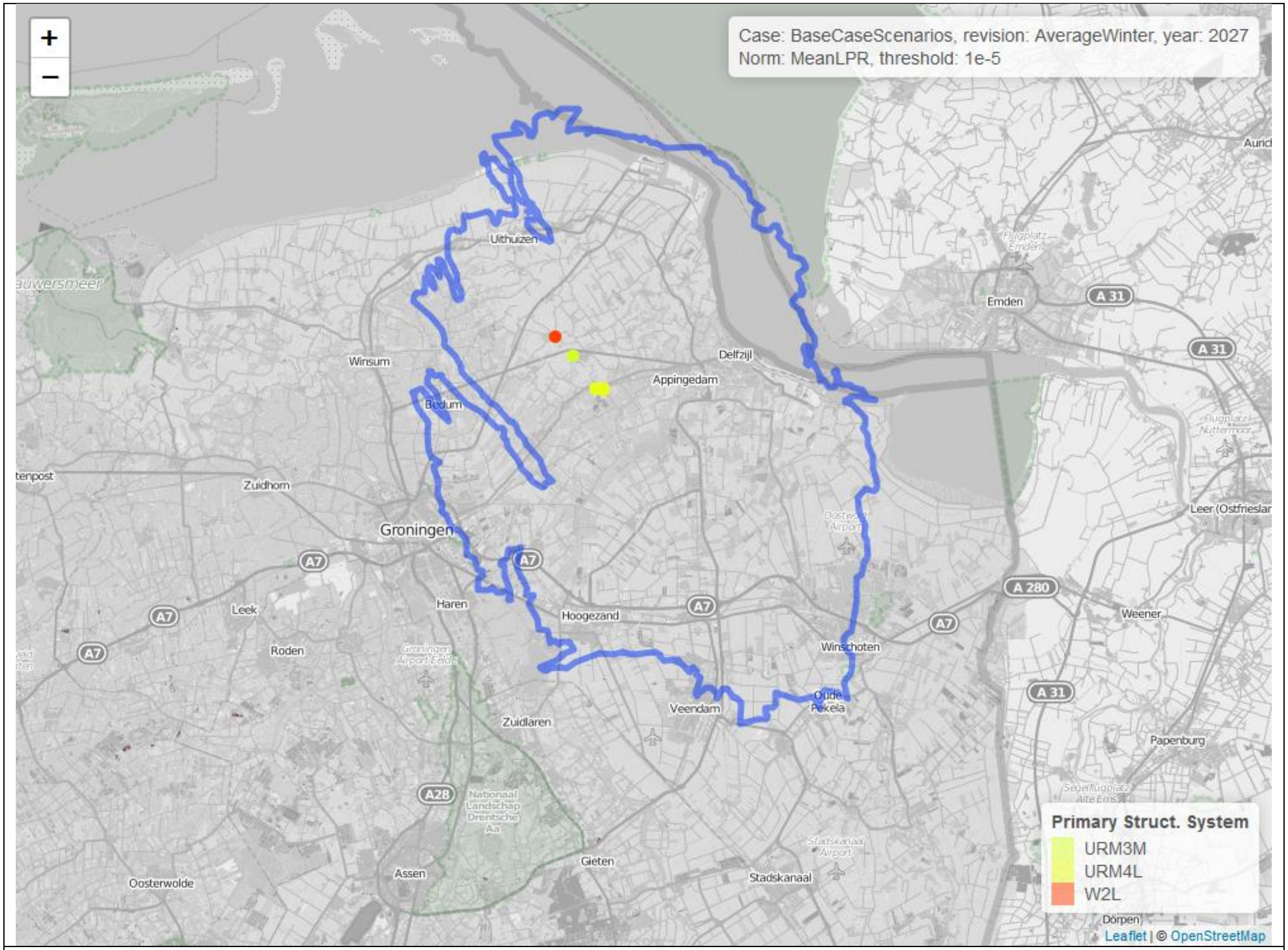
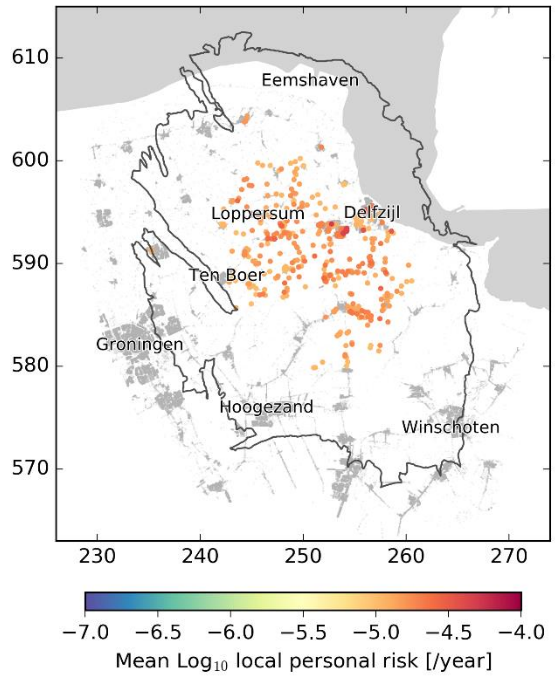
Oosterwolde
Emden
Weener
Papenburg
Leer (Ostfriesland)
Leaflet | © OpenStreetMap

2026

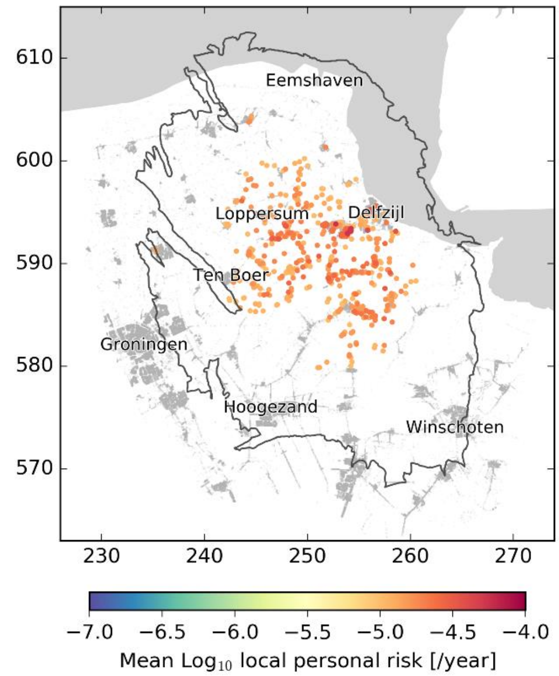


2027

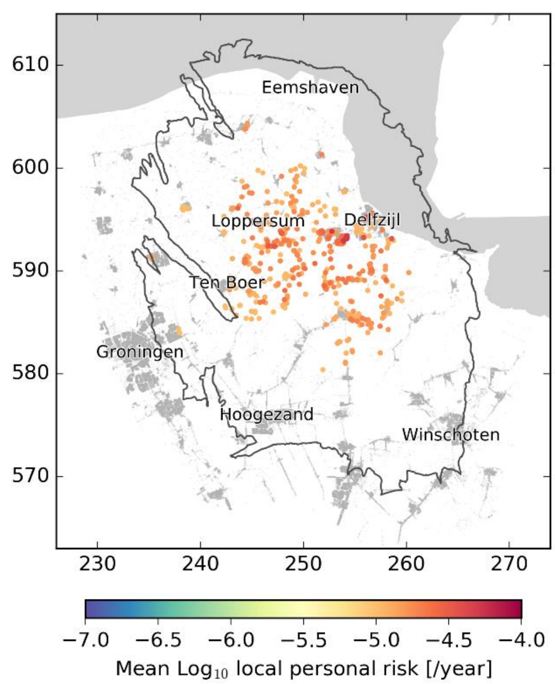
Figure 5.7 Maps of all buildings exceeding mean LPR>10^{-5}/year for the years 2020, 2022, 2024 and 2026. Different colours indicate different building typologies.



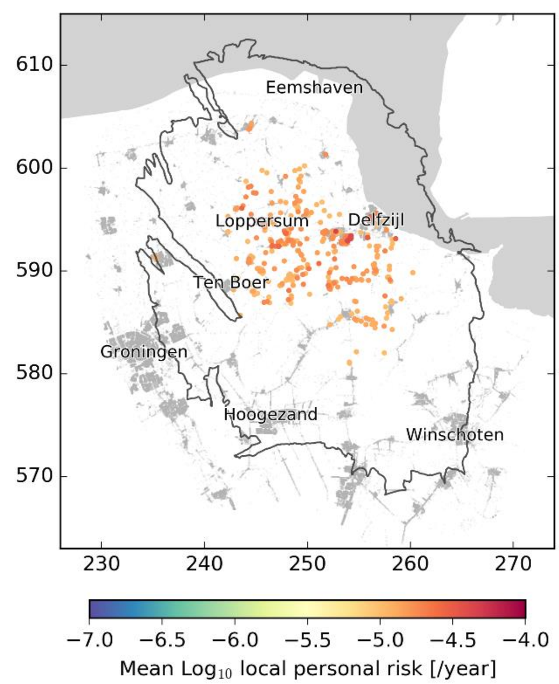
2018



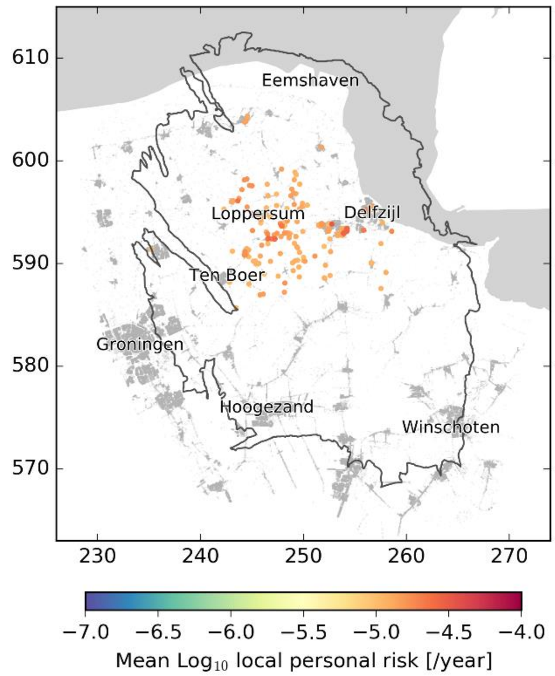
2019



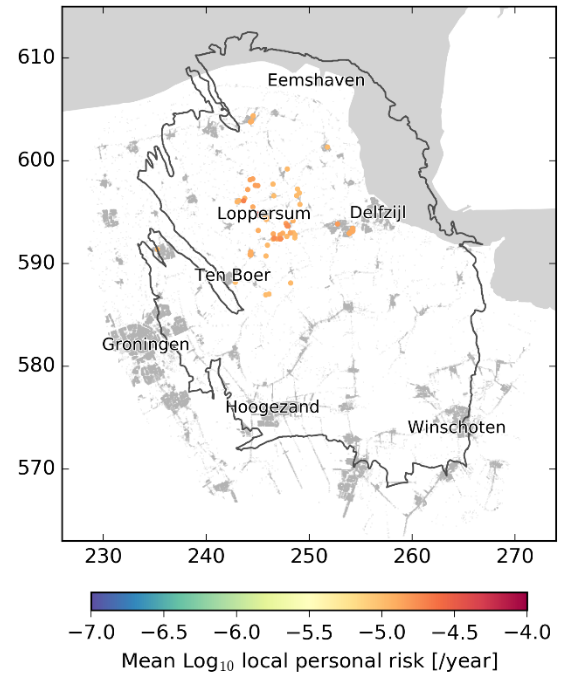
2020



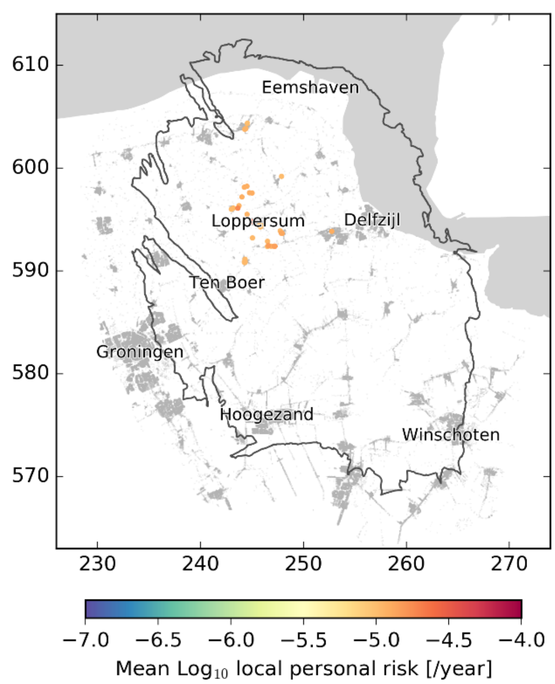
2021



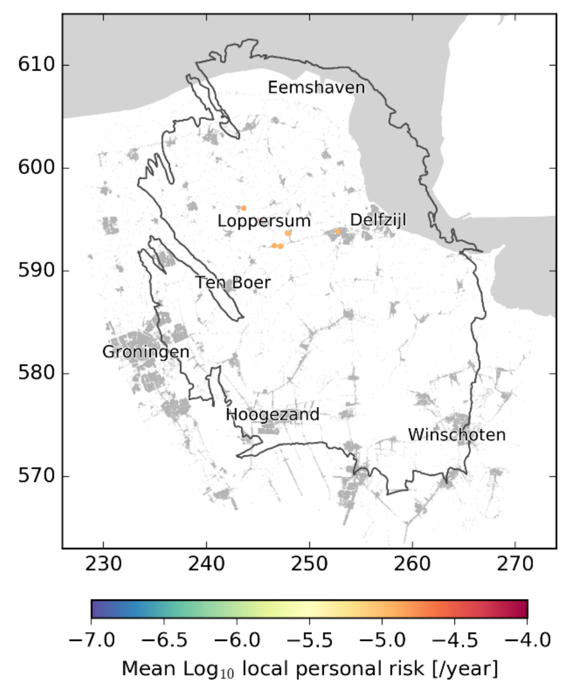
2022



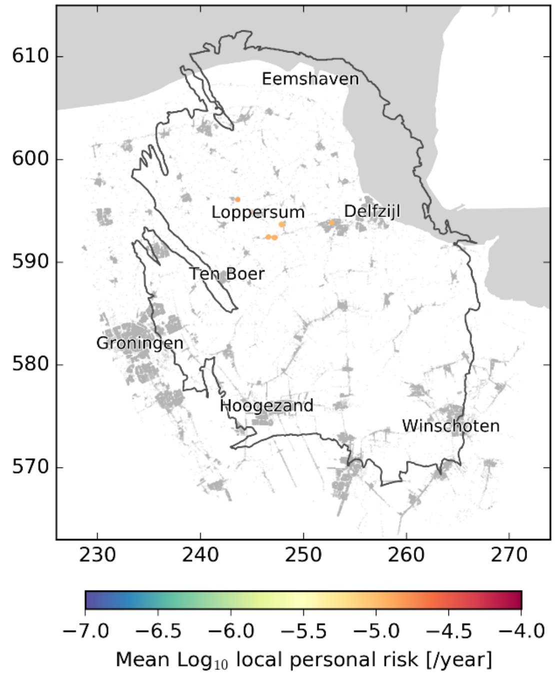
2023



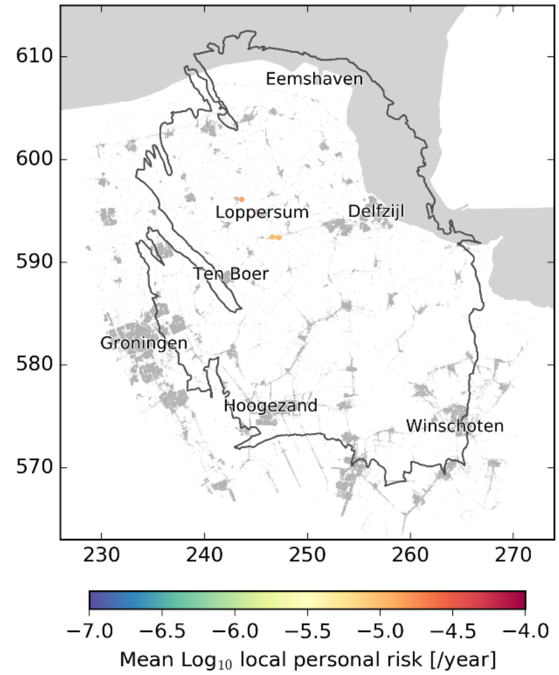
2024



2025



2026



2027

Figure 5.8 *Map indicating individual building with Local Personal Risk exceeding 10^{-5}/year for the years 2020, 2022, 2024 and 2026 and production scenario "Basispad Kabinet".*

5.3 Structural Upgrading Program

The probabilistic assessment of the number of buildings that do not meet the Meijdam Norm does not immediately translate into an estimate of the structural strengthening scope. There are three main reasons why the scope of the structural upgrading plan will in general be larger than the probabilistic assessment of the number of buildings that do not meet the Meijdam norm.

- Efficiency of identifying buildings with LPR >10^{-5} has not yet been proven.
  The Hazard and Risk Assessment is a probabilistic assessment and does not directly identify each individual building that needs to be included in the structural upgrading plan. Through an inspection program these buildings will have to be identified. A risk-based inspection program will be able to identify these buildings with reasonable efficiency.
- Remaining uncertainty in hazard and risk assessment.
  Significant progress has been made towards assessing the risk from Groningen earthquakes. However, uncertainty remains in the estimate of the number of buildings that do not meet the norm based on mean LPR > 10^{-5}/year. Especially building inspections can help reduce this uncertainty.
- Differences between the hazard and risk assessment and NEN-NPR building code.
  Ultimately the structural upgrading scope will be based on the NEN-NPR building code. Improvement of the Hazard and Risk Assessment Updating and calibration of the building code with the latest technical insight from laboratory experiments and modelling are likely to reduce the difference.

The probabilistic estimate of the number of buildings, where the Meijdam-Norm Safety Level is exceeded, does therefore not directly translate into an estimate of the structural strengthening scope. However, the Hazard and Risk Assessment provides a useful tool for prioritisation of building inspections. Ultimately the structural upgrading scope will be based on the assessment of individual buildings based on the NEN-NPR building code.

5.4 References

1. Seismic risk assessment for a selection of seismic risk production scenarios for the Groningen field - Addendum to: Induced Seismicity in Groningen Assessment of Hazard, Building Damage and Risk (November 2017), Jan van Elk, Assaf Mar-Or, Leendert Geurtsen, Per Valvatne, Eddy Kuperus and Dirk Doornhof, March 2018.

Appendix A – Abbreviations

EZK	Ministry of Economic Affairs and Climate Policy
GTS	Gasunie Transport Services BV
GY	Gas-year (12-months period following 1st October). This was introduced for practical reasons. The gas-year starts with the 6 coldest months of the year avoiding a winter period to be split over two one-year time periods, such as a calendar year.
H-gas	High Calorific Gas (Gas from most gas field has a higher calorific content than gas from the Groningen gas field)
HRA	Hazard and Risk Assessment
L-Gas	Low Calorific Gas (Groningen gas had due to the nitrogen content a lower calorific content than gas from many other gas fields)
LPR	Local Personal Risk
MC	Monte Carlo
N_2	Nitrogen
NAM	Nederlandse Aardolie Maatschappij BV
NFA	No Further Activity
UGS	Underground Gas Storage

A more complete list if abbreviations can be found in “Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017, NAM (Jan van Elk and Dirk Doornhof), November 2017” available from www.nam.nl.

Appendix B – Verwachtingenbrief aanvulling Winningsplan Groningenveld 2016

For convenience, the Expectation Letter has been included in the report in this Appendix.

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T 070 379 8430
j.m.vanherk@minez.nl

Ons kenmerk
DGETM-EO / 18085152

Uw kenmerk

Bijlage(n)
1

Datum - 02 MEI 2018 -
Betreft Verwachtingenbrief aanvulling winningsplan Groningenveld 2016

Geachte heer Schotman,

Het is u bekend, dat het kabinet besloten heeft om maatregelen te nemen die ertoe zullen leiden dat de behoefte aan gas (en daarmee ook de winning van gas) uit het Groningenveld de komende jaren sterk zal afnemen. Ik verwijs hierbij naar mijn brief van 29 maart 2018 (DGETM-EI/18057375). Tevens heeft het kabinet besloten om de Gaswet en de Mijnbouwwet aan te passen, waardoor het mogelijk wordt om niet méér gas te produceren uit het Groningen gasveld dan nodig is voor de leveringszekerheid. Naar verwachting zullen deze wetswijzigingen later dit jaar van kracht worden.

Aanvulling winningsplan

In het winningsplan Groningenveld 2016 werd geen rekening gehouden met een snelle afname van de winning, zoals nu is voorzien door het kabinet. Daarom verzoek ik u om een aanvulling op het winningsplan 2016 te maken, bestaande uit twee elementen:

a) een "hazard and risk assessment", gebaseerd op het basispad van het kabinet, waarmee duidelijk wordt wat de gevolgen zijn van een sterke afname van de gaswinning uit Groningen voor de veiligheidsrisico's en de omvang van de versterkingsoperatie.
b) een "operationele strategie" voor de gaswinning voor het gasjaar 2018/2019.

In bijgaand document heb ik mijn verwachtingen voor deze aanvulling op het winningsplan 2016 nader uitgewerkt. Ik zie uw aanvulling graag uiterlijk 15 juni 2018 tegemoet.

Instemmingsbesluit

Ik ga ervan uit dat het nieuwe besluit over de gaswinning in Groningen, dat ik vóór 15 november 2018 zal nemen (op basis van de uitspraak van de Raad van State van november 2017), zal plaatsvinden op basis van de thans geldende wetgeving. Dit besluit zal het karakter dragen van een "overbruggingsbesluit", dat

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Directie Energie en Omgeving

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geldt voor één gasjaar, namelijk het gasjaar 2018/2019. In dit besluit zal ik uw aanvulling op het winningsplan betrekken.

De Minister van Economische Zaken en Klimaat,
Voor deze:

Drs. V.G.Pieterman
Plv.Directeur Energie & Omgeving

Directoraat-generaal Energie, Telecom & Mededinging
Directie Energie en Omgeving

Ons kenmerk
DGETM-EO / 18085152

Bijlage

Verwachtingen aanvulling winningsplan Groningenveld 2016

De aanvulling bevat:

1. nieuwe Hazard & Risk Assessment (HRA), die gebaseerd is op het basispad van het kabinet (ref. brief EZK van 29 maart 2018, kenmerk DGETM-EI/18057375), met dien verstande dat wordt uitgegaan van een stikstofinzet van 85%.
2. een operationele strategie voor de gaswinning voor het gasjaar 2018/2019.

Ad 1 Verwachtingen ten aanzien van de aanvullende Hazard & Risk Assessment

1. Hazard & Risk Assessment uitgaande van het basispad van het kabinet voor een koud, gemiddeld en warm jaar, waarbij voor het koude en warme jaar het uitgangspunt geldt dat de jaren voor en na dat koude respectievelijke warme jaar gemiddelde jaren zijn. Tevens wordt uitgegaan van een stikstofinzet van 85% van de gecombineerde inzet van Ommen en Wieringermeer. De detailcijfers van de productie (per maand uitgewerkt) zijn vastgelegd in een Excelbestand, dat separaat digitaal aan NAM verstuurd zal worden (tegelijk met de verwachtingenbrief).
2. Voor de verdeling van de productie over de verschillende clusters en regio's wordt uitgegaan van NAM's optimalisatiestudie uit december 2017, met dien verstande dat rekening wordt gehouden met volumebeperkingen die SodM naderhand in het "Zeerijp"-advies (1 februari 2018) heeft opgenomen (zie opsomming op p.2 van deze bijlage).
3. NAM berekent (ter referentie) de uitkomsten voor het 24 mld Nm^3 scenario uit de HRA-rapportage van 1 november 2017 volgens de hieronder gegeven specificaties.
4. Voor elk scenario worden de rekenuitkomsten v.w.b. aantallen personen en gebouwen gegeven volgens de adviezen van de cie Meijdam[1], dat wil zeggen: een verwachte (gemiddelde) waarde met een onzekerheidsband.
5. De uitkomsten van beide scenario's worden weergegeven als:
   a. Jaarlijkse berekeningen van het risico (hazard maps en LPR-curves) voor de eerste 10 jaar.
   b. 5-Jaarlijkse berekeningen van het risico voor de eerste 15 jaar.
   c. NAM maakt voor elk scenario aanvullende grafieken:
      i. gebouwen gemiddelde + onzekerheidsband $>10^{-4}$/j tegen tijd;
      ii. gebouwen gemiddelde + onzekerheidsband $> 10^{-5}$/j tegen tijd;
   d. ruimtelijke kaart met de locaties van de huizen waarvan er een kans is dat ze in een gebouwtype vallen waarin de kans op

[1] Eerste advies (Kamerstukken 33529, nr.174), tweede advies (Kamerstukken 33 529, nr. 205), eindadvies (Kamerstukken 33 529, nr. 212).

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overlijden > 10^{-4}/j;

e. ruimtelijke kaart met de locaties van de huizen waarvan er een kans is dat ze in een gebouwtype vallen waarin de kans op overlijden > 10^{-5}/j;

f. NAM zal deze gegevens tevens in de vorm van een tabel opnemen in haar rapportage.

g. Tabel met alle gebouwtypologieën waarvan het risico > 10^{-4}/j en > 10^{-5}/j is.

6. Om SodM in staat te stellen advies uit te brengen over de veiligheidsrisico's stelt NAM een rapport beschikbaar met kaarten die SodM nodig heeft (in overleg met EZK en SodM). Uit privacyoverwegingen (bescherming eigenaren van gebouwen) is dit een niet-openbaar rapport.

Ad 2 Verwachtingen aanvulling winningsplan Groningenveld 2016 voor het gasjaar 2018/2019.

In de aanvulling op het winningsplan Groningenveld 2016 werkt NAM een operationele strategie uit, waarin het scenario van GTS voor het gasjaar 2018/2019 als uitgangspunt wordt genomen. Het gaat om het scenario dat overeenstemt met de brief van EZK van 29 maart 2018 (DGETM-EI/18057375) en nader is omschreven in de brief van GTS van 27 maart 2018, p.4, onder het kopje "Instemmingsbesluit".

Bij het uitwerken van het GTS-scenario neemt NAM de volgende randvoorwaarden in acht:

- De graaddagenformule die in het gasjaar 2018/2019 van toepassing zal zijn als bovengrens voor de Groningenproductie, is de graaddagenformule die GTS in zijn rapport van 27 maart 2018 heeft vermeld:
  *Groningen volume = 0,3 + 0,00886 * gd*
  Hierbij dient het streven te zijn om op jaarbasis een zo hoog mogelijke stikstofinzet te bereiken. Mocht na enige tijd blijken dat een inzet percentage van de stikstof hoger dan 85% haalbaar is, dan kan de (jaarlijks vast te stellen) graaddagenformule daarop aangepast worden.
- NAM maakt bij het opstellen van de operationele strategie gebruik van de 31 temperatuurscenario's die GTS heeft vastgesteld. Deze scenario's zullen in een Excelbestand digitaal aan NAM beschikbaar worden gesteld. Indien de Groningen productie niet past binnen de gestelde randvoorwaarden dient NAM inzichtelijk te maken welke keuzes er gemaakt kunnen worden om een eventueel knelpunt op te lossen.
- Werkvolume Norg: 5 miljard Nm^3 (overeenkomstig het vigerende opslagplan)
- Productiefluctuaties conform advies SodM:
  - Beperking volumefluctuaties Bierum-cluster tot maximaal 20% per maand (met uitzondering van operationele omstandigheden, waaronder onderhoud en uitval)
  - Beperking regionale fluctuaties in de productie van de overige clusters tot het huidige niveau van +/- 50% per maand (behalve van het

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cluster EKL waarvoor een beperking tussen 0 – 150 mln m^3/maand geldt). De beperking van de fluctuaties van +/- 20% per maand voor de productie uit het gehele Groningenveld kan onder deze voorwaarde worden losgelaten.

- Als referentie voor deze bandbreedtes in fluctuaties kan de gemiddelde productie over de afgelopen 12 maanden worden gehanteerd.

- Prioriteitstelling bij overschrijding fluctuaties:
  Uit het GTS rapport van 27 maart 2018 blijkt, dat een analyse van NAM laat zien dat in circa 3-8% van de maanden van alle beoordeelde scenario's (31 temperatuur scenario's per jaar voor de periode 2018/2019 tot en met 2025/2026 en 2029/2030) niet altijd kan worden voldaan aan de gestelde fluctuatiebeperkingen zoals hierboven beschreven. GTS merkt hierbij onder meer op, dat deze incidentele productieoverschrijdingen naar verwachting grotendeels voorkomen kunnen worden (zonder rekening te houden met ongeplande uitval van L-gas middelen) door op momenten back-up of piek conversiemiddelen van GTS in te zetten of tijdelijk injectie van bergingen stop te zetten. Als er een keuze gemaakt moet worden tussen het reduceren van volumes en het loslaten van de fluctuatiebandbreedte dan prevaleert volumebeperking.

  Opmerking:
  Mochten deze fluctuaties in de modellering vaker optreden dan incidenteel, dan zal de Minister van EZK aan NAM verzoeken om alternatieve productiestrategieën aan te dragen, met aangepaste beperkingen. Op basis van deze alternatieve productiestrategieën kan de Minister van EZK aan NAM verzoeken een bepaalde productiestrategie te volgen.

- Definitie regio's:
  - Bierum
  - Centraal-Oost clusters: AMR, TJM, OWG, SCB, SDB
  - Zuidoost clusters: SZW, EKR, ZPD
  - Zuidwest clusters: KPD, SLO, SPI, TUS, ZVN
  - Eemskanaal
  - (P.M. Loppersum clusters)

Appendix C – Implementation of the discrete M_{max} Distribution in the Probabilistic Seismic Hazard and Risk Analysis

The sensitivity of the Probabilistic Seismic Hazard and Risk Analysis to epistemic uncertainties identified on the logic tree (Fig. C.1) is shown in Figure C.2. Four key factors have been identified: the seismological model, ground motion model (GMM), building fragility model, and the consequence model. The extent of each grey bar denotes the average value of the risk metric for the subset of the logic-tree where the given factor is constrained to the lower branch (lower limit) and then the upper branch (upper limit). Results are shown for 2018-2022 under the 24 bcm/year production scenario for a single mean local personal risk (LPR) metric, computed as the mean over all populated buildings and all probability-weighted logic tree branches. Alternative assessment periods and production scenarios yield similar results for the relative sensitivities.

The Hazard and Risk Assessment of November 2017 (Ref. 1) indicated that the distribution of epistemic uncertainty identified for the maximum possible earthquake magnitude, M_{max}, is a significant contributor to epistemic uncertainty in the Probabilistic Seismic Hazard and Risk Analysis.

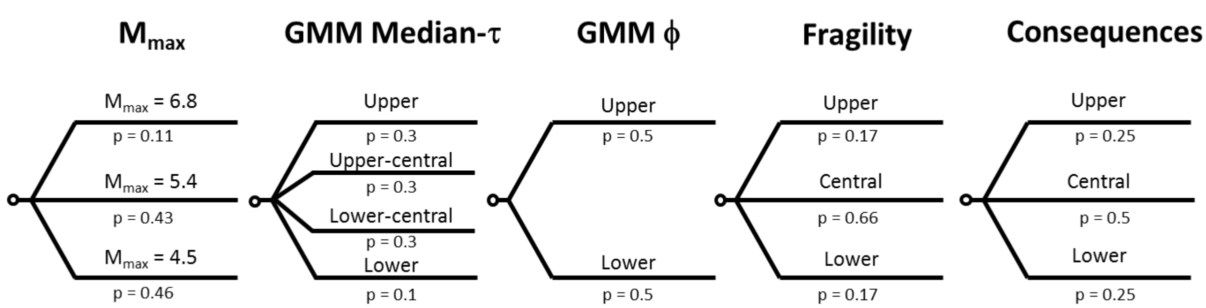


Figure C.1 *Summary of the logic-tree used to characterise epistemic uncertainties within the Probabilistic Seismic Hazard and Risk Analysis. The complete logic tree contains 216 branches which comprises the full factorial combination of these 5 factors and their associated 2—4 levels. Each logic tree branch was analysed by an independent Monte Carlo simulation of the unique combination of sub-models. Mean hazard and risk metrics are derived as the probability-weighted combination of all Monte Carlo results across the complete logic tree.*

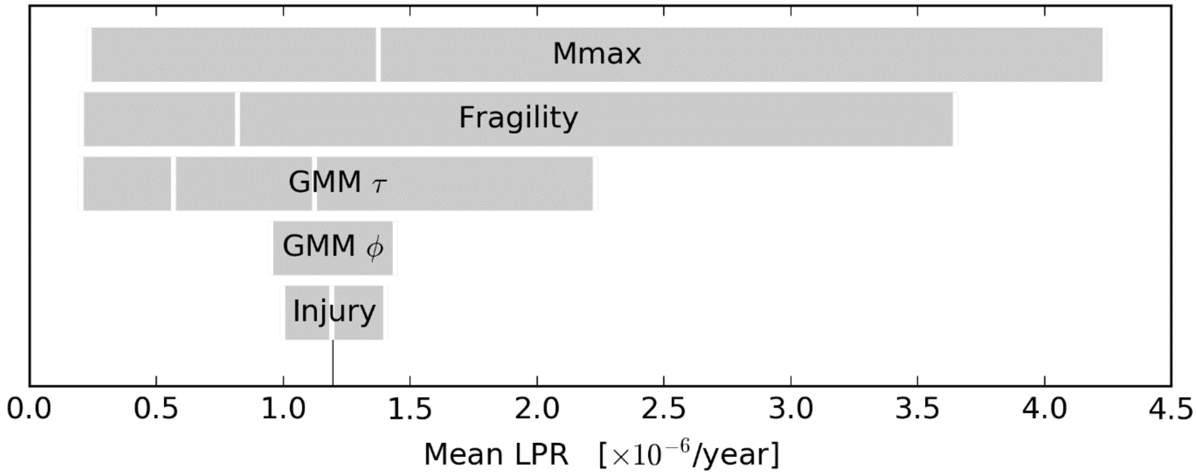


Figure C.2 *Tornado plot to indicate the sensitivity of the Probabilistic Seismic Risk Analysis to the identified epistemic uncertainties. The extent of each bar denotes the values of the risk metric under sequential re-weightings of the logic-tree where the each factor in turn is constrained to the lower branch (lower limit) and then the upper branch (upper limit). Results are shown for 2018-2022 under the 24 bcm/year production scenario for logic tree mean local personal risk for all populated buildings.*

The distribution was established by a panel of experts following a workshop at Schiphol Airport, The Netherlands (Ref. 2). The resulting cumulative distribution function (CDF) for M_{max} was represented by eight values (Fig. C.3).

Moment Magnitude	Cumulative Probability
3.75	0.0
4.25	0.08625
4.75	0.48625
5.25	0.73
5.75	0.8425
6.25	0.92125
6.75	0.97375
7.25	1.0

Figure C.3 *Table of eight values capturing the cumulative distribution function (CDF) for M_{max} taken from "Report on Mmax Expert Workshop – 8 – 10 March 2016" (Ref. 2, page 9 of the Report from the Expert Panel on Maximum Magnitude Estimates for Probabilistic Seismic Hazard and Risk Modelling in Groningen Gas Field 25 April 2016).*

For practical reasons, this distribution was captured by three branches in the logic tree (Fig. C.4). Including a seven-branch representation of the uncertainty in M_{max}, would have been impractical from a computer run-time perspective. The M_{max} values and associated probabilities on the three branches of the logic tree were chosen to exactly match the zero, first, second, third, fourth and fifth moments of the M_{max} distribution, as established by the M_{max}expert panel.

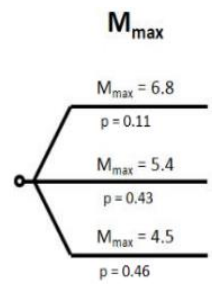


Figure C.4 *Logic tree for M_{max} as used in the Hazard and Risk Assessment of November 2017, taken from reference 3 pg. 117.*

To assess the influence of representing epistemic uncertainty in M_{max} by three levels in the logic tree, a single risk analysis was conducted using the 7-level M_{max} distribution established by the M_{max} expert panel. This single analysis was based on the reference production scenario of 24 Bcm/year also used in the Induced Seismicity in Groningen Assessment of Hazard, Building Damage and Risk of November 2017 (Ref. 1). The hazard maps for these two hazard assessments with a representation of the uncertainty in the M_{max} by 3- and 7- point discrete distributions respectively are shown in Figure C.5.

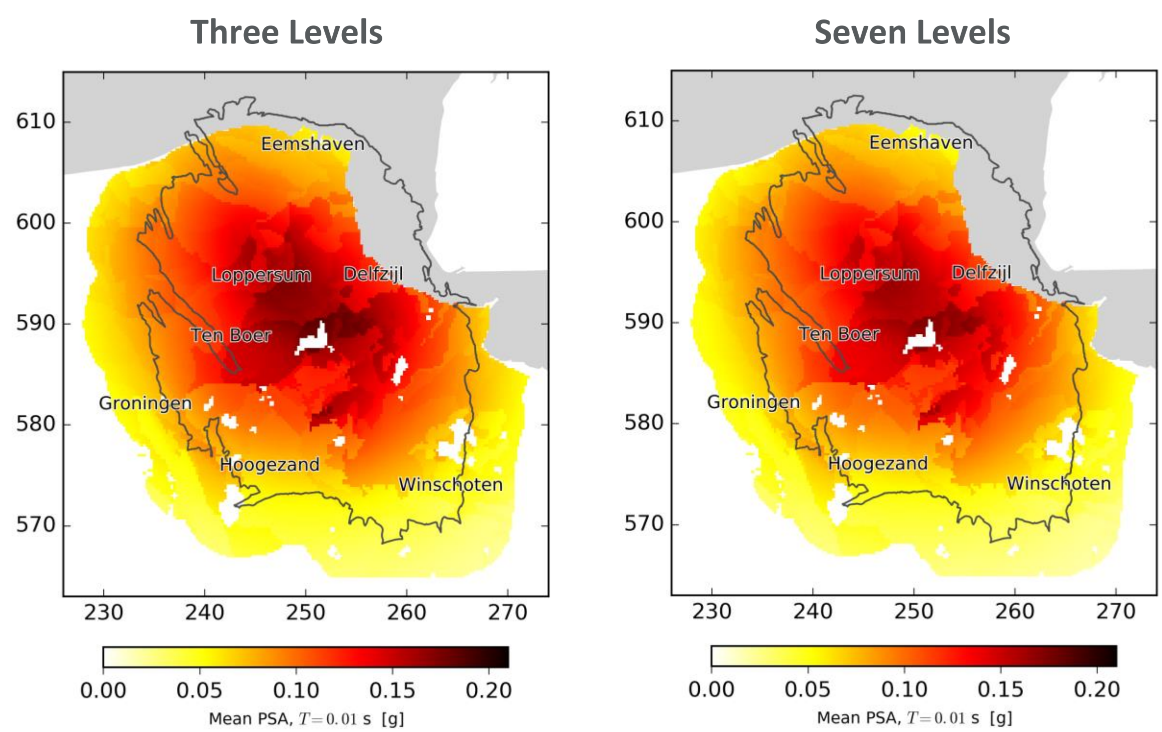


Figure C.5 *Hazard maps for 3-point (left) and 7-point (right) discrete probability M_{max} distributions under the 24 Bcm/year production scenario and a 0.21% annual probability of exceedance.*

Comparison of these figures shows that 7-point discrete M_{max} distribution yields systematically lower Peak Ground Acceleration (PGA) values (Table C.1). The influence of this representation on LPR for buildings in the Groningen area is shown in Figure C.5. Consistent with the hazard results, the influence on risk also results in a lower estimate of buildings exceeding the life-safety norm.

Largest PGA on the Hazard Map	Three Levels	Seven Levels
Including Schildmeer area (as reported in reference 3).	0.207 g	0.196 g
Excluding Schildmeer area	0.185 g	0.174 g

Table C.1 *The largest PGA on the hazard maps (0.21% annual exceedance probability) for the 3-point and 7-point discrete M_{max} distributions under the 24 Bcm/year production scenario.*

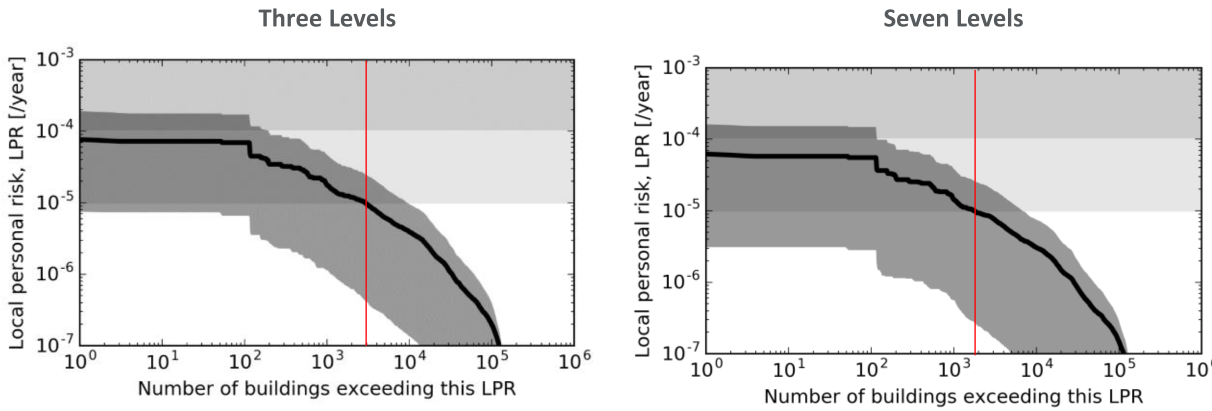


Figure C.5 *LPR distributions under the 24 Bcm/year production scenario for the 3-point (left) and 7-point (right) discrete M_{max} distributions.*

The implementation of a 3-point instead of a 7-point discrete M_{max} probability distribution in the logic-tree approach has not led to under-estimation of Probabilistic Seismic Hazard or Risks metrics. Instead, this the 3-point discrete M_{max} probability distribution is shown to be conservative relative to the 7-point discrete probability distribution established by the M_{max} expert panel.

C.1 References

1. Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017, NAM (Jan van Elk and Dirk Doornhof), November 2017.
2. Report on M_{max} Expert Workshop – 8 – 10 March 2016, World Trade Centre, Schiphol Airport, The Netherlands, Independent Expert Panel, July 2016.

Appendix D – Impact of a production Scenario based on exclusively cold years on the mean LPR

The production scenarios based on warm and cold years are prepared with an individual year being warm or cold and all preceding years and following years being an average temperature year. The warm and cold temperature years have been selected from the years in the period 1986 to 2016. For the cold year the gas-year 1985/1986 was chosen, for the average year the gas-year 2011/2012 was chosen and for the warm gas-year 2006/2007.

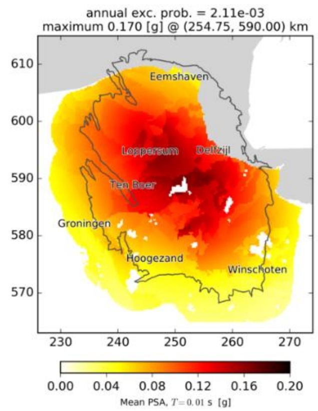
The probability of a warm or cold year is difficult to estimate, but is in the order of 1/31 or probably around 3 to 5%, not taking into account climate trends in the last 31 years. Of course, there is a chance that two years in the period of higher production from gas-year 2018/2019 to gas-year 2021/2022 are cold without the off-set by warm gas-years. However, the chance of a cold year seems independent from the temperature during the previous year (Ref. 1). For instance, during both the consecutive gas-years 1984/1985 and 1985/1986 an Elfstedentocht was held (both won by Evert van Benthem).

An extensive probabilistic assessment of the uncertainty in the annual; temperature and impact through the gas demand on seismic hazard and risk is outside the scope of this appendix. To provide an indication of the impact of the uncertainty in the production demand scenario on the seismic hazard and risk, the unlikely production scenarios based on all future gas-years warm and all future gas-years being cold have been evaluated. Emphasis is on the production scenario with all years being cold temperature years.

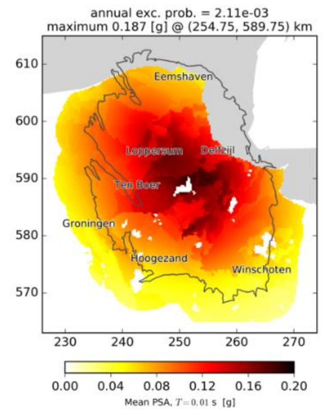
Figure D.1 shows the hazard maps for each of the years in the period 2018 to 2027, based on the production scenario with all years being cold temperature years. In Figure D.2, the mean LPR curves are shown for the same all years being cold production scenario. The number of buildings exceeding the 10^{-4}/year temporary safety norm and the 10^{-5}/year safety norm are compiled in figure D.3. This shows for instance that for the production scenario with all years an average temperature year, the number of buildings that do not meet the 10^{-5}/year safety norm in 2022 is some 678 buildings. If gas-year 2021/2022 is a cold year (and all preceding years an average temperature year) the incremental production during this gas-year increases the number of buildings that do not meet the 10^{-5}/year safety norm in 2022 to some 1,197 years. If all preceding years (all the years from 2018 until 2022) are also cold temperature years this number increases to 1,597 buildings.

D.1 References

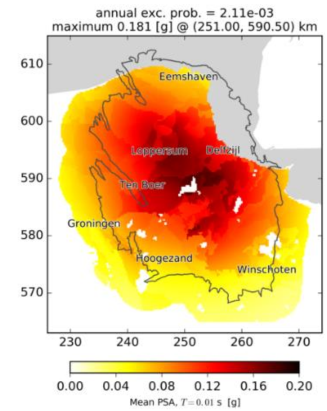
1. Winterverwachtingen wetenschappelijk bekeken, 19 oktober 2011, figuren 2015, Geert Jan van Oldenborgh (https://www.knmi.nl/kennis-en-datacentrum/achtergrond/winterverwachtingen-wetenschappelijk-bekeken)



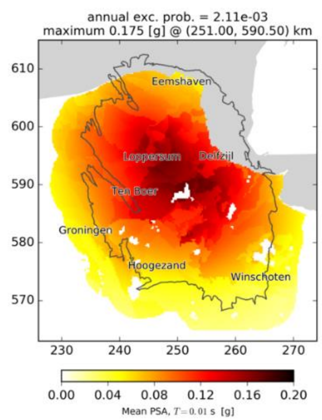
2018



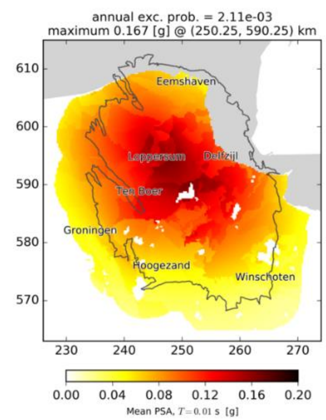
2019



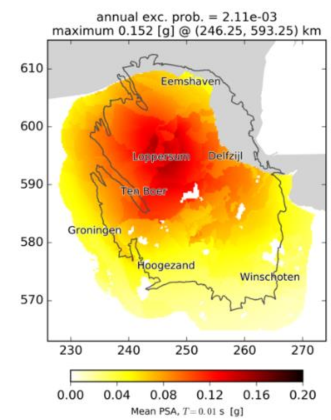
2020



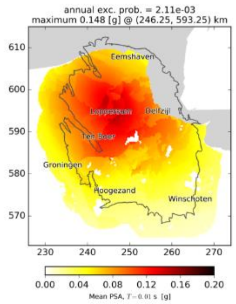
2021



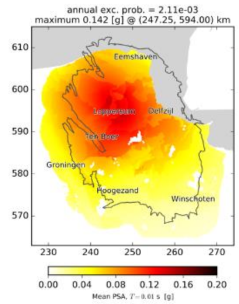
2022



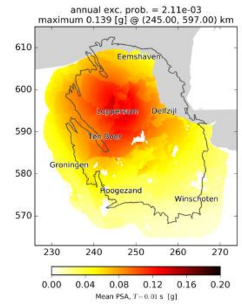
2023



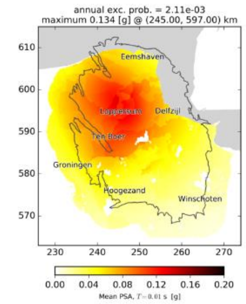
2024



2025

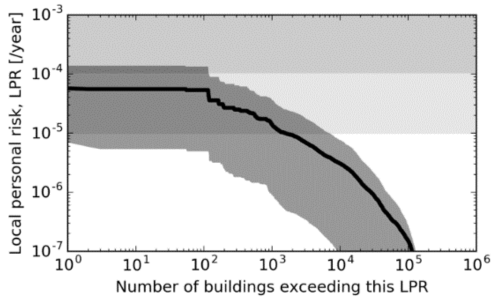


2026

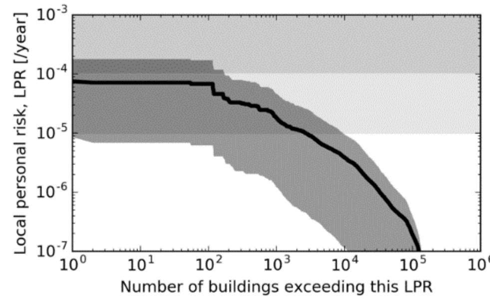


2027

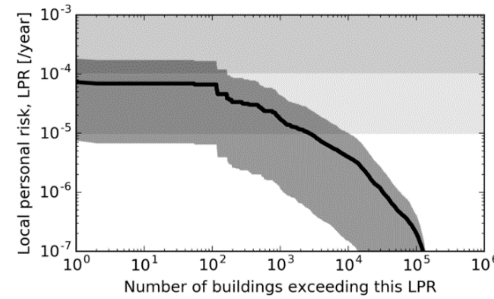
Figure D.1 *Hazard Maps for the production scenario with all years cold, for the years 2018 (top left) to 2027 (bottom right).*



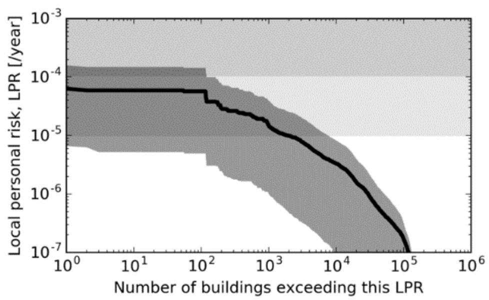
2018



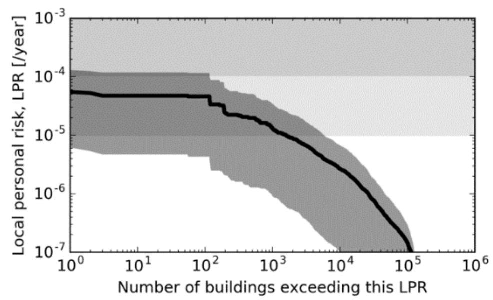
2019



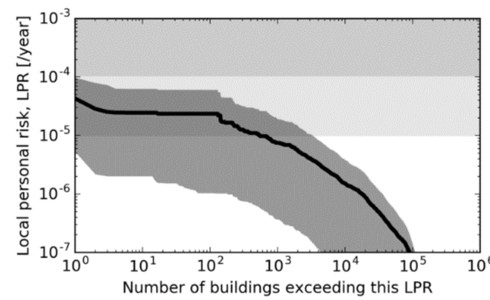
2020



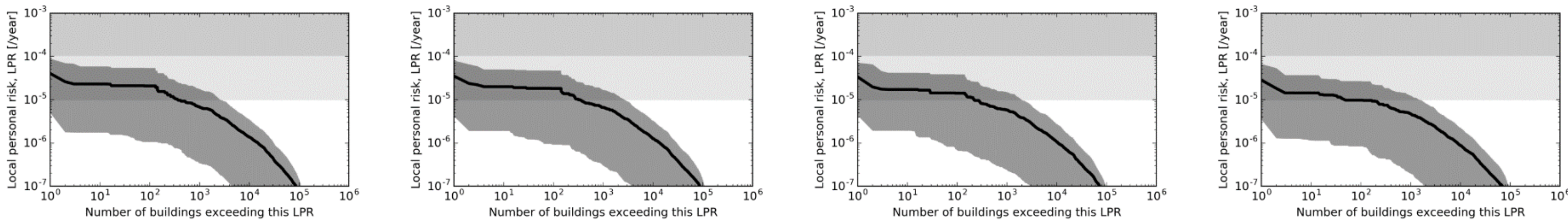
2021



2022



2023



2024 **2025** **2026** **2027**

Figure D.2 *Local Personal Risk graphs for the years 2018 to 2027 for a production scenario based on all year being cold years. These show the number of houses that are exposed to a LPR. The black lines denote the mean and the dark grey areas the uncertainty bands. The two horizontal bands in light grey denote the LPR levels of the Meijdam-Norm.*

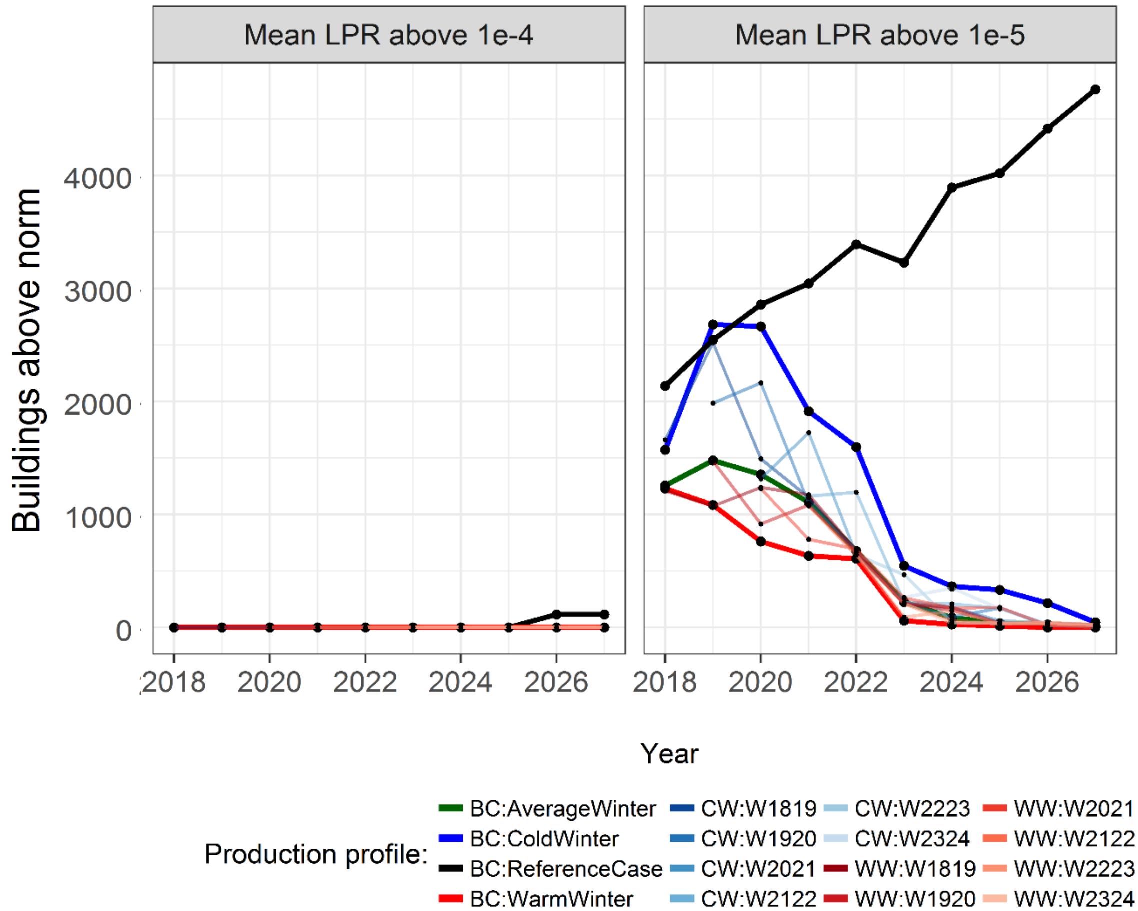


Figure D.3 *Graphs show the Local Personal Risk associated with the production scenario "Basispad Kabinet" for average (green), cold weather and warm weather years, and the Reference Scenario (24 Bcm/year) (black), and for the period 2018 to 2027. This figure is similar to figure 5.5 in the main text of this report. In Figure 5.5 the cold and warm weather years have been gathered. In this figure the blue and red line represent the annual LPR associated with a scenario consisting of exclusively cold years (blue) and exclusively warm years (red)*

Right graph: *number of buildings exceeding the norm mean LPR larger than 10^{-5}/year*

Left graph: *number of buildings exceeding the norm mean LPR larger than 10^{-4}/year*