# Seismic Hazard and Risk Assessment
# Groningen Field
# update for Production Profile
# GTS - raming 2019

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# Contents

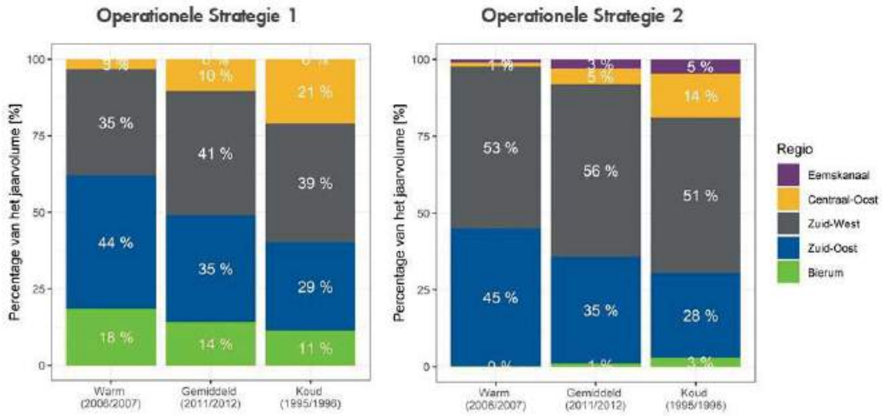
# Samenvatting van de Dreigings- en risicoinschatting

**Deze Nederlandstalige samenvatting van dit rapport met de dreigings- en risicoinschatting is opgenomen in de Operationele Strategie als hoofdstuk 6. Deze is hier herhaald zodat dit rapport ook als een zelfstandig rapport gelezen kan worden.**

# Gevolgen van de operationele strategieën

## Volumeverdeling per cluster voor warm, gemiddeld en koud jaar

In de GTS-dataset zijn de Groningen productievolumes opgenomen voor een warm (referentiejaar 2006-2007), gemiddeld (referentiejaar 2011-2012) en koud (referentiejaar 1995-1996) jaar. Nadat GasTerra de inzet van UGS Norg en PGI Alkmaar voor deze productiescenario’s heeft verwerkt tot de noodzakelijke Groningenveldvolumes, zijn de clustervolumes op dag-basis gemodelleerd volgens de opstartvolgorde zoals in hoofdstuk 5 van de operationele strategie beschreven. Voor het warme, gemiddelde en koude referentiejaar zijn de volumes uit de clusters als percentage van het totale productievolume weergegeven in Figuur 1.




*Figuur 1* *Cluster volume verdeling voor Operationele Strategie 1 en Operationele Strategie 2 voor een warm (2006-2007), gemiddeld (2011-2012) en koud (1995-1996) jaar.*

## Dreigings- en risicoanalyse

In dit document “Seismic Hazard and Risk Assessment Groningen Field update for Production Profile GTS - raming 2019” (verder: de HRA 2019) is conform de eisen uit artikel 1.3a.2 Mijnbouwregeling het volgende opgenomen:

- een beschrijving van de verwachte bodembeweging als gevolg van de wijze waarop de clusters worden ingezet (HRA 2019 – Hoofdstuk 4);
- een beschrijving van de mogelijke omvang en verwachte aard van de schade door bodembeweging als gevolg van de wijze van de inzet van de clusters (HRA 2019 – Hoofdstuk 7);
- een beschrijving van de risico’s als gevolg van de verwachte bodembeweging als gevolg van de wijze van de inzet van de clusters (HRA 2019 – Hoofdstuk 6);
- een analyse van het aantal gebouwen dat een individueel aardbevingsrisico met zich meebrengt dat groter is dan $10^{-5}$ per jaar, waarbij het individueel aardbevingsrisico wordt berekend met toepassing van de verwachtingswaarde (HRA 2019 – Hoofdstuk 6); en
- een analyse van de ontwikkeling voor de komende 10 jaar ten aanzien van het aantal gebouwen (HRA 2019 – Hoofdstuk 6).

Conform de Verwachtingenbrief is hierbij – naast het referentiescenario - uitgegaan van de twee operationele strategieën die zijn voorgeschreven door de minister, zodat een directe vergelijking mogelijk is tussen deze operationele strategieën.

Voor de 10-jaarsverwachting wordt verwezen naar de HRA 2019, de relevante hoofdstukken staan hierboven genoemd in de opsomming. In dit hoofdstuk wordt specifiek in gegaan op de effecten die de operationele strategieën hebben voor het gas-jaar 2019-2020. Omdat in de HRA 2019 – net als de voorgaande jaren – is uitgegaan van een analyse per kalenderjaar, worden daarbij de jaren 2019 en 2020 inzichtelijk gemaakt. De figuren die in dit document zijn opgenomen voor de kalenderjaren 2019 en 2020 zijn daarnaast voor het gas-jaar 2019-2020 opgenomen in de HRA 2019 (hoofdstuk 6).

## Beschrijving van de verwachte bodembeweging

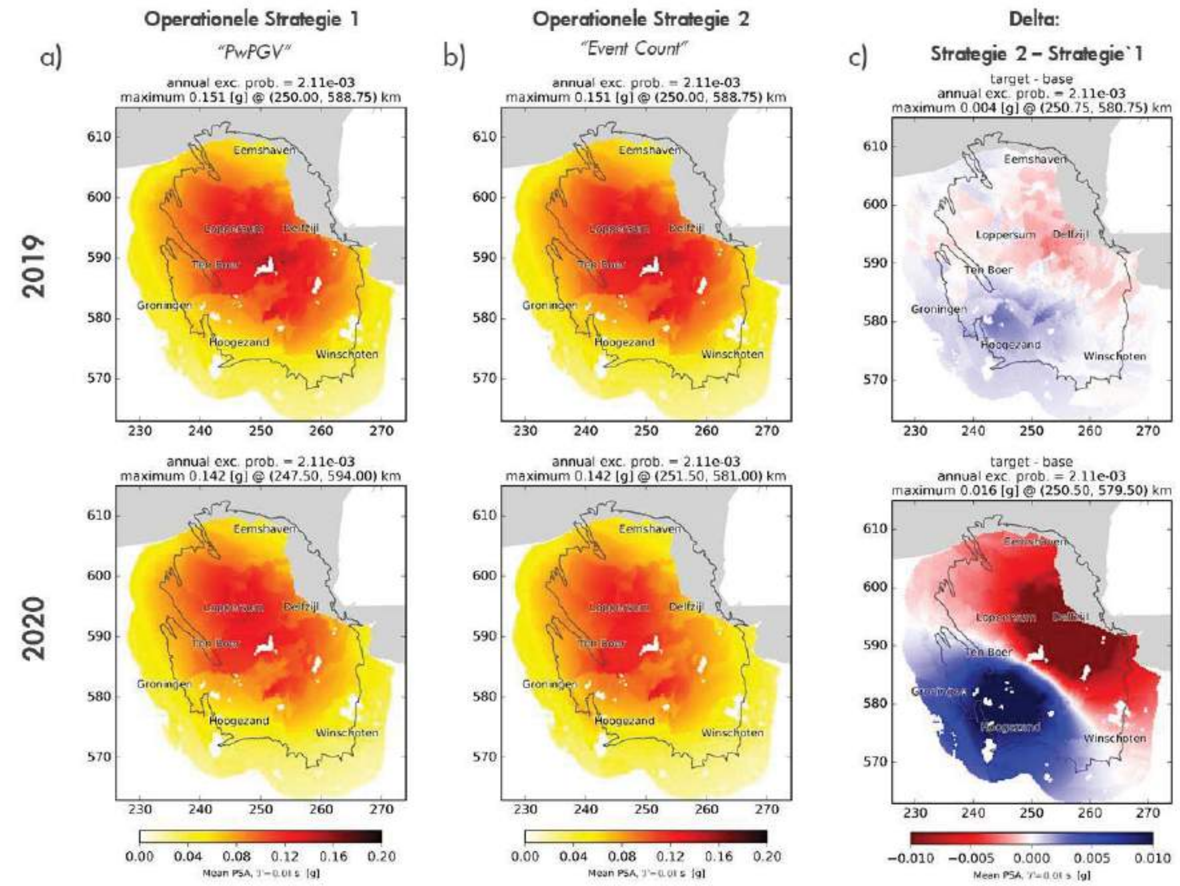
Bodembeweging kan worden opgesplitst in twee componenten: bodemdaling en seismiciteit.

**Bodemdaling**

Op dit moment is NAM nog bezig de gevolgen te onderzoeken van de nieuwe productiescenario's in combinatie met de resultaten van meest recente bodemdalingsmetingen, maar aangezien de productievolumes voor de komende jaren niet hoger zijn dan de uitgangspunten van het rapport "Assessment of Subsidence based on Production Scenario "Basispad Kabinet" for the Groningen Field" uit juni 2018, kan het verloop van de bodemdaling in tijd weliswaar enigszins anders worden dan in het rapport (paragrafen 5.1, 5.2, 5.6) aangegeven, maar worden geen significante wijzigingen verwacht in de conclusies betreffende omvang en aard van de schade door bodemdaling, de te nemen maatregelen en de monitoring (paragrafen 5.3, 5.4, 5.5, 5.7).

**Seismiciteit**

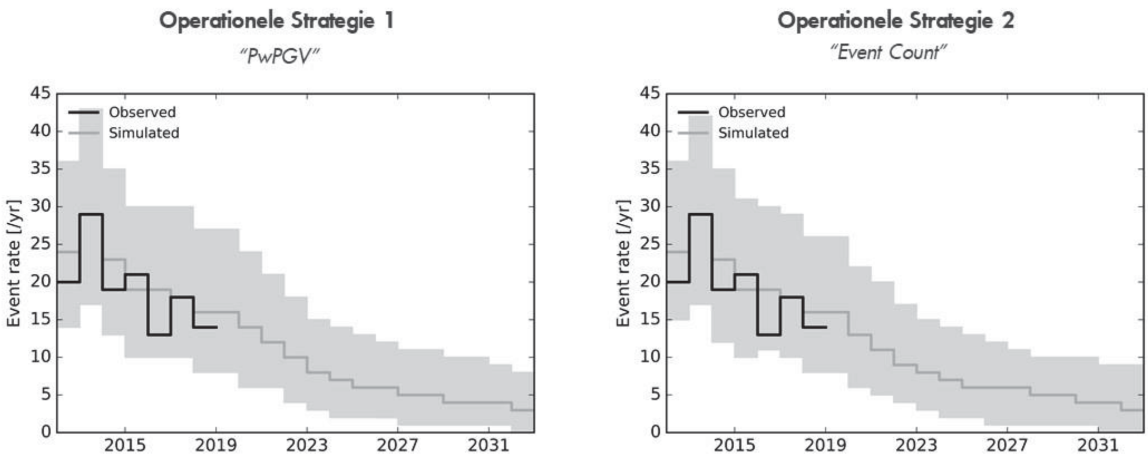
Voor wat betreft seismiciteit geven de onderstaande figuren aan *waar* welke seismische dreiging (hazard) ten gevolge van de gaswinning uit het Groningenveld zich voordoet bij de uitvoering van de twee operationele strategieën.




*Figuur 2* *Dreigingskaarten voor a) Operationele Strategie 1, b) Operationele Strategie 2 en c) het verschil in dreiging tussen beide strategieën. In c) geeft de rode kleur een lagere dreiging weer, de blauwe kleur een hogere dreiging. Voor 2019 is de “delta” minder significant omdat tot en met 1 oktober voor beide analyses een identieke operationele strategie (IB 2018) wordt gehanteerd. Het verschil in dreiging wordt slechts voor 3 maanden door de alternatieve strategieën beïnvloed.*

In Figuur 2 a) en b) zijn de ruimtelijke dreigingskaarten weergegeven. Op basis van deze dreigingskaarten is geen onderscheid waarneembaar tussen Operationele Strategie 1 en 2. Om het verschil inzichtelijk te maken is ook het “delta” (Figuur 2 c)) tussen beide dreigingskaarten opgenomen (Figuur 5.8 in de HRA 2019). Hoewel Operationele Strategie 2 meer dreiging in het zuidwesten tot gevolg heeft in vergelijking met strategie 1, zijn de verschillen nauwelijks significant (<0,004g in 2019 en <0,016g in 2020). Het verschil komt voort uit de hogere bevolkingsdichtheid in deze regio door onder andere de aanwezigheid van de gemeente Groningen. Bij een optimalisatie van de productieverdeling over het veld op basis van PwPGV zal daarom uit het zuidwesten relatief minder gas geproduceerd worden waardoor de persoonsgewogen dreiging lager blijft.

Figuur 3 3 maakt inzichtelijk *hoeveel* seismiciteit te verwachten is in de vorm van het aantal aardbevingen met een magnitude groter dan 1.5 voor de verschillende operationele strategieën (Figuur 4.3 in de HRA 2019).




*Figuur 3* *Aantal aardbevingen (M >= 1.5) uitgedrukt in het verwachte aantal bevingen/events per jaar ("Event rate") voor Operationele Strategie 1 (links) en Operationele Strategie 2 (rechts).*

Voor 2019 en 2020 is in Tabel 1 een overzicht opgenomen met de waarschijnlijkheid waarop een beving met een bepaalde magnitude plaats kan vinden voor de twee operationele strategieën in 2019 en 2020. In hoofdstuk 4 van HRA 2019 staan de resultaten voor latere jaren weergegeven.

| Jaar | Operationele Strategie: | M>3.6 | M>4.0 | M>4.5 | M>5.0 |
|---|---|---|---|---|---|
| 2019 | 1 – "PwPGV" | 12.57% | 4.69% | 0.97% | 0.18% |
| 2020 | 1- "PwPGV" | 10.62% | 3.93% | 0.86% | 0.15% |
| 2019 | 2 – "Event Count" | 12.25% | 4.63% | 0.99% | 0.20% |
| 2020 | 2– "Event Count" | 9.99% | 3.78% | 0.77% | 0.13% |

*Tabel 1* *Overzicht van de waarschijnlijkheid waarmee een beving boven een bepaalde magnitude zich zal voordoen voor Operationele Strategie 1, Operationele Strategie 2 en voor 2019 en 2020 – uitgaande van een gemiddeld jaar.*

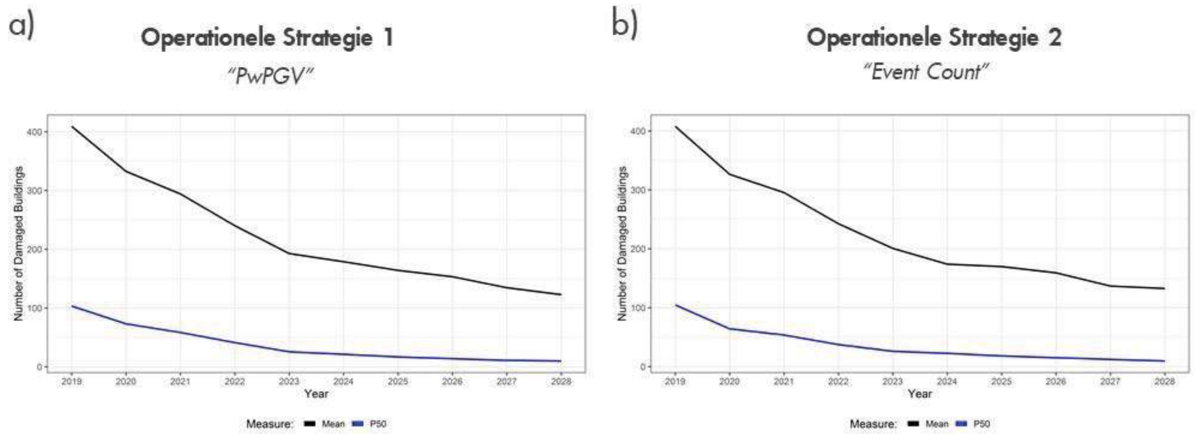
In de volgende paragrafen wordt – in lijn met de volgorde van artikel 1.3a.2. Mijnbouwregeling – nader ingegaan op de risico's die deze seismische dreiging met zich mee brengt voor de omgeving.

## Beschrijving van aard en omvang schade

In de Verwachtingenbrief is aangegeven dat bij de uitwerking van artikel 1.3a.2, lid 3 sub b, Mijnbouwregeling een schadeprognose dient te worden gemaakt voor de schadegrenstoestanden DS1, DS2 en DS3 uit het EMS-98, European Seismological Commission, 1998. NAM dient daarbij een kwantitatieve analyse van de DS1-schades evenals een verwachting van DS2- en DS3-schade categorieën in te dienen bij dit document[1].

In de HRA 2019 staan de gevraagde schadeprognoses beschreven in hoofdstuk 7. De schadeprognose voor DS1 zijn weergegeven in Figuur 4 (figuur 7.4 in de HRA 2019)

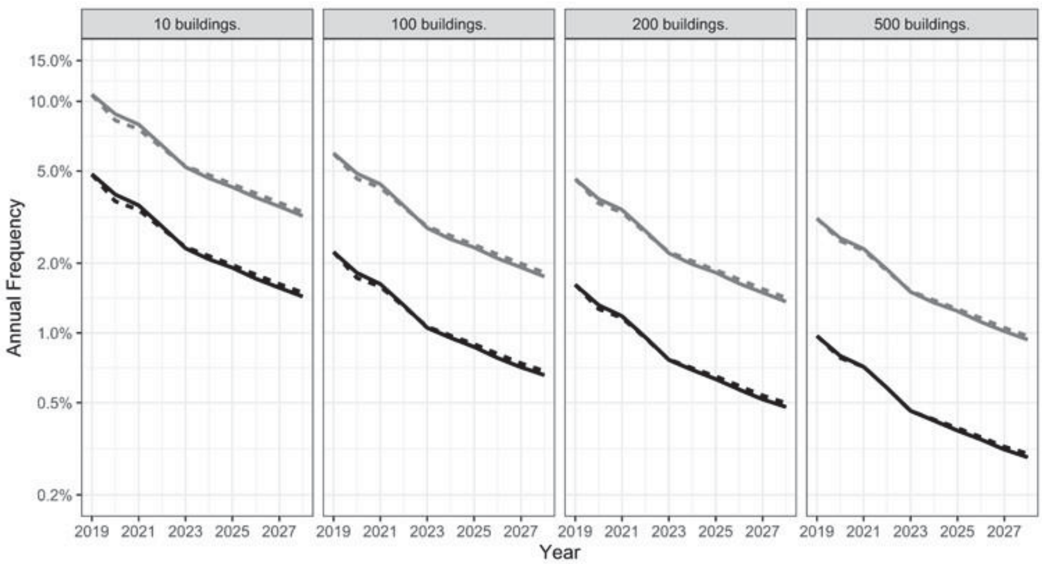
[1] In de Verwachtingenbrief staat aangegeven dat NAM een kwalitatieve analyse van de DSl-schades evenals een verwachting van DS2- en DS3-schades 15 maart dient toe te sturen. De kwantitatieve prognoses van de drie genoemde schades bij het gegeven productiescenario mochten vanwege de omvang uiterlijk 12 april worden ingediend. Deze latere datum van 12 april bleek niet nodig te zijn, alle gevraagde informatie is opgenomen in dit document.




*Figuur 4* *"Mean" en "P50" voorspelling van DS1 schade voor de periode 2018-2028 voor a) Operationele Strategie 1 en b) Operationele Strategie 2.*

Concreet laten de figuren zien dat er geen materieel verschil is in voorspelling van DS1 schades voor de beide operationele strategieën.

Ten aanzien van de verwachte DS2 en DS3 schades geeft de HRA 2019 aan dat er geen materieel verschil (< 1%) is tussen beide operationele strategieën. De resultaten van de vergelijking staan weergegeven in Figuur 5 (Figuur 7.8 in de HRA 2019).




*Figuur 5* *Risico voor DS2 (grijze lijn) en DS3 (zwarte lijn) schade voor Operationele Strategie 1 (vast lijn) en Operationele Strategie 2 (onderbroken lijn) voor de 2019-2028 op basis van een gemiddeld jaar.*

## Beschrijving van de risico's als gevolg van de verwachte bodembeweging

Het risico ten gevolge van de gaswinning uit het Groningenveld kan op verschillende wijzen worden beschreven. In de HRA 2019 is in tabel 6.1 een overzicht opgenomen van de mogelijke wijze waarop risico's kunnen worden gekwantificeerd. Deze risico's zijn:

1. Objectgebonden Individueel Aardbevingsrisico (OIA)

Het objectgebonden individueel aardbevingsrisico, is het risico dat een individu om het leven komt in een jaar als gevolg van instorting van of vallende objecten van een gebouw waar een individu zich in de directe nabijheid van bevindt ten gevolge van een aardbeving. Hierbij wordt het risico gewogen met een statistisch bepaalde gemiddelde verblijfsduur in het gebouw. Op basis van de

Verwachtingenbrief, en aanvullende e-mail, dient NAM in lijn met het advies van de commissie Meijdam en conform het advies van het hooglerarenpanel, het OIA aanvullend te rapporteren in een technische bijlage (HRA 2019).

2. Individueel Aardbevingsrisico (IAR)
Het individuele aarbevingsrisico is het jaarlijkse risico waar een individu aan wordt blootgesteld in de diverse gebouwen waar hij of zij zich in bevindt, dan wel in de nabijheid waarvan hij/zij verblijft. De verblijfsduur wordt bepaald door middel van kennis over de aanwezigheid van iedere inwoner op ieder moment van de dag. Doordat dit technisch niet uitvoerbaar is wordt dit risico niet verder beschouwd.

3. Plaatsgebonden Persoonlijk Risico Binnen (“ILPR”)
De waarschijnlijkheid dat een fictief onbeschermd persoon die permanent aanwezig is *in een gebouw* komt te overlijden.

4. Plaatsgebonden Persoonlijk Risico Buiten (“OLPR”)
De waarschijnlijkheid dat een fictief onbeschermd persoon die permanent aanwezig is *in de nabijheid van een gebouw* komt te overlijden.

5. Plaatsgebonden Persoonlijk Risico (“LPR”)
De waarschijnlijkheid dat een fictief onbeschermd persoon die permanent aanwezig is *in, dan wel in de nabijheid van een gebouw* komt te overlijden. Bij LPR wordt uitgegaan van een permanente verblijfduur in het gebouw. NAM dient op grond van de Verwachtingenbrief, en aanvullende e-mail, in de risicoberekeningen aan te sluiten bij de eerder uitgevoerde Hazard and Risk Assessment van juni 2018 waarbij ook LPR gehanteerd is. De LPR dient ook te worden gerapporteerd in dit document.

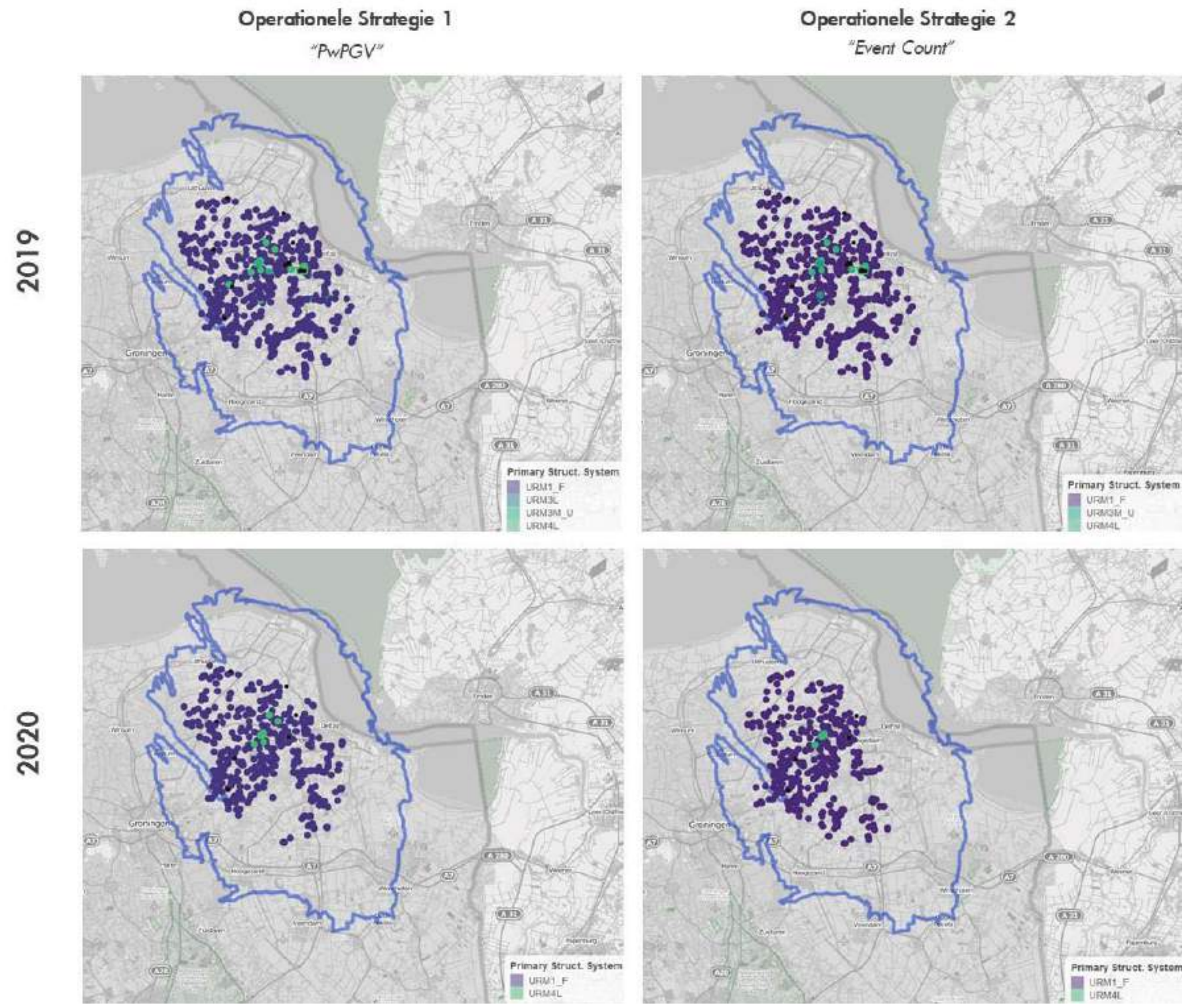
## Analyse van individueel aardbevingsrisico van gebouwen

In de Verwachtingenbrief is in aanvulling op de toepasselijke wettelijke kaders aangegeven dat NAM de volgende informatie moet aanleveren voor het gas-jaar 2019-2020:

- Ruimtelijke kaart met de locaties van de gebouwen waar het OIA[2] groter is dan $10^{-5}$/jaar voor het gas-jaar 2019/2020.
- Ruimtelijke kaart met de locaties van de gebouwen waar het OIA groter is dan $10^{-4}$/jaar voor het gas-jaar 2019/2020.
- NAM zal deze gegevens ook in de vorm van een tabel opnemen in haar rapportage *(zie als voorbeeld: tabel 5.1a & b uit "Seismic risk assessment for production scenario "Basispad Kabinet" for the Groningen field, June 2018").*
- Tabel met alle gebouwtypologieën waarvan het risico >$10^{-4}$/jaar en > $10^{-5}$/jaar is voor het gasjaar 2019-2020.

Figuur 6 geeft een ruimtelijke kaart met de locaties van de gebouwen waar het LPR groter is dan $10^{-5}$/jaar voor het jaar 2019 en 2020 voor de twee operationele strategieën.

[2] Op 14 maart 2019 is door het ministerie van EZK bevestigd dat de bewoording in de Verwachtingenbrief aangaande OIA/IAR/LPR verkeerd zijn opgenomen. Op plaatsen waar OIA genoemd stond in de Verwachtingenbrief dient LPR te worden gelezen, daar waar IAR stond was OIA bedoeld. Dit document zal dus verder de risico-analyses weergeven voor het LPR risico, in Appendix A kan zowel LPR als OIA gevonden worden.




*Figuur 6* *Ruimtelijke kaarten met de locaties van gebouwen waarvan het LPR groter is dan $10^{-5}$/jaar. Links: locaties voor Operationele Strategie 1, Rechts: Operationele Strategie 2, Boven: 2019, Onder 2020. Voor deze ruimtelijke kaarten is uitgegaan van een gemiddeld jaar.*

Voor het gas-jaar 2019-2020 en de jaren daaropvolgend zijn er geen gebouwen met een LPR noch met een OIA groter dan $10^{-4}$/jaar.

Tabel 2 geeft voor de jaren 2019 en 2020 een overzicht van het aantal gebouwen met een LPR > $10^{-5}$/jaar bij een gemiddeld jaar. Ter vergelijking zijn ook het aantal gebouwen opgenomen met een OIA groter dan $10^{-5}$/jaar.

| Jaar | Operationele Strategie: | # gebouwen met LPR >$10^{-5}$/jaar | # gebouwen met OIA >$10^{-5}$/jaar |
|---|---|---|---|
| 2019 | 1 – “PwPGV” | 796 | 403 |
| 2020 | 1- “PwPGV” | 434 | 277 |
| 2019 | 2 – “Event Count” | 780 | 402 |
| 2020 | 2– “Event Count” | 385 | 224 |

*Tabel 2* *Overzicht van het aantal gebouwen met een LPR en OIA > $10^{-5}$/jaar voor 2 operationele strategieën voor 2019 en 2020 bij een gemiddeld jaar[3].*

Voor een analyse van bodembeweging, schade, risico’s en gebouwen voor de koude en warme jaren wordt verwezen naar hoofdstuk 6 van de HRA 2019. Dit hoofdstuk bevat ook een gedetailleerde beschrijving van het aantal woningen, per type en een vergelijking met de resultaten voor HRA-analyse van gas-jaar 2018-2019.

### *Overzicht van gebouwtypologieën met een LPR > $10^{-5}$/jaar*

Voor 2019 zijn er nog een viertal gebouwtypologieën te onderscheiden met een LPR > $10^{-5}$/jaar. Deze typologieën zijn:

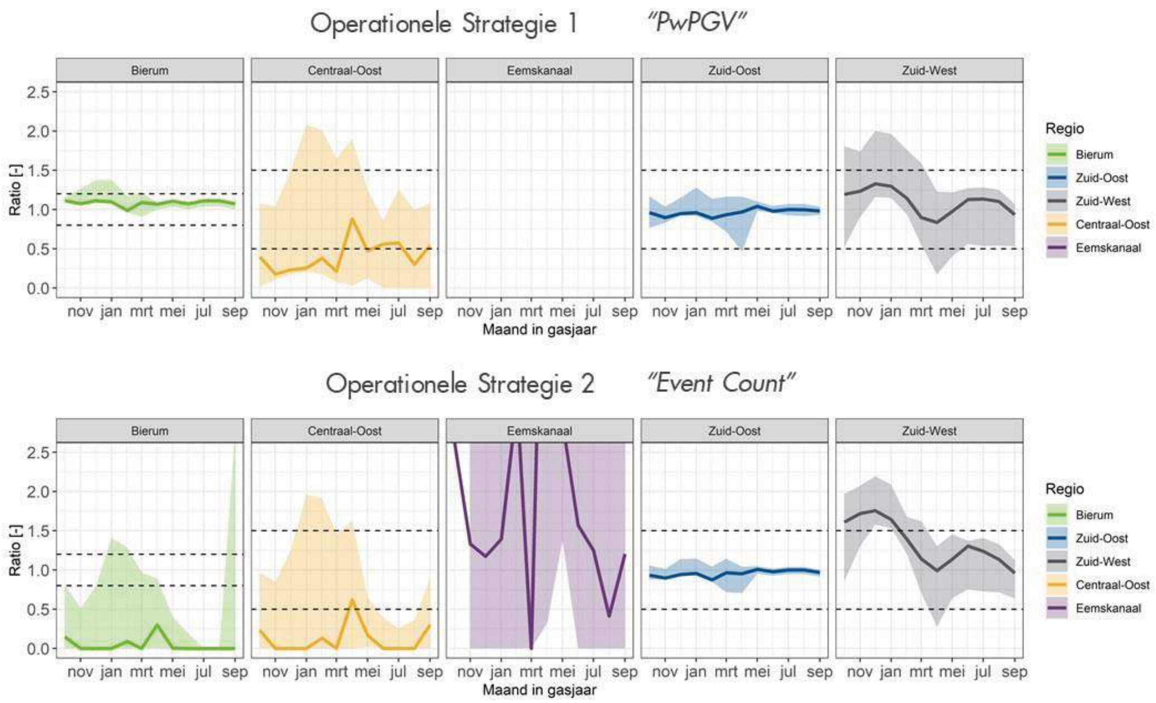
- URM1_F – Typische boerderij met een aangelegen schuur
- URM3M_U – Metselwerk appartementengebouwen met een spouwmuur en betonnen vloeren van minimaal 3 verdiepingen met beperkte sterkte in 1 richting
- URM4L – Rijtjeswoning met een spouwmuur, betonnen vloeren en grote openingen in de gevel(s) van de begane grond.
- URM3L – Vergelijkbaar met typologie URM4L maar met een lager percentage aan opening in de begane grond gevel(s)

De gebouwen die in deze risico inschatting niet voldoen aan de Meijdam-norm, komen voor een groot deel overeen met de gebouwen die ook in juli 2018 niet voldeden aan de norm. In de afgelopen maanden is de volledige gebouwenvoorraad in Groningen opnieuw geëvalueerd om te bepalen of er gebouwen zijn die mogelijk meer kwetsbaar zijn dan tot nu toe werd aangenomen. In deze zoektocht naar de zogenaamde “false negatives” zijn een aantal gebouwen geïdentificeerd die in deze inschatting niet aan de norm voldoen die eerder wel als veilig waren gekwalificeerd. Hierbij zijn de laatste inzichten en opgedane kennis van de gebouwen in Groningen en aanbevelingen van het HRA assurance panels meegenomen. Een beschrijving van de ontwikkeling van het aantal en typologieën van de gebouwen boven de norm met een vergelijking van de resultaten uit 2018 is beschreven in hoofdstuk 6 van de HRA 2019.

## Analyse van regionale productiefluctuaties

In dit hoofdstuk worden de resultaten gerapporteerd betreffende de te verwachten productiefluctuaties in de clusters van het Groningenveld voor gas-jaar 2019-2020. Hierbij wordt tevens het aantal overschrijdingen van de fluctuatiebandbreedte, zoals vastgelegd in de Verwachtingenbrief, inzichtelijk gemaakt. In de dataset van GTS zijn de Groningen productievolumes opgenomen voor 30 temperatuurscenario’s. Nadat GasTerra de inzet van UGS Norg en PGI Alkmaar voor deze scenario’s heeft verwerkt tot resterende Groningenveldvolumes, worden de productielocatie- en clustervolumes op dag-basis gemodelleerd volgens de operationele strategieën zoals in hoofdstuk 5 van de operationele strategie beschreven.

Het aantal overschrijdingen van de fluctuatiebandbreedte is gedefinieerd als het aantal maanden dat een overschrijding van de fluctuatiebandbreedte plaats vindt op basis van alle 30 geanalyseerde temperatuurscenario’s, uitgedrukt als fractie van het totaalaantal “clustermaanden”. Op basis van de GTS-dataset met hierin dertig temperatuurscenario’s zitten 30 (scenario’s) x 12 (maanden) x 5 (clusters) = 1800 clustermaanden. Onderstaande figuren geven grafisch weer welke fluctuaties plaatsvinden in de vijf clusters en of er sprake is van overschrijdingen.




*Figuur 7 Resulterende fluctuaties voor Operationele Strategie 1 en Operationele Strategie 2 voor relatieve maandvolume veranderingen en ten opzichte van de gemiddelde productie over de 12 voorgaande maanden voor de verschillende clusters.*

Het aantal overschrijdingen voor de operationele strategieën bedraagt:

- Operationele Strategie 1: 380 van de 1800 clustermaanden ofwel 21%
- Operationele Strategie 2: 834 van de 1800 clustermaanden ofwel 46%

Een alternatieve operationele strategie waarbij de regionale productiefluctuaties worden geminimaliseerd door alle clusters gelijkmatig op en af te regelen is momenteel niet opgenomen in dit document. Bij een dergelijke operationele strategie is de relatieve clustervolumeverdeling constant en dus niet afhankelijk van het temperatuurscenario. Daarentegen zal zowel de event count als de PwPGV, op basis van een kwalitatieve inschatting op basis van de resultaten in het Bouwstenen document in 2018, toenemen. Voor een volledig HRA-analyse van deze operationele strategie was onvoldoende tijd beschikbaar.

Voor de Operationele Strategieën 1 en 2 ligt het aantal te verwachten overschrijdingen aanzienlijk hoger dan de in het Bouwstenen document 2018 gerapporteerde aantallen. Dit is een gevolg van de volgende aspecten:

- Voor de operationele strategie 2019-2020 worden ook maand-op-maand fluctuaties meegenomen in het bepalen van het aantal overschrijdingen. Voor de analyse van het gas-jaar 2018-2019 zijn alleen de overschrijdingen ten opzichte van het 12 maanden voortschrijdend gemiddelde beschreven in het Bouwstenen document.
- Het benodigde volume uit het Groningenveld is ~25% lager dan de volumes opgegeven voor de analyses voor gas-jaar 2018-2019. Dit komt voornamelijk door de hogere inzet en uitbreiding van conversiemiddelen van GTS waarbij Groningen nog wel steeds op momenten van hoge vraag moet produceren ten behoeve van de leveringszekerheid. Op deze momenten zullen met name clusters die met de laagste prioriteit worden ingezet alsnog een bijdrage moeten leveren, hetgeen zal leiden tot relatief grotere fluctuaties ook buiten de in de Verwachtingenbrief opgegeven bandbreedtes.

In het algemeen geldt dat bij een lager volume uit Groningenveld de fluctuaties toe zullen nemen in aantal en grootte daar de absoluut toegestane volume variaties lager zullen zijn. Verder zal bij een sterkere preferentiële onttrekking uit bepaalde clusters, zoals het geval is onder Operationele Strategie 2, ook de kans op het aantal overschrijdingen van de in de Verwachtingenbrief opgegeven bandbreedtes toenemen. Deze overschrijdingen treden dan met name voor de clusters die alleen ingezet worden bij een hogere gasvraag.

## Vergelijking en samenvatting van operationele strategieën

De operationele strategieën kunnen als volgt worden samengevat:

**Operationele Strategie 1:**

- Optimalisatie op bevolkingsdichtheid gewogen grondsnelheid risico resulteert in een inzetvolgorde met voornamelijk onttrekking uit de productielocaties in de clusters Zuidwest en Zuidoost bij een vlakke inzet van cluster Bierum.
- De clusteropstartvolgorde die hoort bij deze Operationele Strategie sluit aan bij de in het instemmingsbesluit voor gas-jaar 2018-2019 gekozen inzetstrategie. Vooralsnog blijkt dat deze Operationele Strategie operationeel goed uitvoerbaar is.
- Het aantal overschrijdingen van de fluctuatiebandbreedte is kleiner dan het aantal overschrijdingen onder Operationele Strategie 2.
- In Operationele Strategie 1 wordt onder gemiddelde condities de capaciteitsvraag over meer clusters verdeeld ten opzichte van Operationele Strategie 2, waardoor er meer operationele flexibiliteit is in het geval van geplande of ongeplande productie-uitval.

**Operationele Strategie 2:**

- Optimalisatie op het minimaal aantal te verwachten bevingen resulteert in een inzetvolgorde met voornamelijk onttrekking uit de productielocaties in de clusters Zuidwest en Zuidoost.
- Doordat cluster Centraal-Oost én Bierum opgeregeld worden in momenten van hoge vraag, zal de kans op overschrijding van de fluctuatiebandbreedtes groter zijn dan bij Operationele Strategie 1. Door de wijze waarop cluster Bierum in deze Operationele Strategie wordt ingezet zal veelal niet voldaan kunnen worden aan de bandbreedtebeperking van 20%.
- Doordat nagenoeg alle volumes in een gemiddeld jaar uit slechts 2 clusters zal komen, zullen compressoren op de productielocaties op een relatief hoge inzet draaien waardoor bij ongeplande uitval en onderhoud de regionale fluctuatieoverschrijdingen zullen toenemen door het verschuiven van productie naar overige clusters.
- Doordat de compressoren op de productielocaties op een hoge inzet draaien, zal het stroomverbruik van de compressoren voor deze Operationele Strategie het hoger liggen dan in Operationele Strategie 1 en hiermee ook de hoogste $CO_2$ intensiteit hebben.

Tussen de verschillende operationele strategieën is geen verschil in de volumes die geproduceerd worden in het gas-jaar 2019-2020 en tussen de inzetbare capaciteit. Ook zijn dreiging, risico en het aantal gebouwen dat niet aan de Meijdam-norm voldoet vergelijkbaar.

In Tabel 3 is een kwalitatieve beoordeling opgenomen tussen de operationele strategieën. Een "+"-teken geeft een positief effect weer, een "-"-teken een negatief effect en een "+/-"-teken een neutraal of geen effect. Daarbij is de beoordeling relatief ten opzichte van de andere strategie.

| | Operationele Strategie 1 | Operationele Strategie 2 |
|---|---|---|
| *Beschrijving / doelcriteria* | *HRA pwPGV geoptimaliseerd* | *HRA Event Count geoptimaliseerd* |
| Schade (DS1) | +/- | +/- |
| Aantal gebouwen LPR > $10^{-5}$ (# 2019/2020) | +/- (796/434) | +/- (780/385) |
| Aantal overschrijdingen fluctuatiebandbreedte minimaal | 21 % (+/-) | 46 % (-) |
| Operationele uitvoerbaarheid | + | - |
| Laagste energieverbruik / $CO_2$ emissie | + | - |

*Tabel 3 Kwalitatieve vergelijking van de operationele strategieën.*

# 1 Introduction

## Previous Hazard and Risk Assessment Reports

### 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 supporting 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 (damage and risk).

The Wijzigingsbesluit of 24th May 2017 (Ref. 4), limited the production in an average temperature year to 21.6 Bcm/year. Because in the Wijzigingsbesluit special circumstances were identified that could require an increase in the production from the field, the Hazard and Risk Assessment of November 2017 (Ref. 5) was prudently based on an average annual production level of 24 Bcm/year gas production, which covered these eventualities.

### Complementary production profiles

To assess the effect of different production profiles on seismic risk, a complementary set of production profiles covering a wide range of production levels was presented in the addendum to the November 2017 Hazard and Risk Assessment (Ref. 6), issued March 2018. The set of production profiles analysed included the production aspirations as outlined in the Regeerakkoord (10/10/2017) and several production profiles 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.

### 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). Different production profiles were presented for cold, average and warm temperature years.

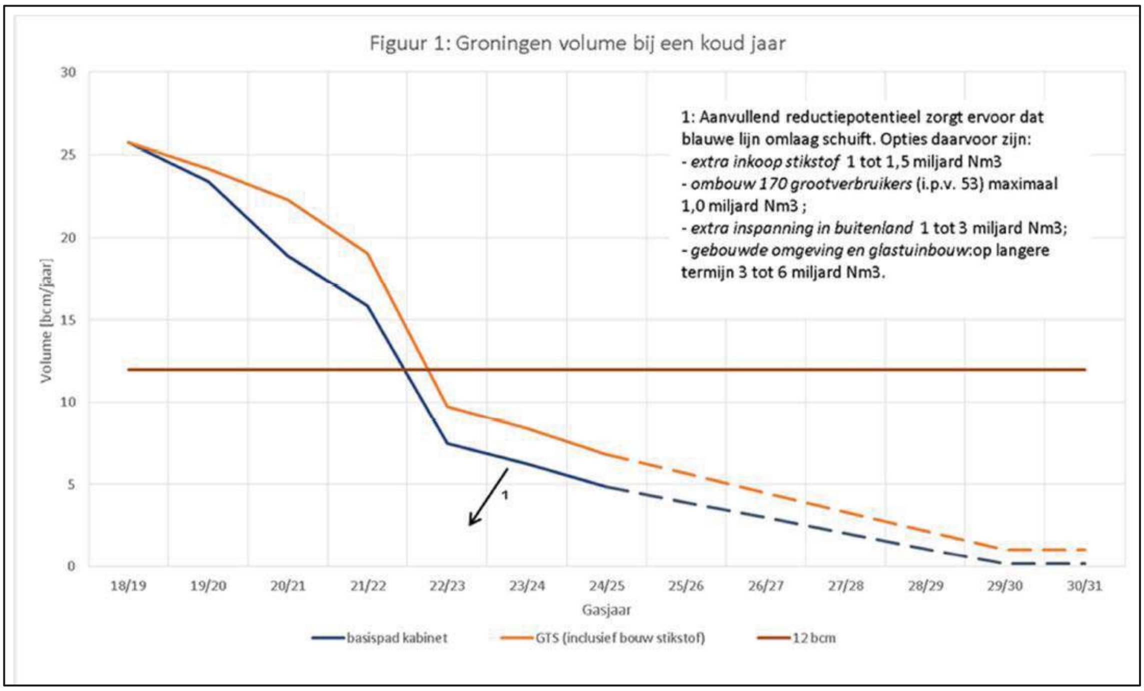



*Figure 1.1* *Production profile prepared by GTS (including construction of a nitrogen blending plant) in orange and production profile "Basispad Kabinet" in blue from reference 7. Both these production profiles are for a sequence of cold ambient temperature years.*


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

## Verwachtingenbrief (Expectation Letter) (2/5/2018)

A verwachtingenbrief (Expectation Letter) was sent to NAM on 2nd May 2018 (Ref. 8) by the Minister of Economic Affairs and Climate Policy. It detailed 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" production profile, 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 verwachtingenbrief (Expectation Letter) the Minister of Economic Affairs and Climate Policy has provided the Groningen gas-quality demand production profile dataset (Fig. 1.3) to NAM which served as basis for the Hazard and Risk Assessment for the production profile "Basispad Kabinet" (Ref.12). In an addendum to the verwachtingenbrief (Expectation Letter), the request was further described (Ref. 8):

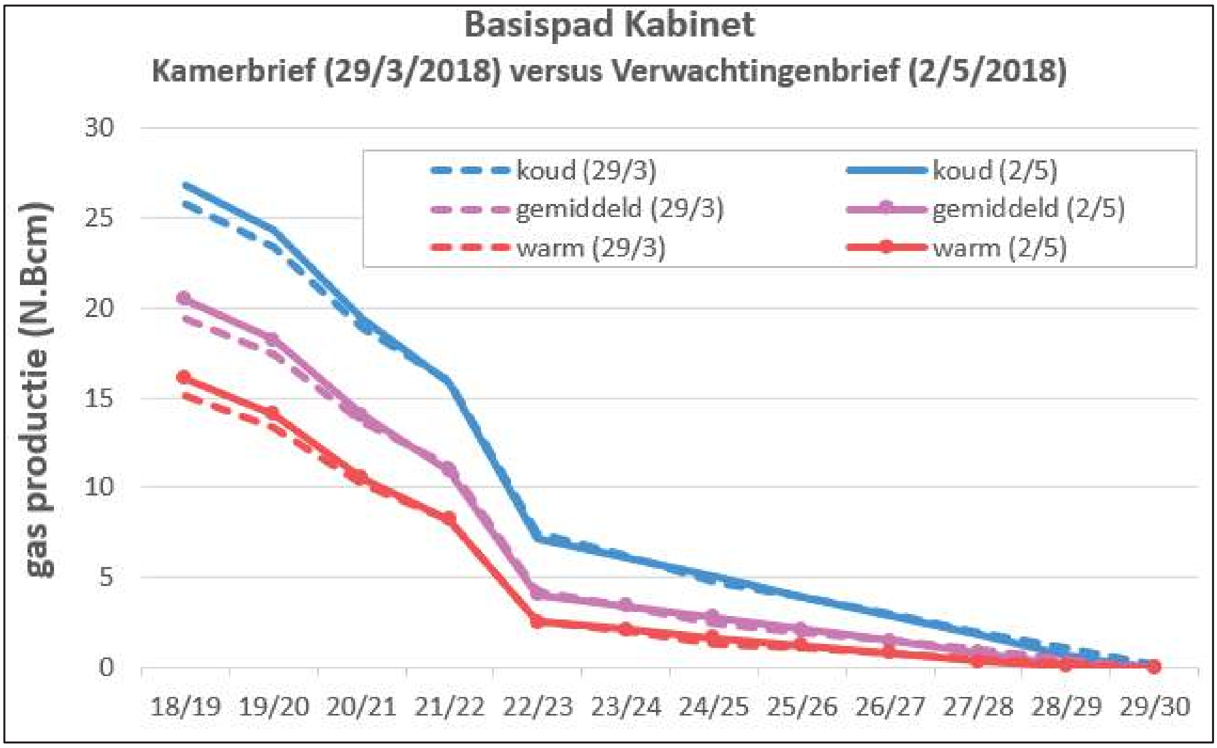



*Figure 1.3 "Basispad Kabinet" for the annual production from the Groningen field, Kamerbrief (29/3/2018) (Ref. 7 (dashed lines) versus Verwachtingenbrief (Expectation Letter) (2/5/2018) (Ref. 8) (solid lines). Note small differences in the first two gas-years.*

Following the report on the Hazard and Risk Assessment for "Basispad Kabinet" (Ref. 12), three supplementary reports were published, on subsidence (Ref. 13), building damage (Ref. 14) and impact of tectonic stresses on the hazard and risk (Ref. 15). The Hazard and Risk Assessment November 2017 (Ref. 5) and the following addenda to this report (Ref. 12 to 15) to assess the impact of the production profile "Basispad Kabinet" were all based on the same workflow and version of the Hazard and Risk Model.

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

On 6th June 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.16). 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 profile based on the maturation of these additional measures to reduce Groningen gas demand was not assessed but would directionally have reduced the risk further as compared to the Hazard and Risk Assessment based on the production profile "Basispad Kabinet" (Ref. 12).

## Production Profile GTS-raming February 2019

Actual production realised in gas-year 2018-2019 was 18.8 Bcm compared to 19.4 Bcm in the production profile of "Basispad Kabinet". This 0.6 Bcm lower production has been included in this Hazard and Risk Assessment.

On 12th February 2019, NAM received the verwachtingenbrief (Expectation Letter) with the updated production profile prepared by GTS: "GTS-raming 2019" (Ref. 17). In figure 1.4 the annual production rates for the three production profiles (Basispad Kabinet March 2018 Letter, Basispad Kabinet Expectation May 2018 Letter and verwachtingenbrief (Expectation Letter) February 2019) are compared. The comparison is shown in this figure for cold, average and warm year gas demand.

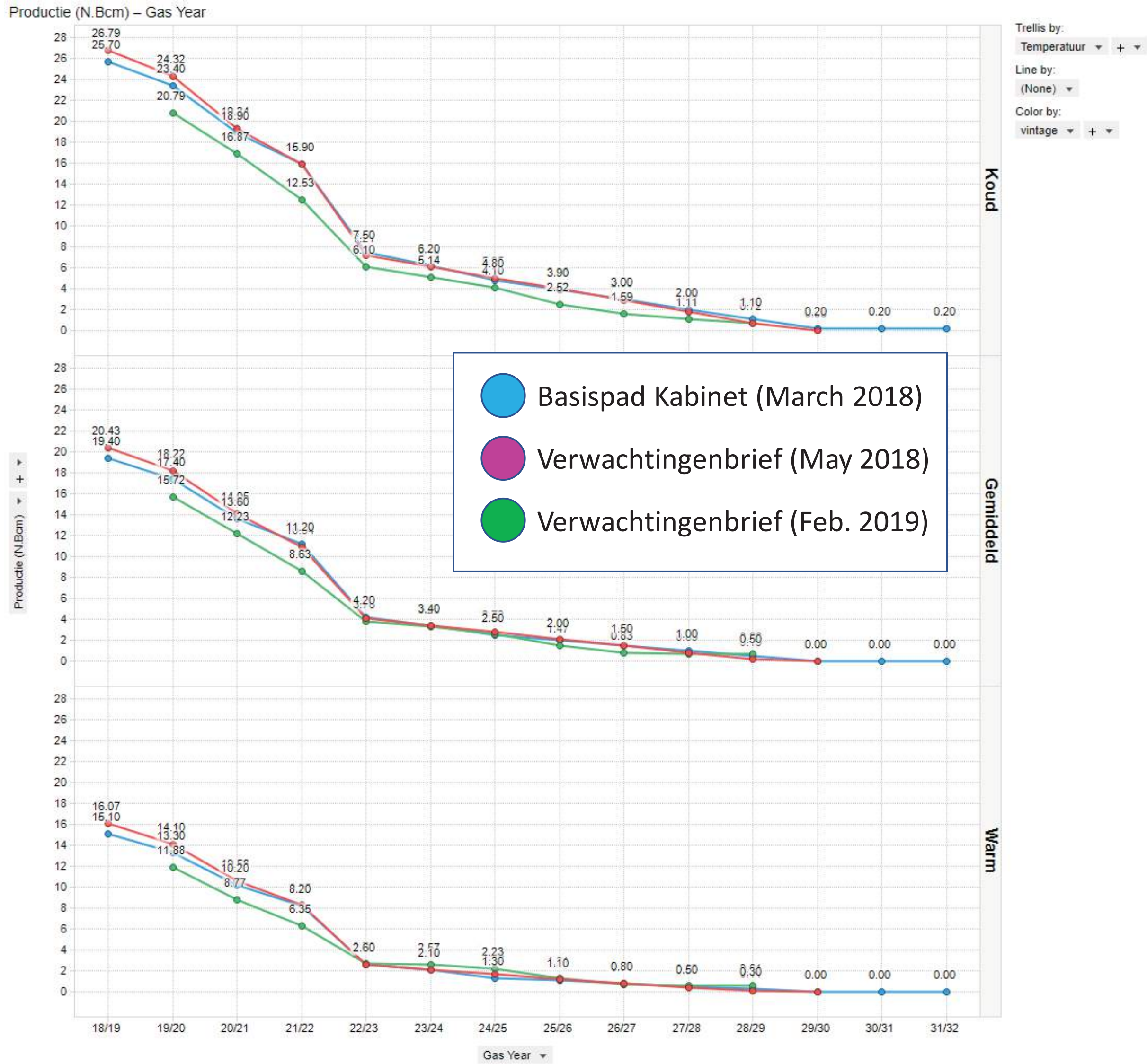



*Figure 1.4* *Comparison of the production profiles "Basispad Kabinet" from Kamerbrief (29/3/2018) in blue (Ref. 7), "Basispad Kabinet" from the verwachtingenbrief (Expectation Letter) (2/5/2018) in red (Ref. 8) and the new production profile GTS-raming 2019 in green (Ref. 17). The upper graph shows comparison for cold (koud) year gas demand, the middle for average (gemiddeld) year gas demand and the bottom for warm (warm) year gas demand.*

In the first three years, the new GTS-raming 2019 is considerably lower than the other production profiles. For a cold temperature year demand, the GTS-raming 2019 is approximately 3 Bcm below the Basispad Kabinet (verwachtingenbrief) for this period. For the average temperature year demand, this difference is approximately 2.5 Bcm per year.

# 2 HRA-Model Improvements

## Introduction

A number of improvements and changes have been implemented in this Hazard and Risk Assessment relative to the previous version based on production profile Basispad Kabinet (Ref.12). These improvements and changes are:

- The software implementation of the HRA-tool based on the programming code in the C-language has been used (Ref. 18). Previously often the implementation using the Python-programming language was used with the implementation based on the C-programming language used for validation. Due to the tight deadline for this report (6 weeks after the production profile GTS-raming 2019 was received), the faster implementation of the HRA-tool using programming code in the C-language was used in the preparation of this report. The impact of this change is very small.
- To capture the epistemic uncertainty, the logic tree with 7 branches for the maximum magnitude of the earthquakes was used. In the report on the Hazard and Risk Assessment based on production profile Basispad Kabinet (Ref.12), the assessment was based on a condensed 3-branch description of this uncertainty, with the results for the 7-branch description of this uncertainty in the logic tree described in an appendix.
- The Exposure Database, containing the description of the houses in the Groningen region, was continuously updated throughout 2018. The current hazard and risk assessment is based on version 6 of the exposure database. The improvements are described later in this section.
- The fragility curves describing the chance of partial and full collapse for buildings in a typology was further refined for several typologies. This further development of the fragility curves was based on the recommendations made in the Assurance Workshop (Ref. 19).

The last two improvements will be further described in this section.

## Exposure Database

To be able to assess the risk for the buildings and community in Groningen resulting from induced earthquakes, knowledge of the occupied building stock in the region of the Groningen field is required. To assign unique building typologies to each individual building in the earthquake area, a program of building inspections was initiated in 2013. The program consists of the collection of building data from existing databases and data sources. This is supplemented by building data gathered from public sources (e.g. observation from public areas (street level) and Google Street View) and engineering drawings of buildings, publicly available at the municipality office. The taxonomy of building typologies of GEM (Global Earthquake Model) is used to assign typologies, based on the structural system of each building.

For practical reasons the Groningen field area has been divided in two areas[4]. The core area consists of the seismically most active area and contains some 20,000 buildings. Additionally, data on the use of the buildings and occupancy are collected. The data on the buildings in the Groningen field area are stored in the exposure database (EDB). An earlier version of this database (V2) (Ref. 20) was used for the Hazard and Risk Assessment of November 2015 (Ref. 21) and Hazard and Risk Assessment for Winningsplan 2016 (Ref. 1). Early 2017 and mid-2018, updated versions of the database were issued

[4] These areas have been introduced by the NCG based on a hazard map of KNMI. The 0.2 g contour of the 2015 KNMI hazard map was chosen as the boundary between these areas.

(Ref. 22, 23 and 24). The exposure database of mid-2018 (Ref. 22) was used in the Hazard and Risk Assessment for the production profile "Basispad Kabinet", which was issued June 2018.

The exposure database combines many data sources (BAG, AHN, Deltares top soil, etc.) together with inference rules to assign typologies to individual buildings. The datasets used for the EDB are categorised as follows:

- **Source data** Datasets which have been received and maintained by external sources such as government departments.
- **Project data** Datasets which have been produced within the project such as inspection datasets and desktop studies. This includes project information produced by ARUP and external consultants.
- **Processed data** Datasets which ARUP has created utilising source datasets, assumptions and analysis to provide information that is not available from external sources.

This leads to a non-unique typology description for many buildings. In the core area, almost every building has a unique typology assigned. Away from this area, the typology of many buildings is based on inference rules, reflecting the experience of local engineers with the knowledge of the development of local building methods. These inference rules are also updated in light of the on-going building data gathered. The Hazard and Risk (HRA) model applies the assessed earthquake hazard to the buildings and the population in the exposure database to assess the earthquake risk. The inference rules will in most cases not be able to establish the building typology uniquely and will assign a number of typologies to the building, each with a probability. On a regional level this provides a reliable assessment of the number of buildings where the safety-norm is exceeded and a risk-based ranking of all building in the Groningen field area.

## Recent activities to improve the expose database

The exposure database is continuously improved. For this hazard and risk assessment version 6 of the exposure database has been used. This section describes the improvements implemented in version 6.

NAM has published reports on the progress of this activity in July and September 2018 (Ref. 23 and 24). Especially for the buildings high on the risk-based ranking the typology has now been assigned with confidence. This improvement program of building inspections executed primarily by ARUP has continued with the release of the Exposure Database version V6, ready for use in this update of the Hazard and Risk Assessment.

1. Existing data has been gathered through, 14,000 Rapid Visual Screening (RVS), 800 Extended Visual Screening (EVS) and 15,000 Arcadis damage inspection records.
2. CycloMedia, HORUS companies provided a service whereby images from the building stock were used (or specifically gathered) and computer processed to determine properties of the building façade. This can be used to determine similarities between buildings, window surfaces in the façade (% or $m^2$), height, aspect ratio, degree of tilt etc. The effort was further extended in the second half of 2018 by Ticinum Aerospace which has, based on analysis of publicly available photo's, further improved the assessment of building characteristics such as number of floor levels and window openings (Fig. 2.1).
3. Collection of Building Drawings to validate and confirm knowledge of buildings. Focus was recently on the collection of data on apartment buildings and buildings with any probability of having higher risk (see also item 5 below).

4. Neighbourhood check – Buildings with similar geometric properties and construction year will be compared.
5. Re-evaluate buildings with low probability of belonging to a vulnerable typology. This exercise has led to identification of additional vulnerable buildings, also in the core area. Especially, buildings with a typology with a mixed structural system or belonging to multiple typologies (one of which is a vulnerable typology) have been assessed in detail.

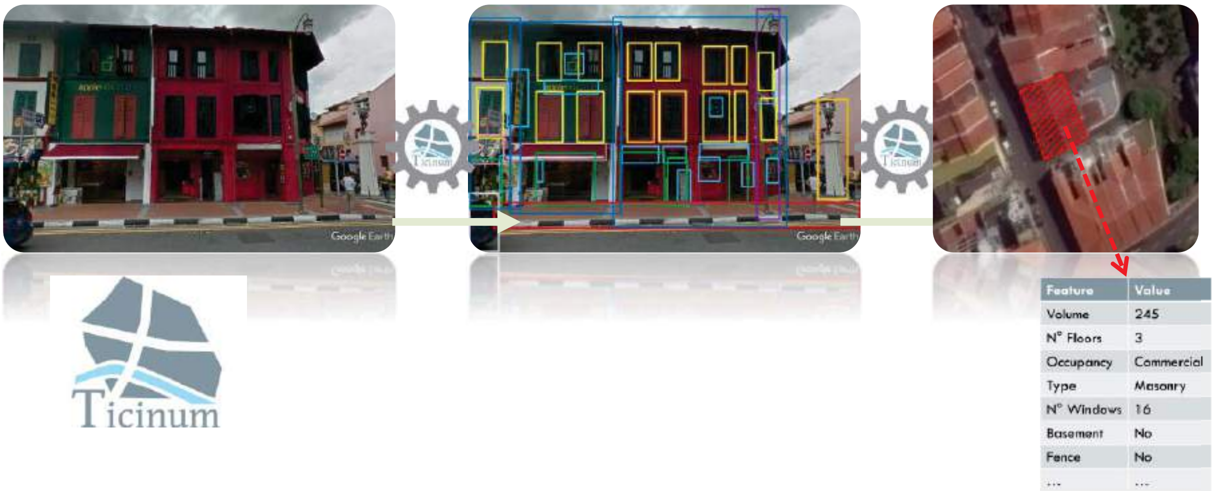



*Figure 2.1 The CountFloor service of Ticinum can automatically extract building features by analysing street-level pictures*

As part of the efforts to improve the Exposure Database some 190,000 documents have been collected primarily from municipality archives, building associations and owners (Tab. 2.1) on various building aspects (Tab. 2.2).

| Source | Number of Documents |
|---|---|
| Municipalities | 177,390 |
| Building Associations | 4,348 |
| Owners | 15 |
| Other Sources | 7,373 |
| Total | 189,126 |

Table 2.1 Number of documents collected to improve the Exposure Database split by source.

| Document | Others | Municipality | Building Associations | Owners | Total |
|---|---|---|---|---|---|
| Calculations | 16 | 9,629 | 146 | 1 | 9,792 |
| Secondary Buildings | 19 | 1,044 | | | 1,063 |
| Soundings | | 2,304 | 71 | | 2,375 |
| Details | 114 | 3,269 | 466 | | 3,849 |
| Reckoning Calculations | 1,001 | 33,351 | 561 | 3 | 34,916 |
| Floors | 1,207 | 14,208 | 290 | 2 | 15,707 |
| Foundations | 589 | 17,130 | 225 | | 17,944 |
| Others | 3,052 | 3,447 | 2,001 | | 8,500 |
| Building Requests | 319 | 15,502 | 80 | | 15,901 |
| Renovations | 14 | 37,753 | 24 | 8 | 37,799 |
| Technical calculations | 141 | 15,105 | 126 | 1 | 15,373 |
| Situations | 551 | 10,941 | 342 | | 11,834 |
| N/A | | 4,707 | 16 | | 4,723 |
| Undefined | 350 | 9,000 | | | 9,350 |
| | 7,373 | 177,390 | 4,348 | 15 | 189,126 |

Table 2.2 Number of documents collected to improve the Exposure Database split by building aspect.

More than 350 visits have been made to the municipality archives (Tab. 2.3) to collect this building data.

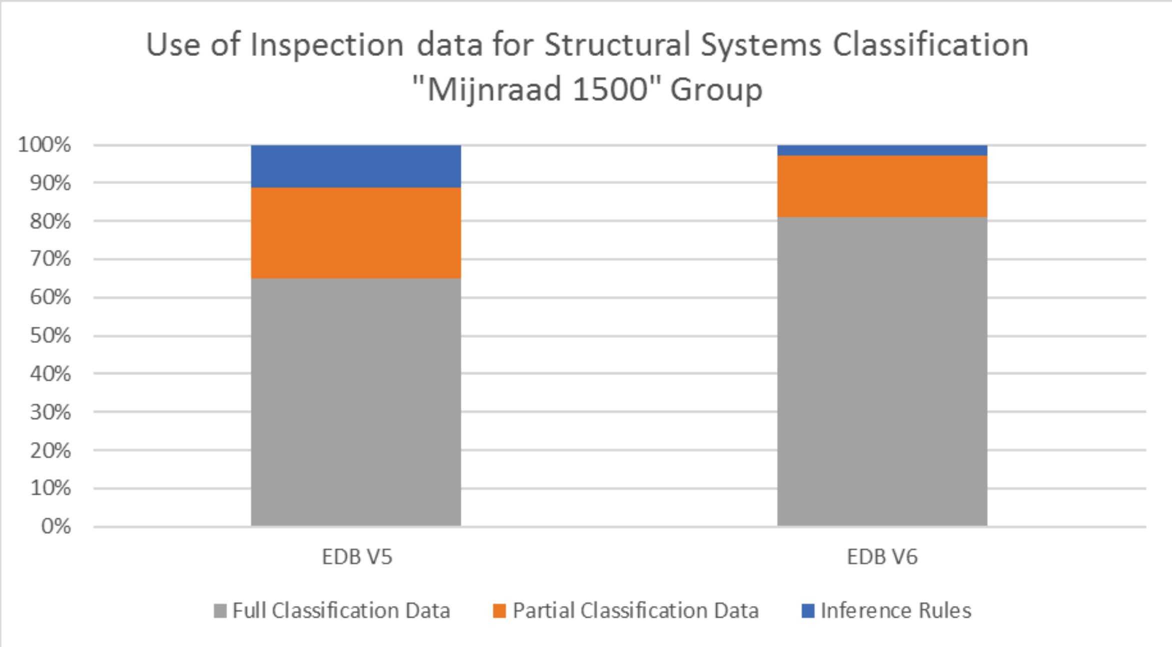
| Municipalities | Appart-ment | Terraced Buildings | Detached Building | Total |
|---|---|---|---|---|
| Appingedam | 7 | 20 | 37 | 64 |
| Delfzijl | 3 | 19 | 39 | 61 |
| Hoogezand | 4 | | 1 | 5 |
| Slochteren | 2 | 6 | 27 | 35 |
| Loppersum | 2 | 15 | 54 | 71 |
| Eemsmond | 4 | 13 | 36 | 53 |
| Ten Boer | 1 | 14 | 29 | 44 |
| Bedum | | 3 | 2 | 5 |
| De Marne | | 1 | | 1 |
| Aanvullend | | 5 | | 5 |
| Groningen | | | 5 | 5 |
| Winsum | | | 1 | 1 |
| Oldambt | | | 1 | 1 |
| WoCo | | | 2 | 2 |
| Total | 23 | 96 | 234 | 353 |

Table 2.3 Number of visits to municipality archives split by studies on Apartments, Terraced Buildings and Detached Buildings.

An important source of information are the results of the Engineering inspections carried out on behalf of NCG/CVW for the strengthening campaign. Unfortunately, this data source is not available to NAM.

## Conclusions and general results of the studies

For the vast majority of the buildings high on the risk-prioritised list of buildings in the Groningen area, the unique typology has been established. This is the direct result of all activities described above. Figure 2.2, which is similar to figure 2 in "Exposure Database (EDB) voor het gebied van het Groningen veld - Stand van Zaken - september 2018" (Ref. 24), shows the data sources available to assign each typology. Further improvements are difficult to realise because they would require inspection inside the buildings.




*Figuur 2.2 Data sources used to assign Structural Systems to buildings of the "Mijnraad 1500" list, based on production profile "Basispad Kabinet". The figure shows that more deterministic building specific data has been used than before.*

## Fragility and Consequence Models for building typologies

A full overview of the development of the fragility curves describing the response of buildings for each building typology and the further development of these during 2018 is provided in the January 2019 version of the "Study and Data Acquisition Plan induced seismicity Groningen" (Ref. 25) and in the specific report on the topic [Ref. 49]. Although the results of experiments carried out in 2018 have contributed to the further development of the fragility curves, in this report we'll focus on the development of the fragility curves themselves.

As with the other components of the hazard and risk assessment, the fragility and consequence models have been regularly updated and documented. Version 2 of the fragility and consequence models was used for the hazard and risk assessment supporting the Winningsplan 2016 (Ref. 26). This version was shared with experts in structural modelling, fragility and risk assessment in a first assurance review that took place in November 2015.

The previous version of the fragility and consequence models, version 5, uses SDOF models calibrated using the dynamic analysis results of index buildings, as presented previously (and documented in Ref. 27). Elastic springs and dashpot dampers at the base of the SDOF account for the effects of soil-structure interaction (i.e. foundation-soil flexibility and damping) (Ref. 28). The SDOF models are subjected to hundreds of accelerograms (cloud analysis) and regression analysis is undertaken to relate the characteristics of the accelerograms (spectral acceleration at varying periods of vibration, significant duration) with the nonlinear displacement response.

Fragility functions that describe the probability of exceeding a given threshold of damage, conditional on a level of ground shaking can then be developed from the aforementioned regression analysis and by identifying the value of displacement at which different damage and collapse states occur. The thresholds for damage states DS2 and DS3 of URM and reinforced concrete structures have been obtained from the experimental activities described previously, whereas the collapse state thresholds are obtained via explicit collapse modelling within the numerical software used to model the index buildings.

In addition to structural collapse, chimney collapse fragility functions have also been developed using empirical data from a number of earthquakes including Liege (1983) and Roermond (1992) (Ref. 29, 30). Consequence models (i.e. the probability of loss of life inside or outside the building, given collapse) for both structural and chimney collapse were also developed considering the percentage of internal/external floor area covered in collapsed debris (Ref. 27).

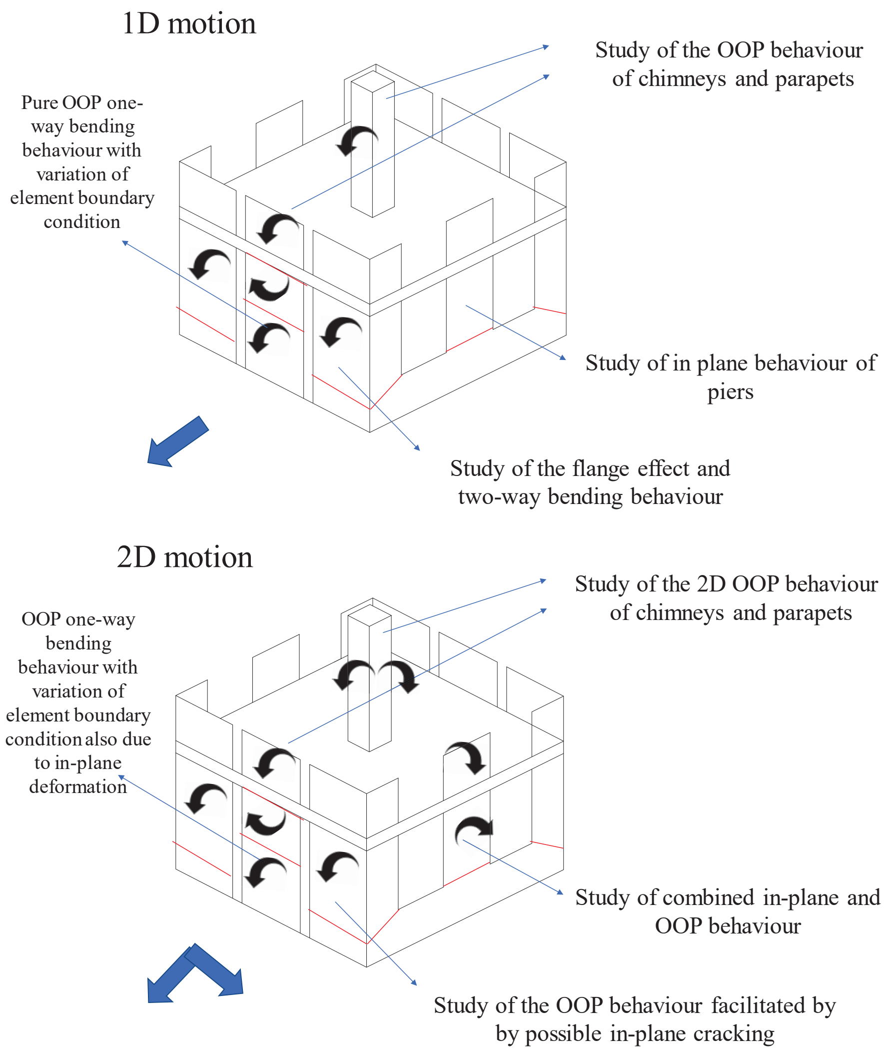
## Study activities following assurance meeting

The experimental and numerical work described above, which led to version 5 of the fragility and consequence models, was subjected to a second assurance review that took place in February 2018. The recommendations laid out by the Review Panel in their Assurance Letter (Ref. 19) played an important role in the definition of the further activities currently being carried out or planned for 2019. Below, such activities are first listed, and then further discussed, where pertinent.

- Shake-table testing of full-scale structural subassemblies under triaxial input motions (i.e. simultaneous application of two horizontal components plus the vertical one), so as to validate the accuracy of the employed structural modelling approaches under such loading conditions.
- Use of the outputs of the blind predictions to quantify the fidelity of the structural models employed in the fragility functions derivation, and thus constrain the uncertainty bounds used in the associated logic tree.
- Undertaking of sensitivity and parametric studies to understand the impact of modelling assumptions regarding issues such as e.g. wall-to-wall and wall-to-diaphragms connections, foundations flexibility, openings, non-structural partition walls.
- Use of hazard consistent ground motions (conditional on spectral acceleration at specific periods of vibration as well as Average Spectral Acceleration, AvgSa) for both the modelling of index buildings and the development of fragility functions.
- Employment, in the SDOF analyses used to derive the fragility functions, of a more advanced Soil-Structure-Interaction (SSI) model, so that effects such as nonlinear soil response and failure are taken into account.
- Validation of the SDOF approach employed to derive the fragility functions for the entire set of structural systems, through a comparison, for one or two structural systems, against fragility functions developed directly from multi-degree-of-freedom (MDOF) models.

- Scrutiny of fragility and consequence models through history checks on damage and fatalities (by repeating all earthquake events with local magnitude greater than 2.5 that have been measured in the field), and through comparisons against other published models from around the world (with a critical evaluation of the differences).

With regards to the first of the further activities listed above, it is noted that shake-table tests conducted so far have highlighted and confirmed how the out-of-plane (OOP) behaviour of load-bearing walls may be influenced by boundary conditions and how these may vary due to effects of multi-directional input. The impact of the vertical acceleration on the out-of-plane performance of slender walls, parapets and chimneys will hence be investigated through tests on similar sub-assemblages/structures subjected to unidirectional and multidirectional motions. Further, the tests previously carried out have also highlighted that laterally supported walls subjected to OOP behaviour (i.e. two-way-bending) resulted to be very sensitive to the damage state of the panel itself and of its lateral connections; undamaged panels had a low vulnerability while it increased considerably for damaged ones. Hence, relatively complex assemblages will be tested to study the combined effect of in- and out-of-plane excitation and interaction with perpendicular elements (damage due to flange effect). The influence of vertical motion will be studied also in these cases.



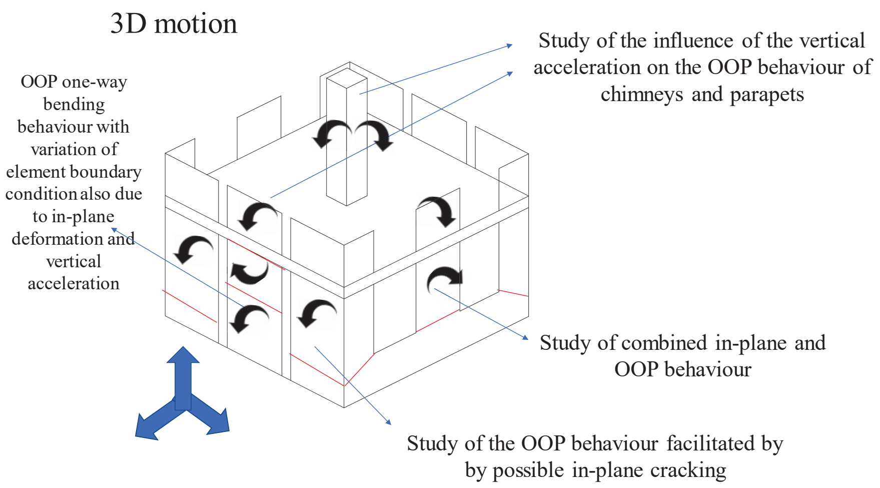



*Figure 2.3 Rationale and objectives for the envisaged further multi-direction shake table tests*

For what concerns the second of the further activities listed above, regarding the analysis of the blind predictions outcomes in order to assess the fidelity of the structural models currently employed in the fragility model (and to then constrain the uncertainty bounds used in the logic tree), the plan is to systematically compare the predicted collapse displacements (from each given software/modelling approach) with those observed in the tests, so to quantity the bias and variability in the predictions. An example of such an exercise is shown in Fig. 2.4 below, regarding the blind predictions carried out for the testing of EUC-BUILD6 specimen.

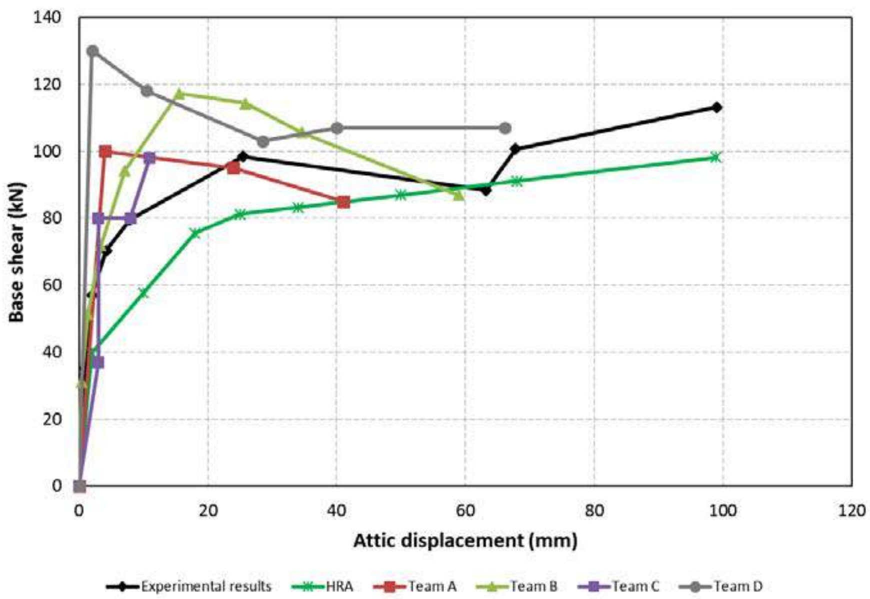



*Figure 2.4 Comparing blind-predictions with experimental results for EUC-BUILD6*

Finally, for what concerns instead the planned improvements on the SSI modelling approach employed in the SDOF analyses used to derive the fragility functions, this involves a review and verification of alternative approaches, including e.g. lumped parameter elastic models (Fig. 2.5), nonlinear macro-element models (Fig. 2.6), soil box analyses under MDOF models, etc. In addition, the now available 140.000 soil profiles created within the framework of the Ground Motion Model development are also to be considered in the derivation of the stiffness and strength input properties for the SSI models.

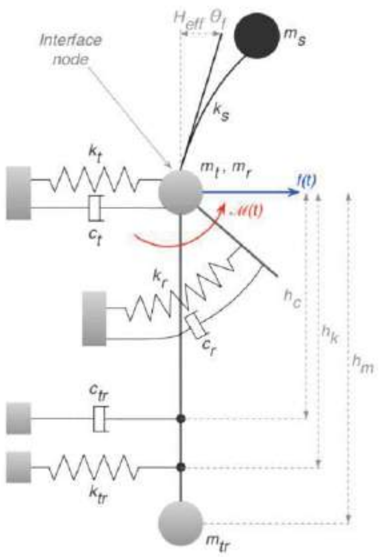



*Figure 2.5 The lumped parameter elastic SSI model*

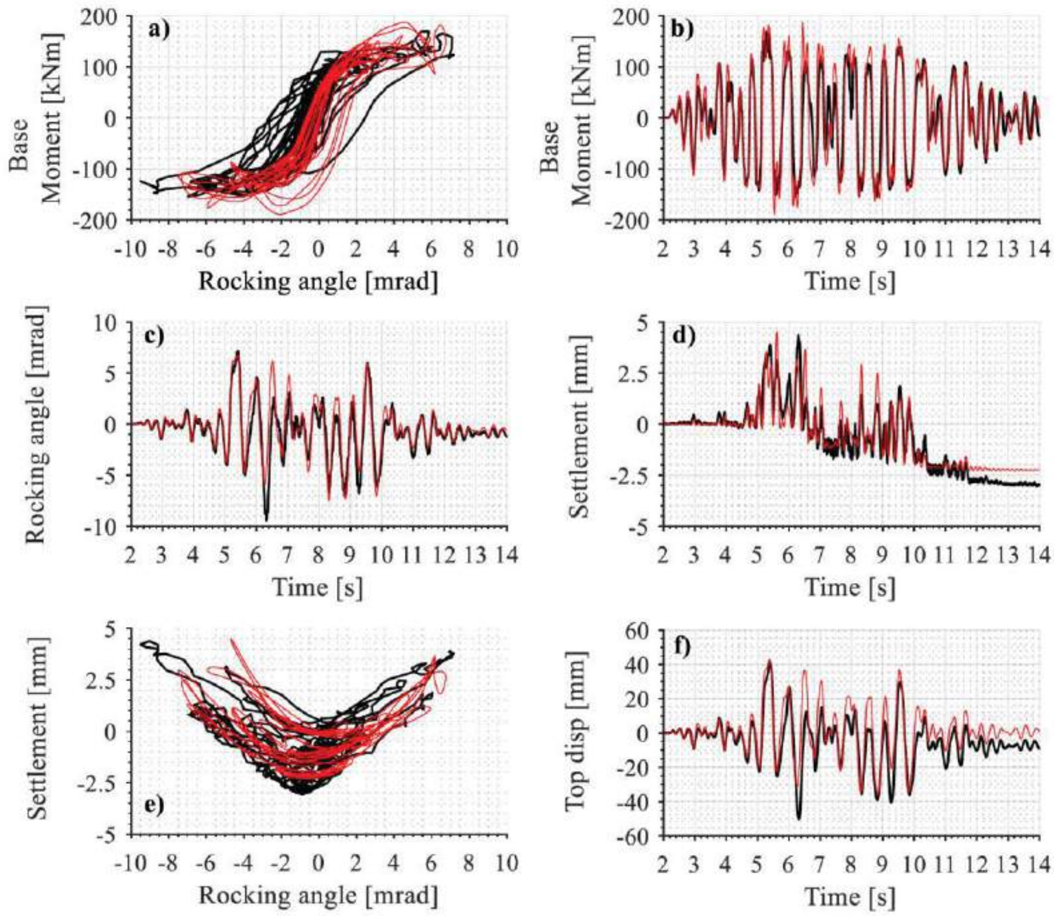



*Figure 2.6 Example of literature-available validation of the nonlinear inelastic macro-element SSI model.*

## Summary of main improvements to the fragility curves – Version 6

The following activities, as recommended by the International Expert Review Panel (Ref. 19) have been undertaken:

- Further validation of the SDOF models using the MDOF models has been made.
- The SDOF model has been used in the blind prediction of the EUC-BUILD6 test (which represents the typology with one of the largest number of buildings).
- The impact of foundation failure on the MDOF models has been investigated.
- The simple spring/dampener used to model soil-structure interaction has been replaced by a more advanced macro-element model that more directly accounts for nonlinear soil response and failure.
- Hazard consistent records have been selected for the development of fragility functions.
- The records are conditioned on different levels of AvgSa, an intensity measure that is common for all building typologies and that now allows direct comparisons between fragility functions to be made (to aid validation).
- The fragility functions have been derived in terms of PGA and compared with other models from the literature (for further validation).
- The damage state thresholds used for the damage fragility functions have been updated based on the latest experimental test results.
- History checks have been undertaken to estimate the expected damage/loss using ShakeMaps from the largest events as well as the full event catalogue.

In addition, more index buildings have been studied and used in fragility function development, in particular:

- URM1L and URM3M typology divided in sub-typologies recognising the fact that the variation with respect to seismic behaviour within these typologies was still relatively large
- URM3M_D (drive-in buildings) now explicitly modelled with 2 index buildings (rather than mapped to URM3M_U: 3 storey town house with cavity walls and concrete floor).
- URM5L (terraced house with timber floors and cavity walls) is now explicitly modelled (rather than mapped to URM8L, detached house with cavity walls and timber floors).
- URM3L (terraced house with concrete floors and cavity walls and low % of openings) is now represented by two index buildings.
- PC3L (pre-cast terraced houses) have now been modelled with 2 index buildings.
- URM9L (URM building with steel frames at ground floor) is now modelled with an index building.

# 3 Production Profile

## Production profile: Demand profiles GTS-raming 2019

Demand profiles were provided by the Ministry of Economic Affairs and Climate Policy, by means of a verwachtingenbrief (Expectation Letter) dd 12th of February 2019, representing the Groningen-quality gas demand in excess to the other L-gas supply sources. The demand profiles are presented on a daily level during either a cold, average or warm temperature gas-year for the individual gas-years in the period up to the 30th of September 2029. The appendix “*uitgangspunten volumeberekeningen*” to the GTS document “*Raming benodigd Groningenvolume en capaciteit gas-jaar 2019/2020 en verder*” states that the average utilisation of the GTS nitrogen plants Ommen, Wieringermeer and Zuidbroek (if available) is assumed to be 92.5%. Hence the subset of the full dataset, identified as “G+N+A 92.5%” is selected to represent the demand profiles for the Hazard and Risk Assessment (see Figure 3-1).

The demand profiles do not distinguish between gas produced from Groningen field, UGS Norg or PGI Alkmaar, nor does it recognise the volumes required for injection in UGS Norg. Pre-processing of the dataset was required to redistribute contribution between UGS Norg, PGI Alkmaar and Groningen field. Redistribution processing is performed by GasTerra, as they have knowledge on the L-gas market demand throughout the year and determine 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. It assumes the underground gas storages UGS Norg 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 PGI Alkmaar facility is available for production in the period October till March and is filled with pseudo-G-gas during the period April – September.

The applied methodology to determine the utilisation of Groningen system assets is based on perfect insight on the future temperature profile (e.g. weather conditions are upfront known for every single day in the future). This perfect foresight assumption is a deterministic 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.

GasTerra has reported the daily volumes required from the Groningen field for each of the individual gas-years and the 3 temperature profiles (cold, average and warm). As the hazard and risk assessment requires monthly time steps, the daily volumes have been converted to monthly volumes to be produced from the field. The graphs below show both the full G-gas demand and the Groningen field production volumes on a monthly basis. The requirement to fill Norg UGS in the summer has a flattening effect on the Groningen field production profile (see Figure 3-1).

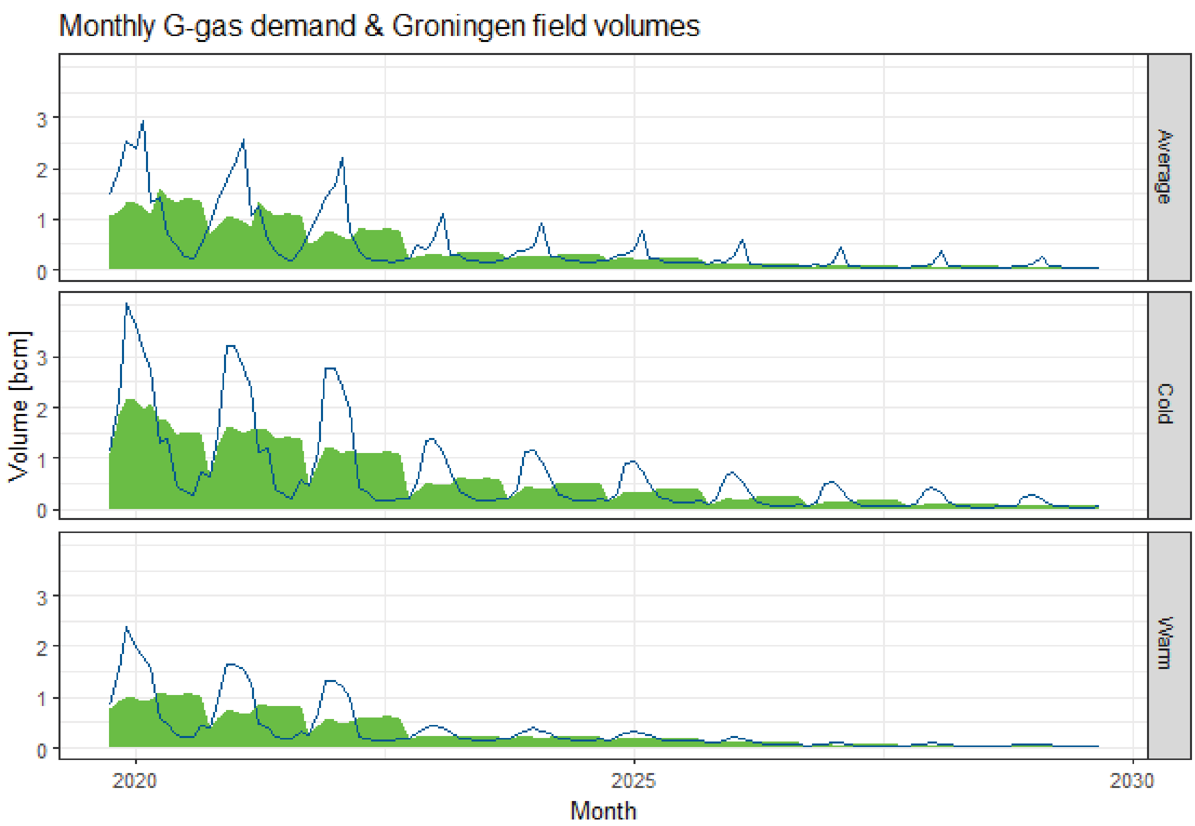



*Figure 3-1 Monthly G-gas demand based on GTS estimate (blue line) and Groningen field volumes after reprocessing by GasTerra (in green) for warm, average and cold gas-year.*

The resulting net production from the Groningen field is given in Figure 3-2 and Figure 3-3.

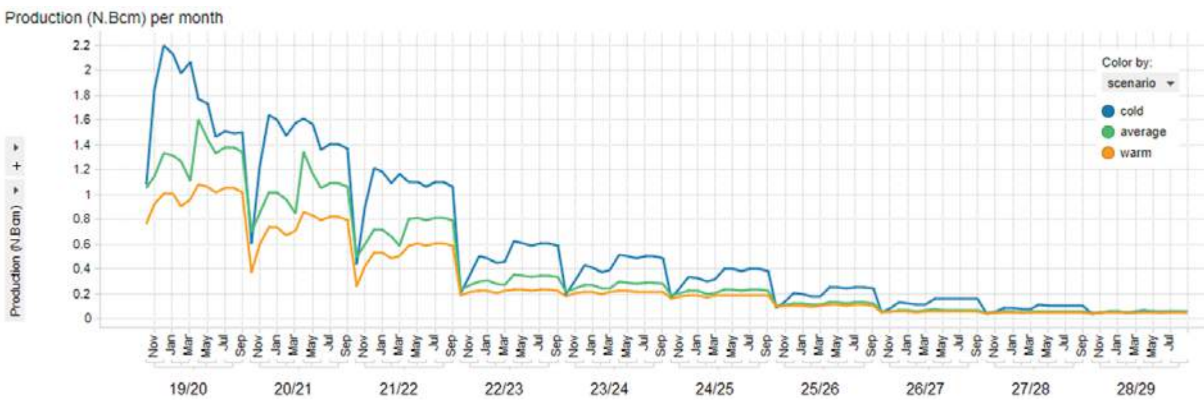



*Figure 3-2: Groningen field production profile by month*

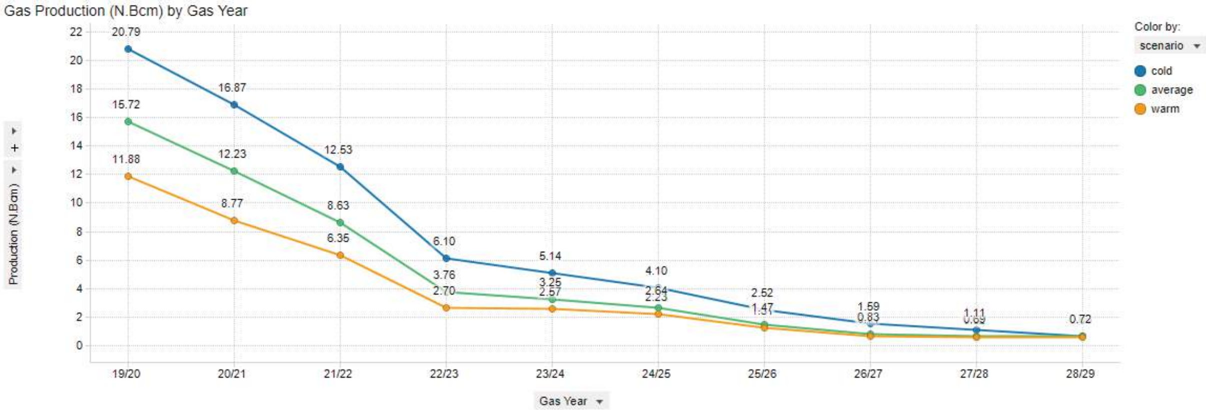



*Figure 3-3: Groningen field production by Gas-year*

## Spatial distribution of production (Operational Strategy)

### Optimisation of production distribution to minimize seismic hazard and risk

On 1/10/2018 NAM issued the 2018 update of the Production Optimisation study to SodM (Ref. 31). In this study, NAM investigated whether the seismic hazard and risk in Groningen could be influenced by the distribution of production across the production locations and at which distribution of the determined production volume the seismic risks would be minimized as much as possible over the period 2018-2022. Various optimisation metrics were investigated (e.g. event count, maximum Peak Ground Acceleration, etc).

In a letter to the Ministry of Economic Affairs on 16/10/2018, SodM advised the Minister to use NAM's 2018 optimisation study to steer the production distribution in the field (Ref. 32). Production distribution as calculated for the optimisation metric "population weighted Peak Ground Velocity" was judged to minimize the seismic risks over the entire Groningen gas field in a socially responsible manner. This distribution resembles "Operational Strategy 1" in NAM's 2018 "Bouwstenen document", the document which outlines options for the Operational Strategy of Gas-year 2018/2019 (Ref. 34). "Operational Strategy 1" was adopted as the operational strategy of choice in the 14/11/2018 Ministerial Instemmingsbesluit (Ref. 33).

For this 2019 HRA update, NAM was requested by the Ministry of Economic Affairs (Ref. 17) to define two Operational Strategies, based on two specific volume distribution strategies (spatial distribution of production) as described in the 2018 NAM production optimisation study (Ref. 31), being the Populated weighted peak ground velocity strategy and the Event count strategy. These two strategies are requested to be evaluated for three temperature profiles.

### Strategy definition

- **Strategy 1 – Population weighted Peak Ground Velocity**
  Strategy 1 distributes the production in order to minimize the population weighted Peak Ground Velocity (see spatial overview of production start-up order in of production clusters, Figure 3-4 left-hand side). Gas is produced preferentially from the South-East, if more production is required clusters are opened in South-West and Central-East region. Cluster Bierum is kept at a stable rate whereas cluster Eemskanaal is used as capacity provider. This strategy resembles the strategy as selected by the Minister in Instemmingsbesluit 2018 and in gas-year 2018/2019 operationalized by NAM.

- **Strategy 2 – Event count**
  Strategy 2 distributes the production in a way to minimize Event count. Gas is preferentially produced from the South of the field (see spatial overview of production start-up order in of production clusters, Figure 3-4 right-hand side). Starting in the South-East, opening-up additional clusters from South-West and cluster Eemskanaal. Clusters in the region Central-East and cluster Bierum are opened only at a higher production demand.

In order to be able to control production distribution a cluster start-up order is being applied in the model. For both strategies a different sequence is used, see Table 3-1. The modelled cluster utilisation (monthly times steps) might differ from the day-to-day cluster utilisation because of daily production fluctuations and operational constraints.

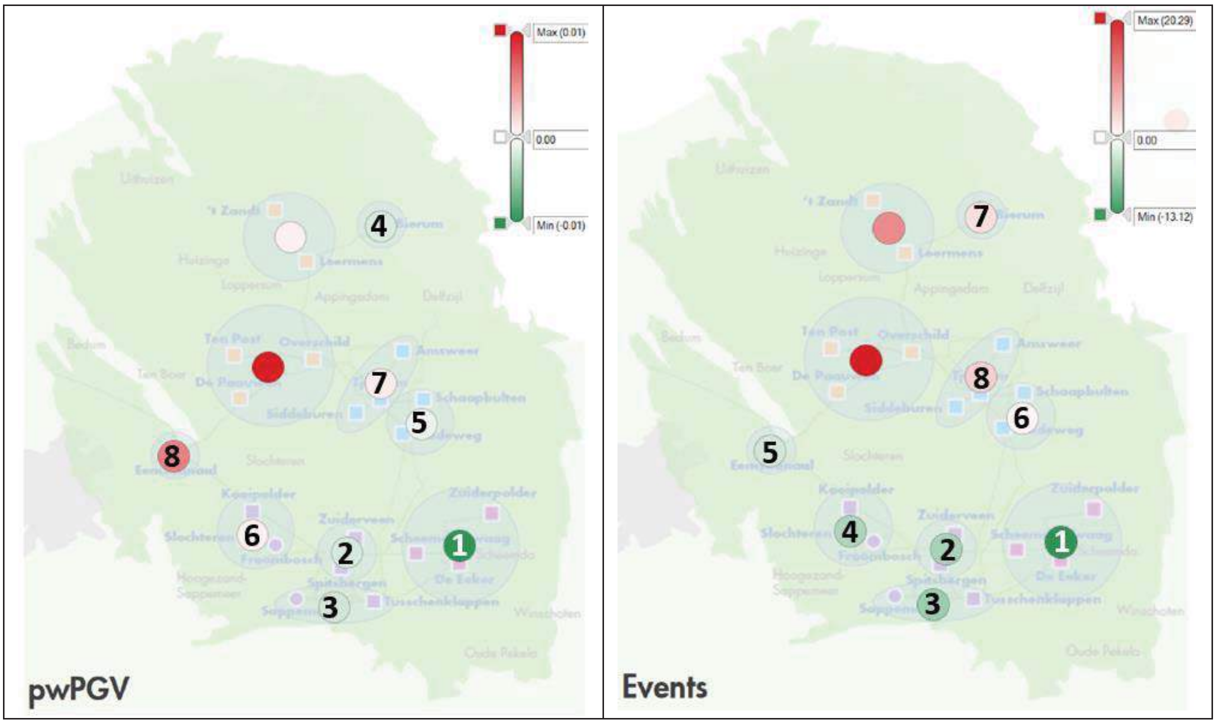



*Figure 3-4: Spatial overview of production start-up sequence when optimising for pwPGV (left-hand side) and for Event count (right-hand side). Source: Ref.31*

## Temperature profiles

As per the updated Mining Law (Article 1.3a.2), the verwachtingenbrief requested evaluation for three temperature profiles:

- Average temperature
- Cold temperature in gas-year 2019/2020, followed by average temperatures for subsequent years
- Warm temperature in gas-year 2019/2020, followed by average temperatures for subsequent years

These demand profiles have been constructed from the data as provided by the Ministry of Economic Affairs and Climate Policy, by means of the verwachtingenbrief (Expectation Letter) dd 12th of February 2019.

Hence in total 6 profiles were requested by the Ministry.

## Production regions

In Article 1.3a.1 of the updated Mining Law, the production regions are defined:

- East-Central (clusters Amsweer, Tjuchem, Oudeweg, Schaapbulten, Siddeburen)
- South-East (clusters Scheemderzwaag, De Eeker, Zuiderpolder)
- South-West (clusters Kooipolder, Slochteren, Spitbergen, Tusschenklappen, Zuiderveen)
- Loppersum (clusters Leermens, Overschild, Ten Post, De Paauwen, 't Zandt)
- Eemskanaal cluster
- North (Bierum cluster)

Similar to the June 2018 hazard and risk assessment, for this HRA update further granularity was applied within regions East-Central and South-West. This additional granularity allows for optimisation of production within the (larger) regions and reflect operational conditions (lower number of clusters in operation when low demand), see Figure 3-5.

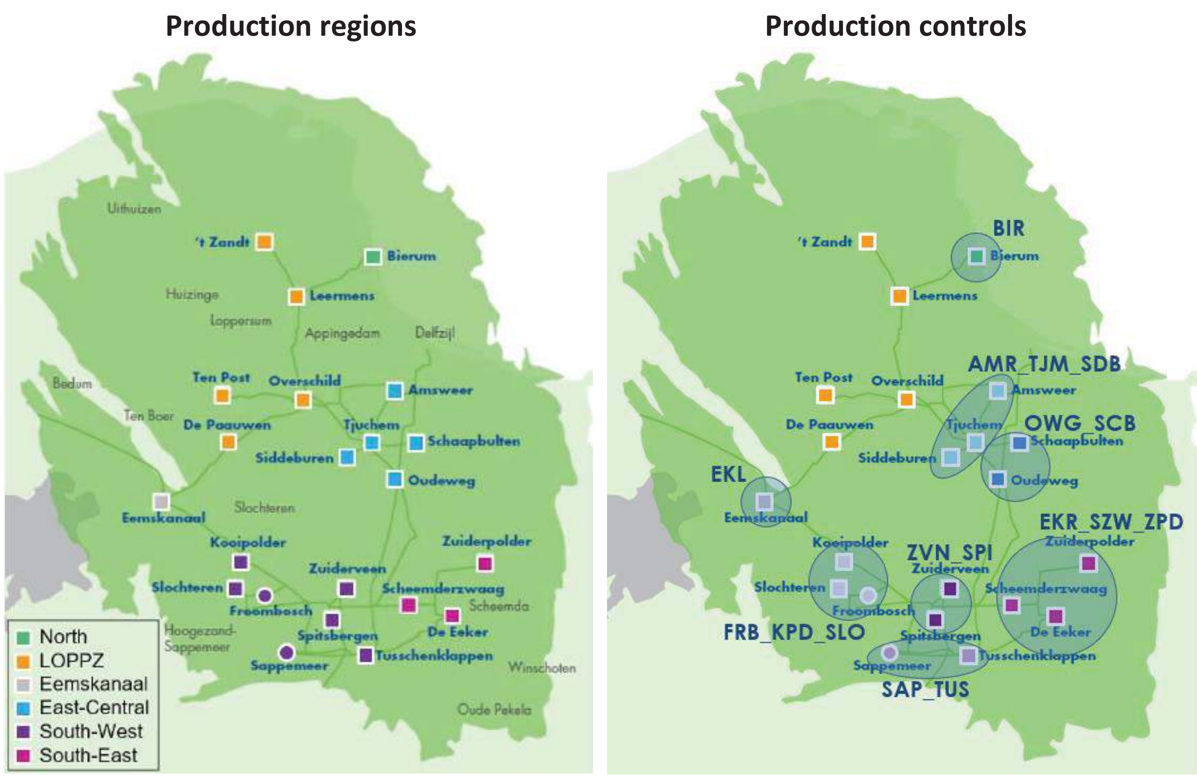



*Figure 3-5: Production regions and control groups as used in the start-up list*

## Model implementation

### Start-up order

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). The surface network model sequentially opens-up (groups of) clusters following the start-up sequence until the total required production demand is achieved.

| | pwPGV |
|---|---|
| BIR | |
| EKR/SZW/ZPD | 1 |
| SPI/ZVN | 2 |
| SAP/TUS | 3 |
| SCB/OWG | 4 |
| FRB/KPD/SLO | 5 |
| AMR/SDB/TJM | 6 |
| EKL | |

| | Event count |
|---|---|
| EKR/SZW/ZPD | 1 |
| SPI/ZVN | 2 |
| SAP/TUS | 3 |
| FRB/KPD/SLO | 4 |
| EKL | 5 |
| SCB/OWG | 6 |
| BIR | 7 |
| AMR/SDB/TJM | 8 |

*Table 3-1: 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.*

**Load Factor**

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 maximum cluster capacity. It is calculated for each individual cluster at every timestep and a maximum value can be set as a constraint in the surface network model. 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).

A pre-set maximum load factor of 70% has been used in the model, in order to reflect the daily operational situation. This load factor assumption is considered a challenging achievement as it includes all scheduled and unscheduled production deferments. Daily production fluctuations have not been encountered for in this analysis, as hazard and risk assessment is based on monthly time step.

## Modelling setup

### Dynamic reservoir model (Mores model V5)

For establishing the reservoir pressure response to the various production profiles, the V5 Mores dynamic reservoir model was used (Ref.35). This is the same model as was used for the June 2018 HRA (Ref.12) and for the 2018 Production Optimisation study (Ref.31). The history match was updated with actual production data up to 31/12/2018.

### Production data 1/1/2019 to 30/9/2019

All profiles have a common starting point, the start of gas-year 2019/2020. It is assumed that up to 1/10/2019 production will take place as per the 14/11/2018 Instemmingbesluit for average temperature.

### Surface network model (Genrem)

The capabilities of the surface facilities are reflected through the Genrem surface network model (as implemented for the June 2018 HRA).

### Production considerations

**Loppersum production**

In line with the 14/11/2018 Instemmingsbesluit, the Loppersum clusters are not used for production.

### Eemskanaal production

The Eemskanaal cluster is used as capacity provider in Operational Strategy 1. It is only used to meet capacity demand. The Eemskanaal cluster is produced at an annual total of 100 mln $Nm^3$ in winter months only (on a stand-by rate), and shut-in over summer. It is assumed the Eemskanaal cluster is shut-in from gas-year 2022/2023 onwards.

For strategy 2, the Eemskanaal cluster production is led by the start-up list.

### Bierum production

In strategy 1, the Bierum cluster production is kept at a base-load rate of 6 mln $m^3/d$ in gas-year 2019/2020, and in subsequent years proportional scaled down with total annual volume. From gas-year 2022/2023 onwards Bierum is assumed to be fully shut-in.

For strategy 2, the Bierum cluster production is utilised as per the start-up list.

## Production Fluctuations

For both operational strategies (see Strategy Definition) a fluctuation analyse has been performed for gas-year 2019/2020. GTS has provided the Groningen system demand (Groningen plus UGS Norg) for 30 historical temperature profiles for gas-year 2019/2020. Groningen field demand has been calculated in a post-processing by GasTerra (see Demand profiles GTS 2019).

Two indicators to monitor production fluctuation are compared to the average produced monthly volume over the preceding 12 months and month-on-month production fluctuation. The bandwidth of the fluctuation limits for both indicators is set at +/-50% for the regions South-East, South-West and Central-East. For the Bierum region a bandwidth of +/-20% applies to both indicators.

The production fluctuation analysis is performed in daily steps. For 30 temperature profiles the daily Groningen field demand is distributed over the production clusters following the production start-up list (see Table 3-1).

The production fluctuation indicator based on the average produced monthly volume over the preceding 12 months describes the difference of volume produced during one month in a region with the average monthly volume over the 12-month period preceding the relevant month for the respective region. This difference is expressed in a percentage with the average monthly volume over the 12 preceding months as a reference. An overrun of the fluctuation bandwidth occurs if the volume is not within that bandwidth in one month.

A month-on-month production fluctuation is the difference of volume produced during one month in a region with the volume produced in that same region in the preceding month. This difference is expressed in a percentage with the volume of the previous month as a reference.

Fluctuations are reported in region months with 5 regions and an analyse period of 30 we have 5 * 12 * 30 = 1800 region months.

- **Strategy 1 – Population weighted Peak Ground Velocity**

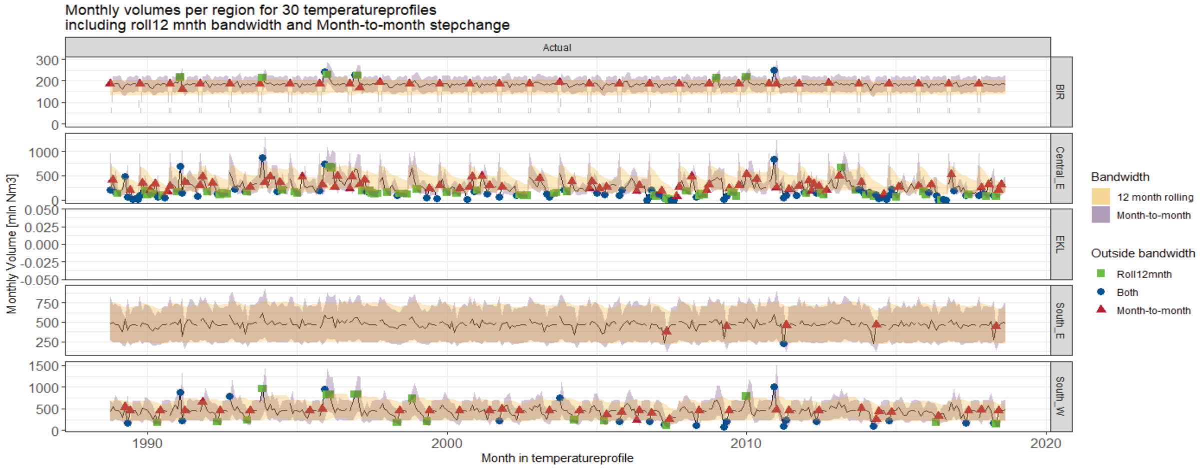



*Figure 3-6* *Strategy 1 production fluctuations for the regions Bierum, Central-East, Eemskanaal, South-East and South-West for both rolling 12 month average and month-to-month indicator. The line shows monthly volume and the area indicates the allowed bandwidth. Exceedance is of bandwidth is indicated with marker (triangle relates to month-to-month, square relates to rolling 12 month and dot relates to both).*

In this operational strategy 403 of the 1800 region months (or 22%) are found with an exceedance of the fluctuation limits. The re-occurring month-to-month exceedance in Bierum is caused by the production stop scheduled in October 2019. The frequent exceedances in region Central-East are caused by the start-up sequence in this strategy.

- **Strategy 2 – Event count**

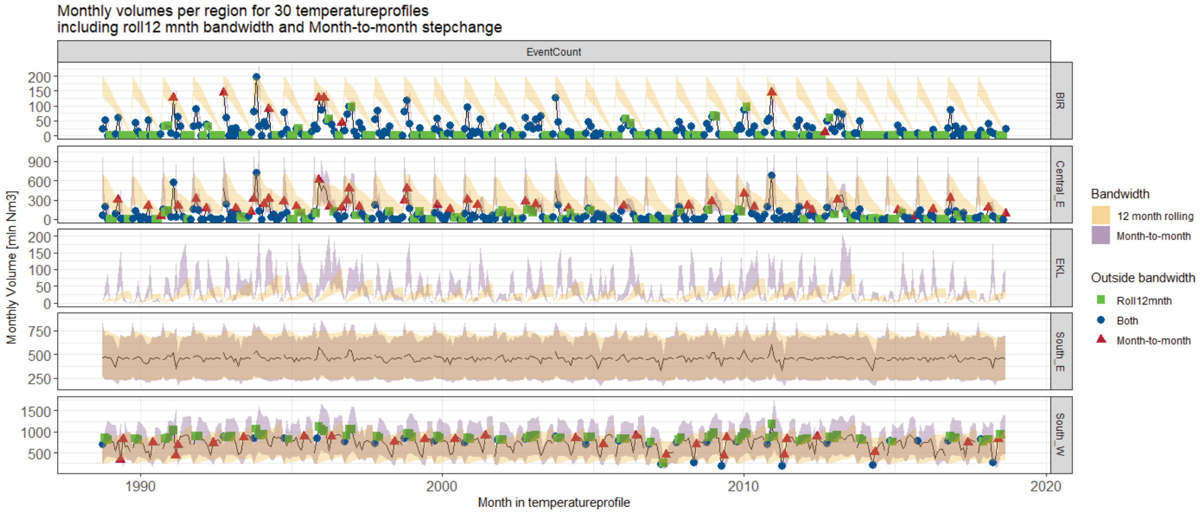



*Figure 3-7* *Strategy 2 production fluctuations for the regions Bierum, Central-East, Eemskanaal, South-East and South-West for both rolling 12 month average and month-to-month indicator. The line shows monthly volume and the area indicates the allowed bandwidth. Exceedance is of bandwidth is indicated with marker (triangle relates to month-to-month, square relates to rolling 12 month and dot relates to both).*

In this operational strategy 828 of the 1800 region months (or 45%) are found with an exceedance of the fluctuation limits. The frequent exceedances in Bierum and Central-East are related to the start-up sequence, as these regions are only used for production in periods with higher Groningen gas demand.

Production fluctuations are (mainly) caused by variation in Groningen volume demand, every operational strategy investigated shows a certain level of occurrences of exceedance. The production fluctuations could be minimized or even set to zero by increasing the volume offtake of the Groningen field.

## Production profiles

### Reference case (IB2018)

As a reference case for the new production profiles, the Basispad Kabinet is used as defined by EZ in the 2/5/2018 Verwachtingenbrief and approved on 14/11/2018 in the Ministerial InstemmingsBesluit (IB2018), Figure 3-8. Note that the history match of the dynamic reservoir model was updated to reflect the actual production up to 31/12/2018. From 1/1/2019 onwards the exact same production (distribution) was imposed on the model. This introduces small differences with respect to the 2018 evaluation of the same profile[5].

Figure 3-9 gives the reservoir pressure at 1/1/2019, and the depletion over the next 5 years (1/1/2019 to 1/1/2024). The pressure starting point has a reasonable gradual gradient within the gas closure (black outline) and lagging depletion within the lateral aquifer. Due to the reducing offtake rates over the next 5 years, pressure depletion in the vicinity of the field is allowed to catch-up a little with respect to the gas closure. There is no production from the FRB/KPD/SLO clusters, nor from the EKL cluster. This allows the higher pressured South-Western Periphery (EKL area) to recharge the South-West area, resulting in a notable absence of depletion in the latter area over the five-year period, Figure 3-10.

[5] As explained in Reference 12, there are small differences between the Basispad Kabinet as issued by the Ministry on 29/3/2018, and the Basispad Kabinet as issued by the Ministry on 2/5/2018 with the Verwachtingenbrief. Specifically for gas-year 2018/2019 at average temperature, a Groningen production volume of 19.4 N.Bcm is quoted on 29/3/2018, based on an average of 85% and 100% nitrogen utilization by GTS. In the supporting GTS analysis (Advies GTS leveringszekerheid middels scenario analyse, 27/3/2018) a volume of 20.6 N.Bcm is quoted at a 85% nitrogen utilization. The 2/5/2018 Verwachtingenbrief quotes a volume of 20.4 N.Bcm. The actual volume used in this analysis is 20.7 N.Bcm, because the models are updated with the actual production for the period October-December 2018 (from January 2019 onwards, the production profile is exactly as per the 2/5/2018 Verwachtingenbrief).

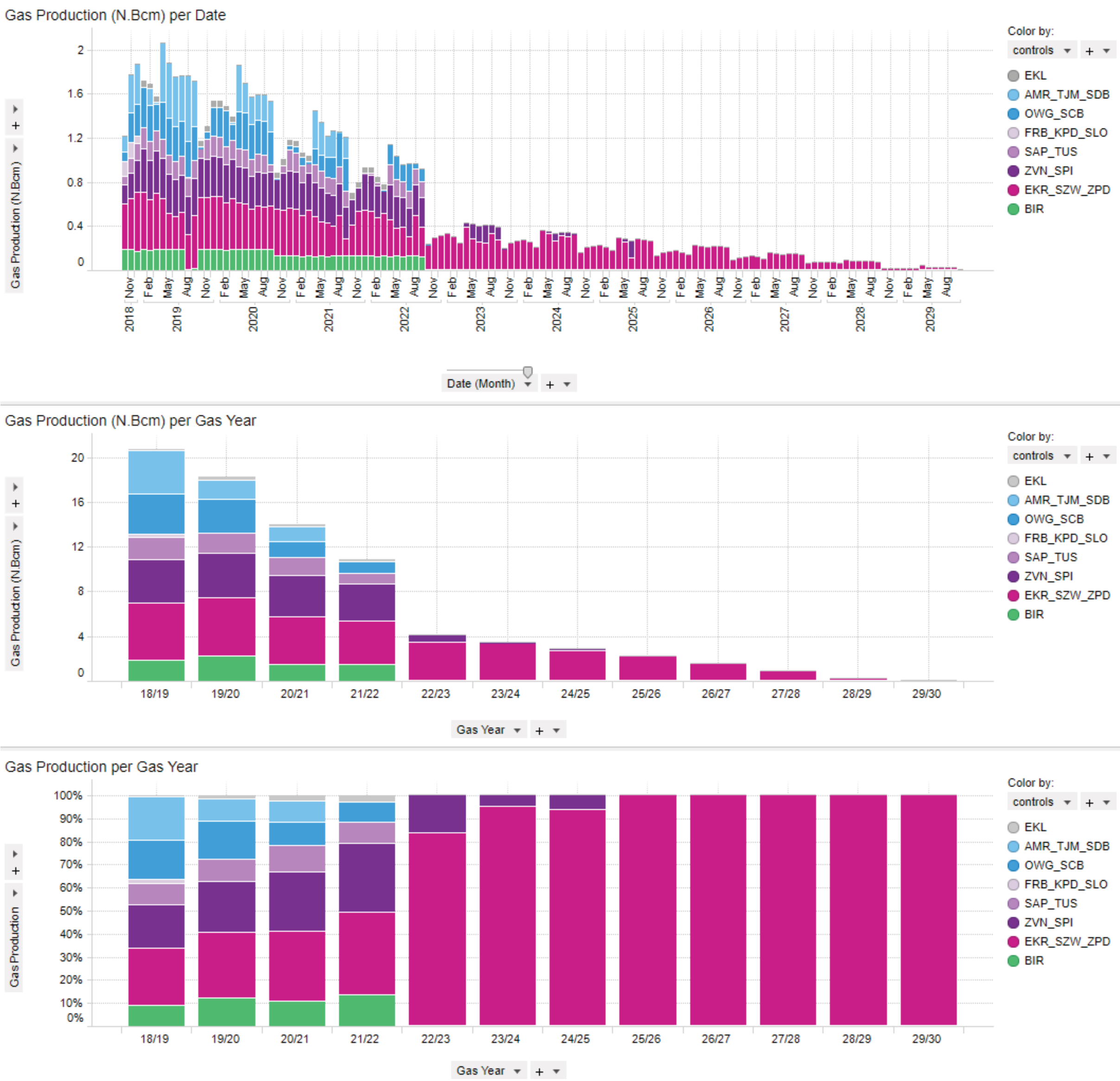



*Figure 3-8:* *Production as per 14/11/2018 Instemmingsbesluit*

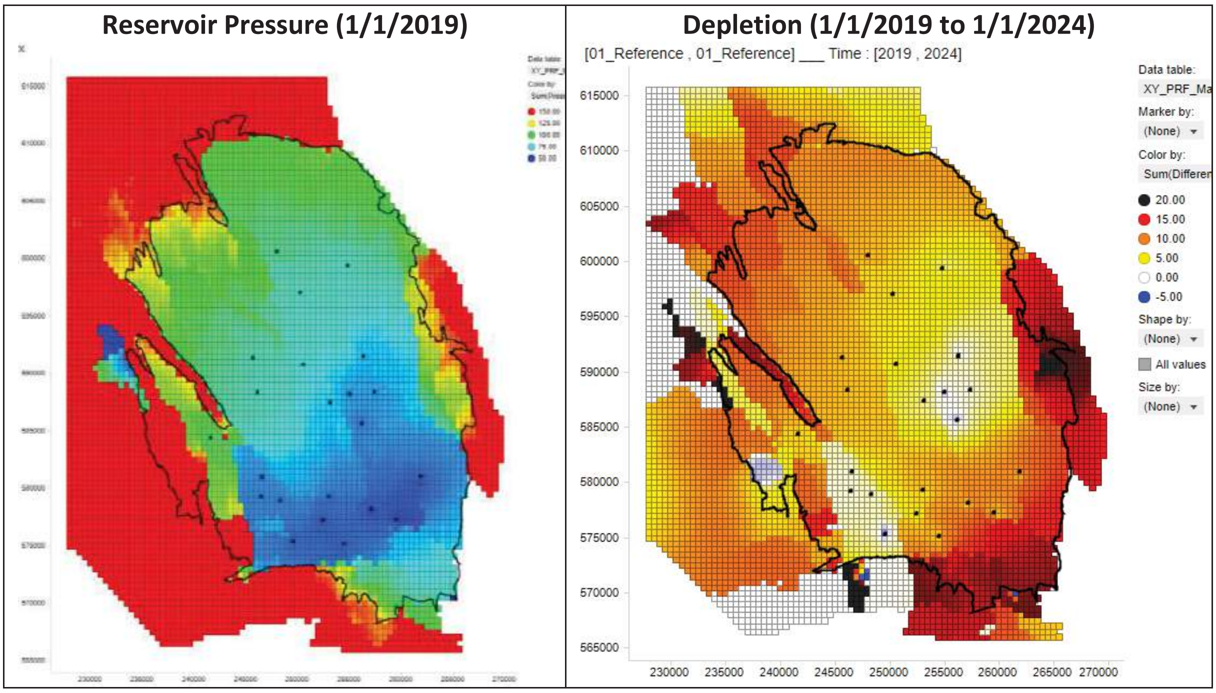



*Figure 3-9: Reservoir pressure at 1/1/2019*

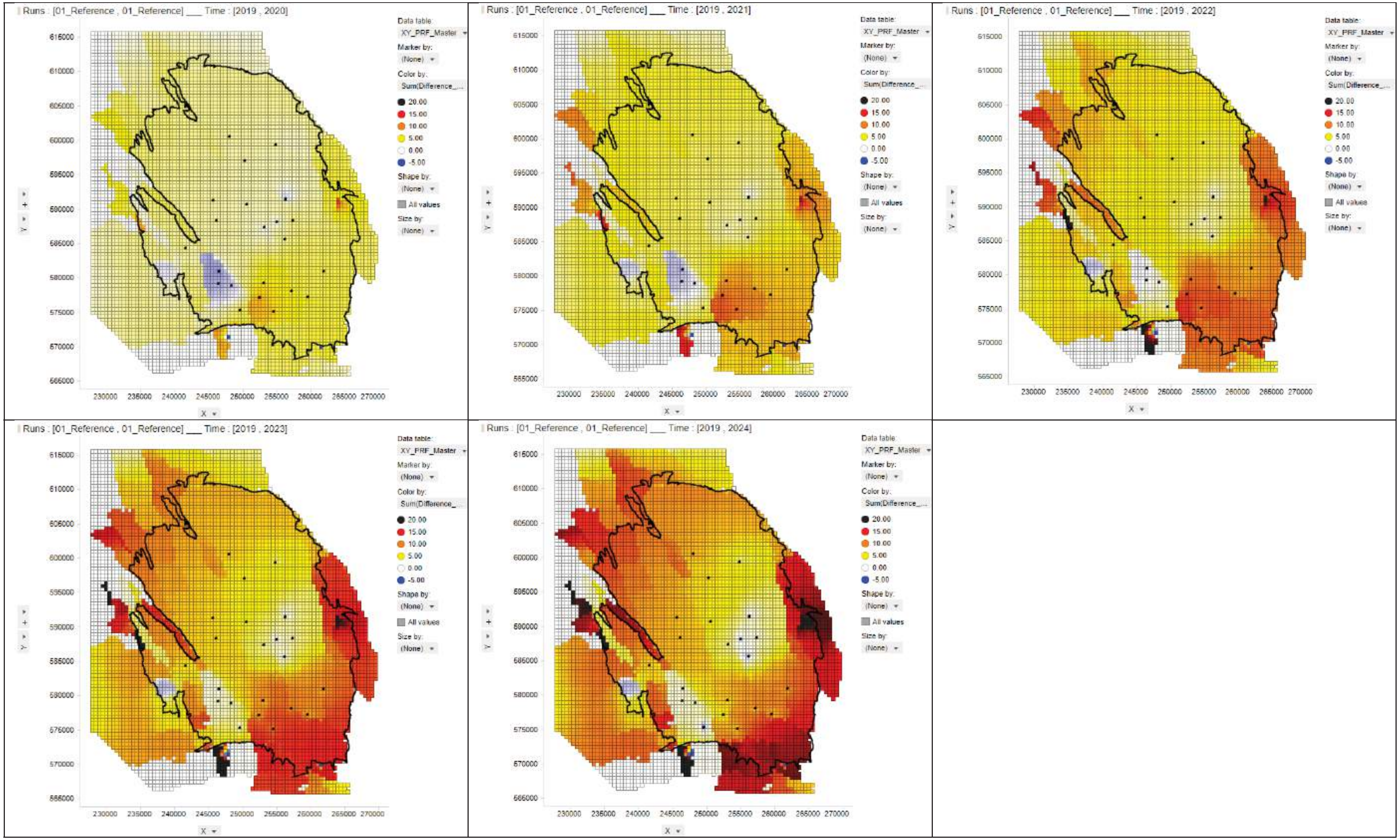



Figure 3-10: *Cumulative depletion from 1/1/2019 for the next 5 calendar years, top left hand graph to 1/1/2020, bottom-centre graph to 1/1/2024*

### Strategy 1 (pwPGV) – Average Temperature

A production overview for Strategy 1 is given in Figure 3-11. Figure 3-12 shows the gas production versus the production capacity by region, and their ratio (Load Factor). It clearly brings out that the South-East area (EKR/SZW/ZPD) is utilized at its maximum assigned Load Factor.

When comparing the associated pressure maps from Strategy 1 (pwPGV) to the reference case (IB2018), the reduction in total volume offtake dominates the reservoir pressure response. Field-wide, there is some 1 bar less depletion by 1/1/2024.


*Figure 3-11: Production distribution for Strategy 1 (pwPGV), Average temperature*

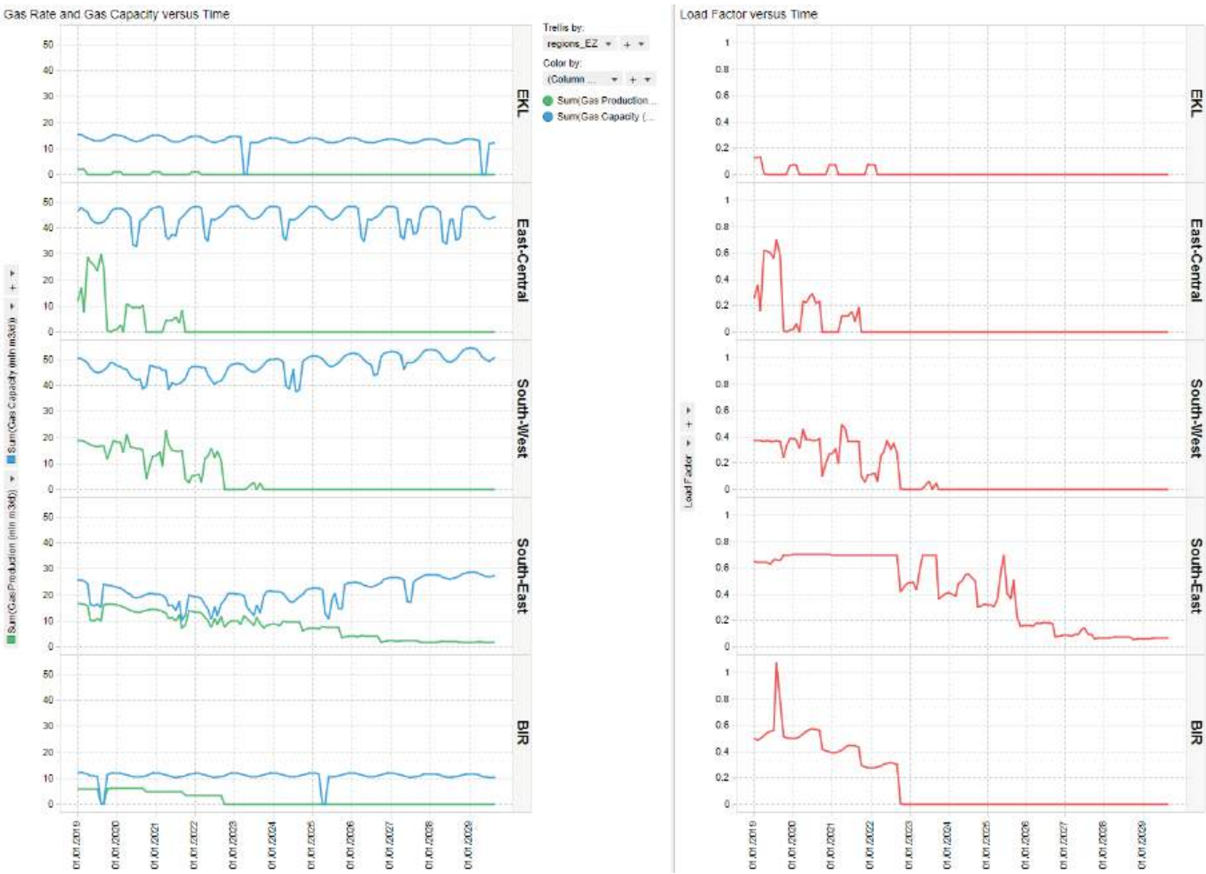



*Figure 3-12:* *Utilisation of the various production regions for the population weighted PGV, average temperature (16_pwPGV_avg)*

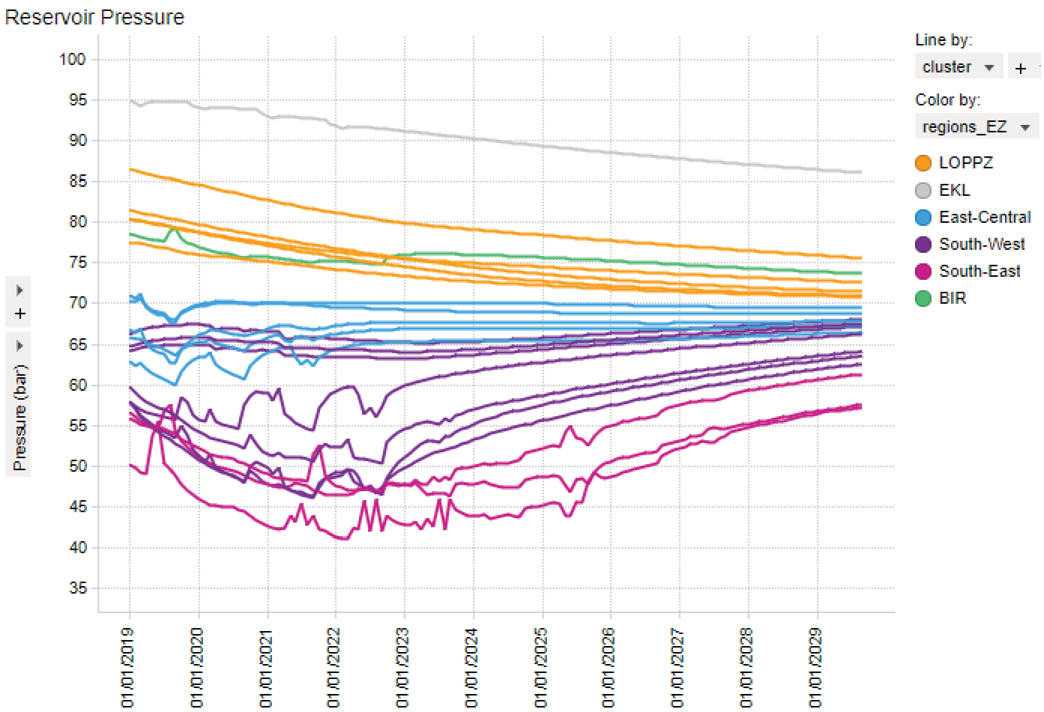



*Figure 3-13:* *Reservoir pressure at the production clusters for Strategy 1 (pwPGV), average temperature.*

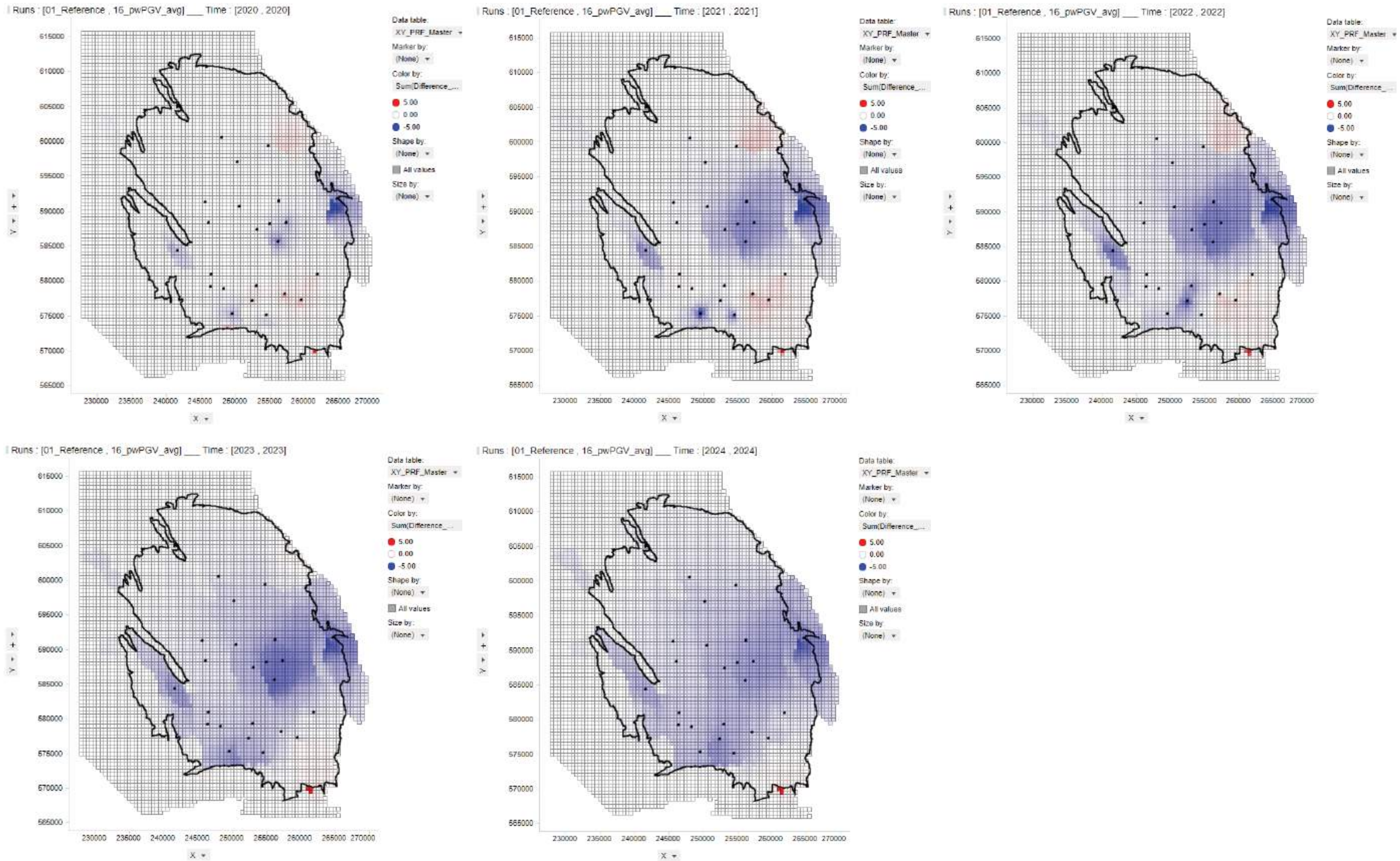



*Figure 3-14: Difference in depletion between Reference case (14/11/2018 Instemmingsbesluit) and Raming GTS 2019 for Strategy 1 (production distribution optimised for pwPGV). Cumulative difference in depletion given from 1/1/2019 for next 5 calendar years, top left-hand graph to 1/1/2020, bottom-centre graph to 1/1/2024.*

## Strategy 1 (pwPGV) – Cold temperature year

For the cold temperature year in gas-year 2019/2020, Strategy 1 starts to call more upon the western-most clusters within the South-West region to meet the production demand (clusters FRB/KPD/SLO). This clearly stands-out in Figure 3-18 for 1/1/2019 and 1/1/2020. In later years, the additional depletion in that area dissipates over the greater gas closure with respect to the average temperature profile.

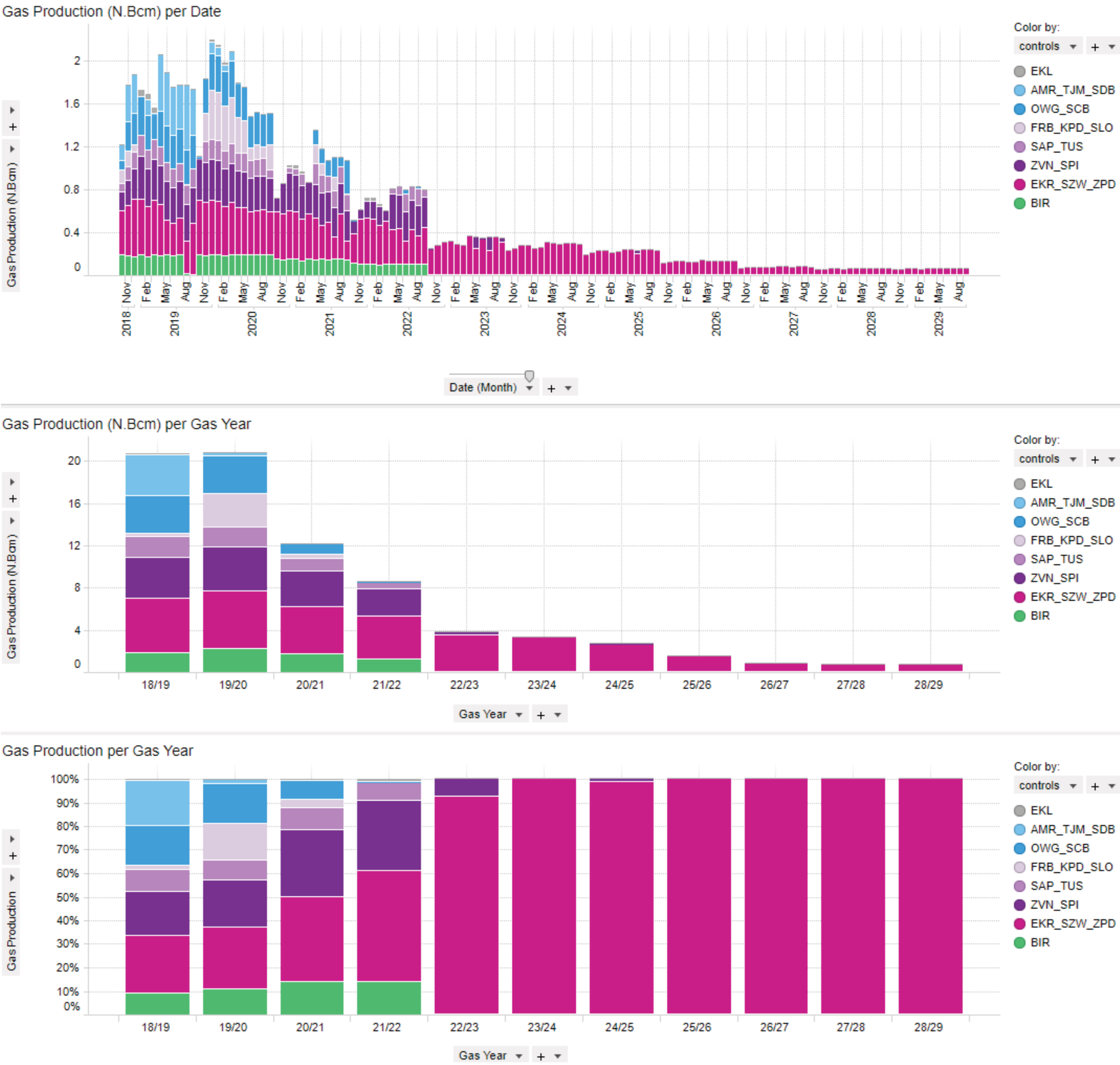



*Figure 3-15: Production distribution for Strategy 1 (pwPGV), cold temperature year.*

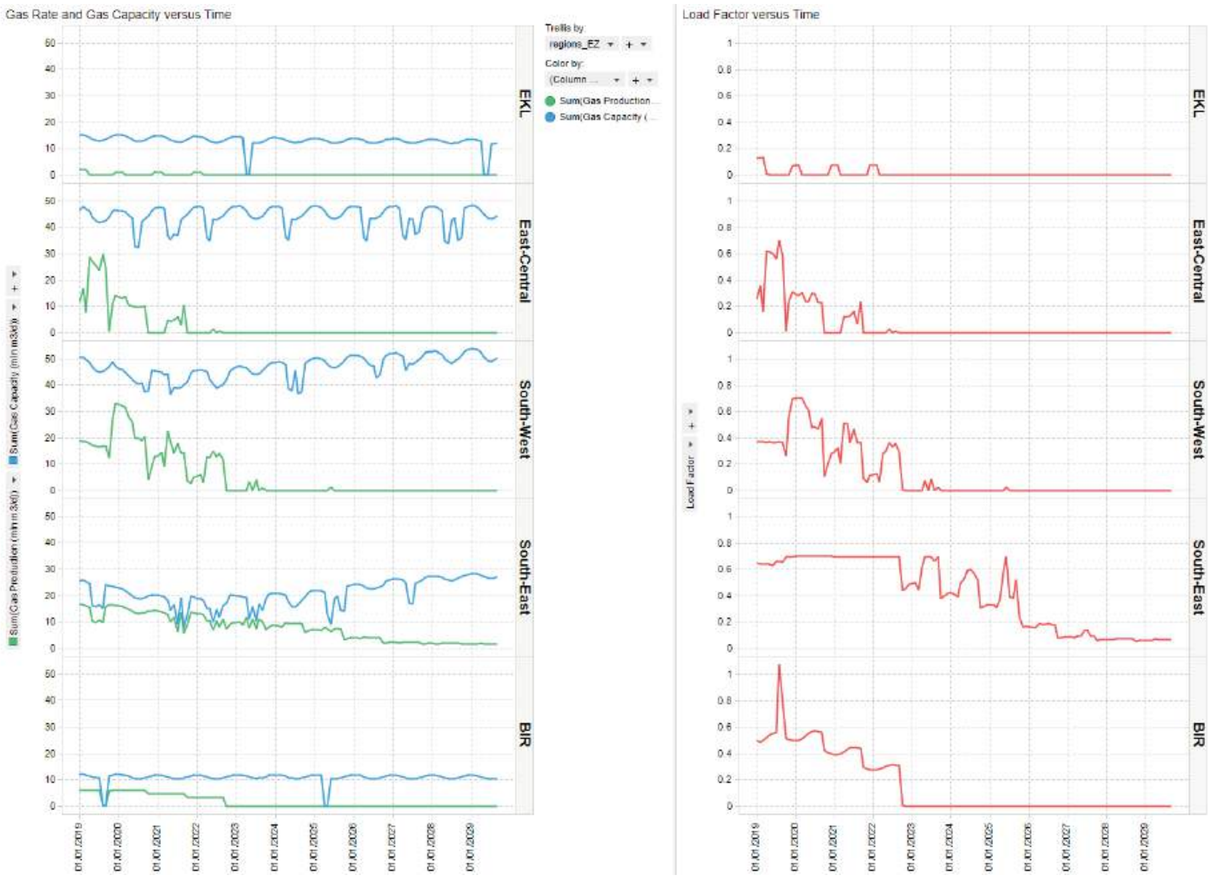



*Figure 3-16: Utilisation of the various production regions for the population weighted PGV, cold temperature year.*

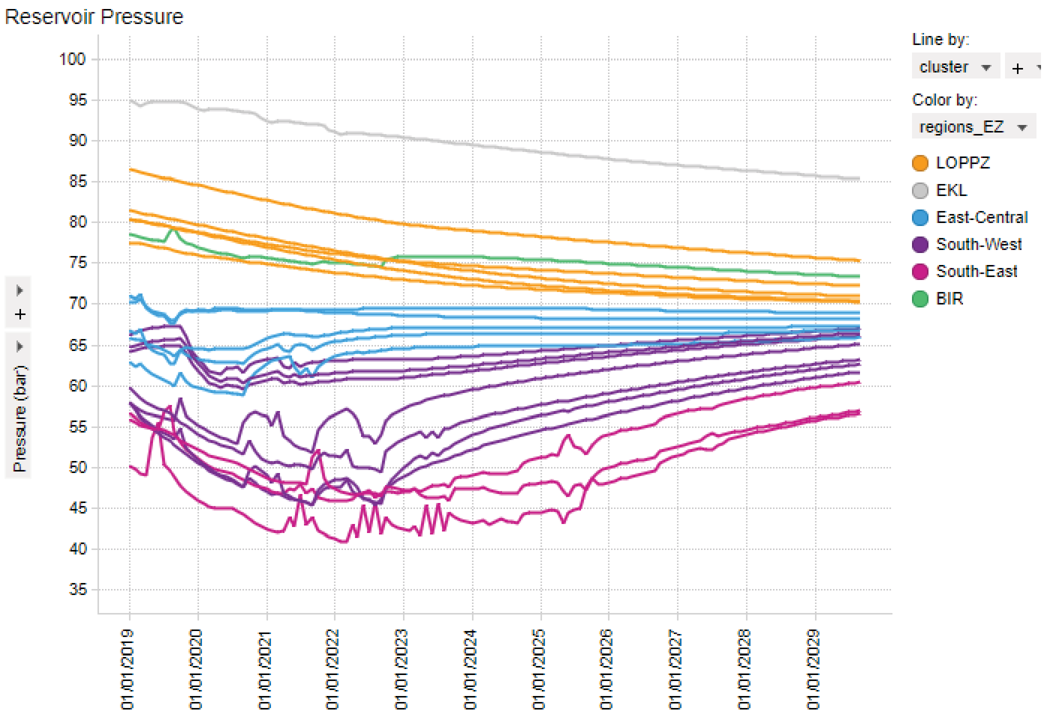



*Figure 3-17: Reservoir pressure at the production clusters for Strategy 1 (pwPGV), cold temperature year.*

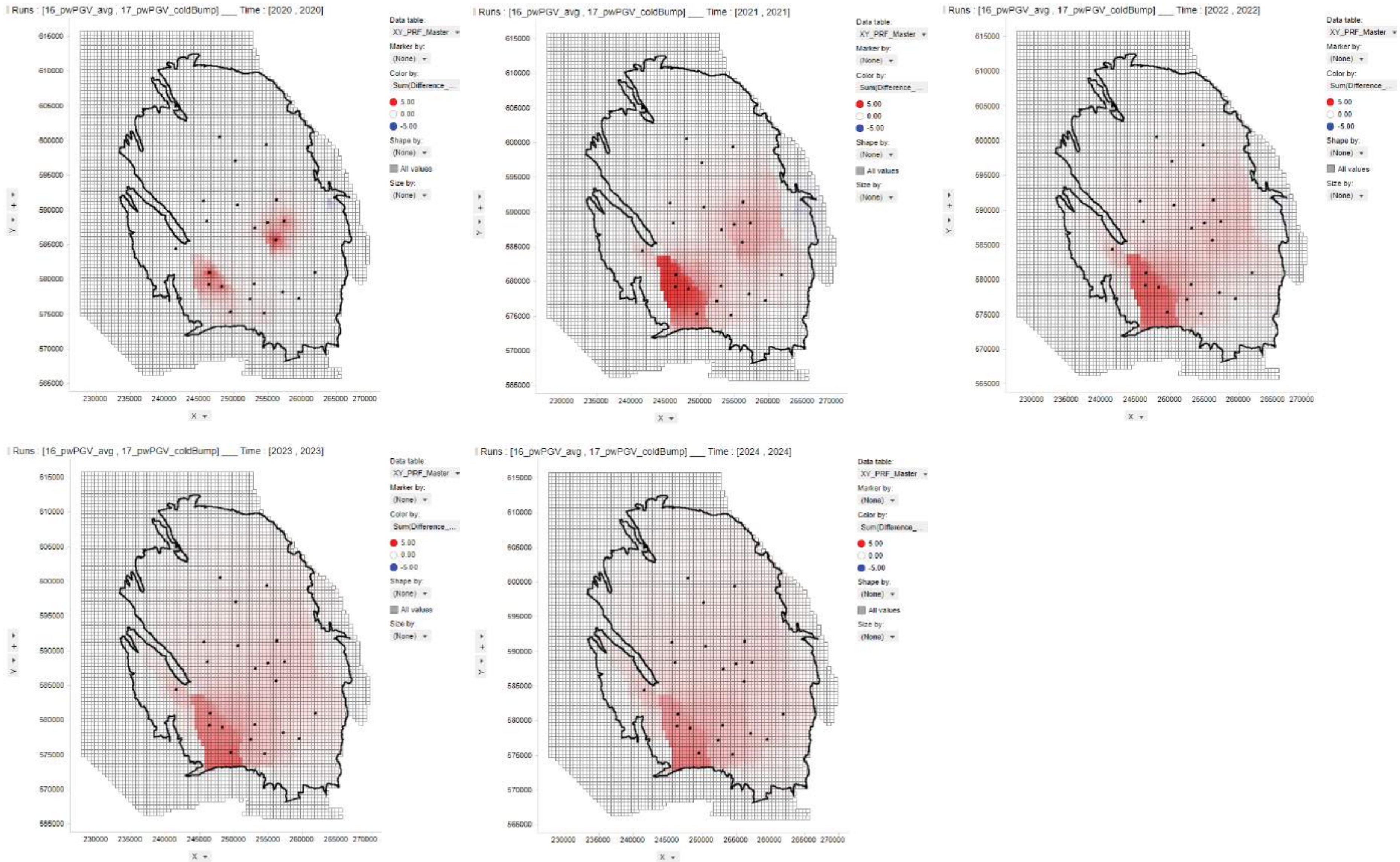



*Figure 3-18: Pressure slices comparing Strategy 1 (pwPGV) for the cold temperature year versus the average temperature profile.*

## Strategy 1 (pwPGV) – Warm temperature year

For the warm temperature year profile, Strategy 1 utilizes the South-West and East-Central regions less as compared to the average temperature profile, Figure 3-19 to Figure 3-22.

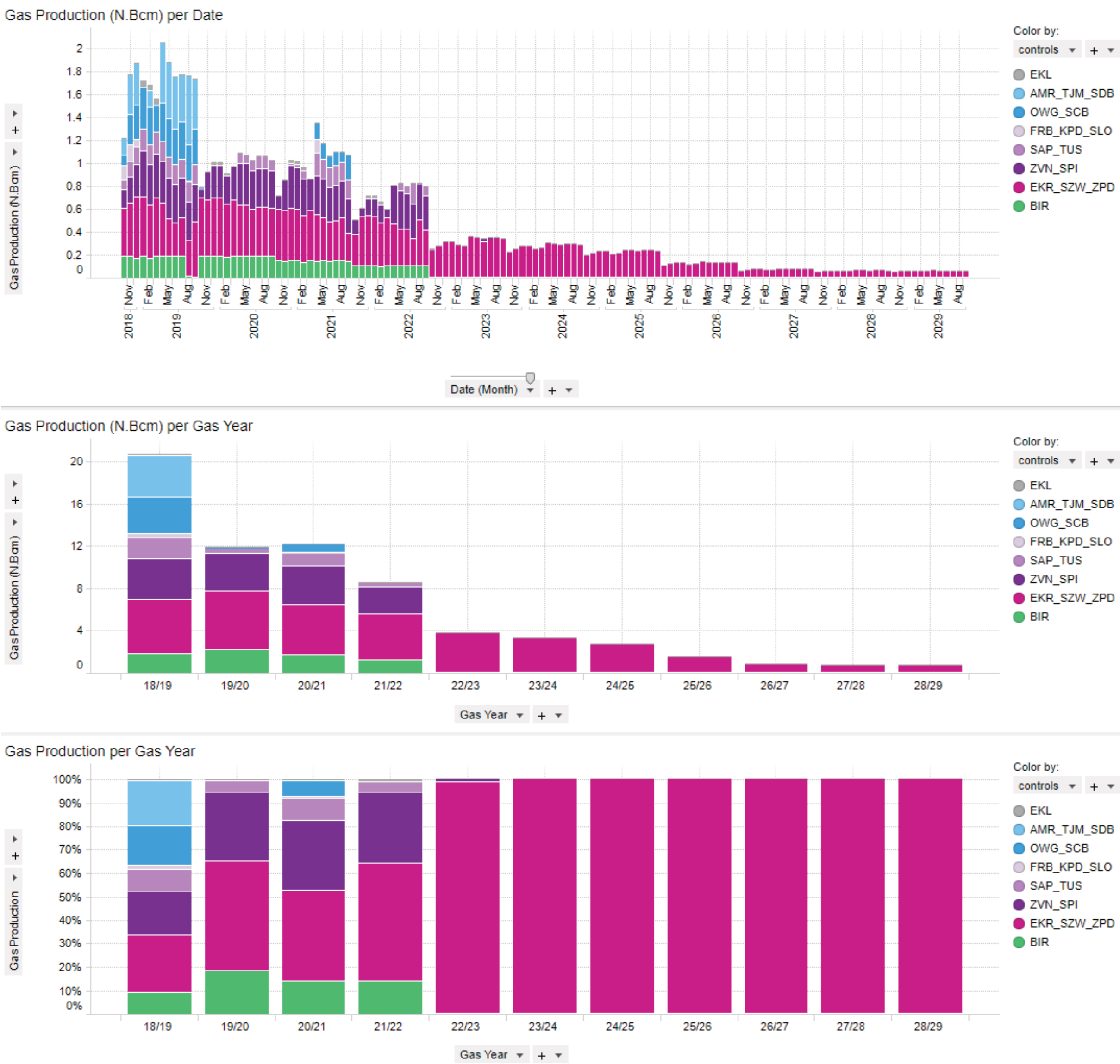



*Figure 3-19: Production distribution for Strategy 1 (pwPGV), warm temperature year.*

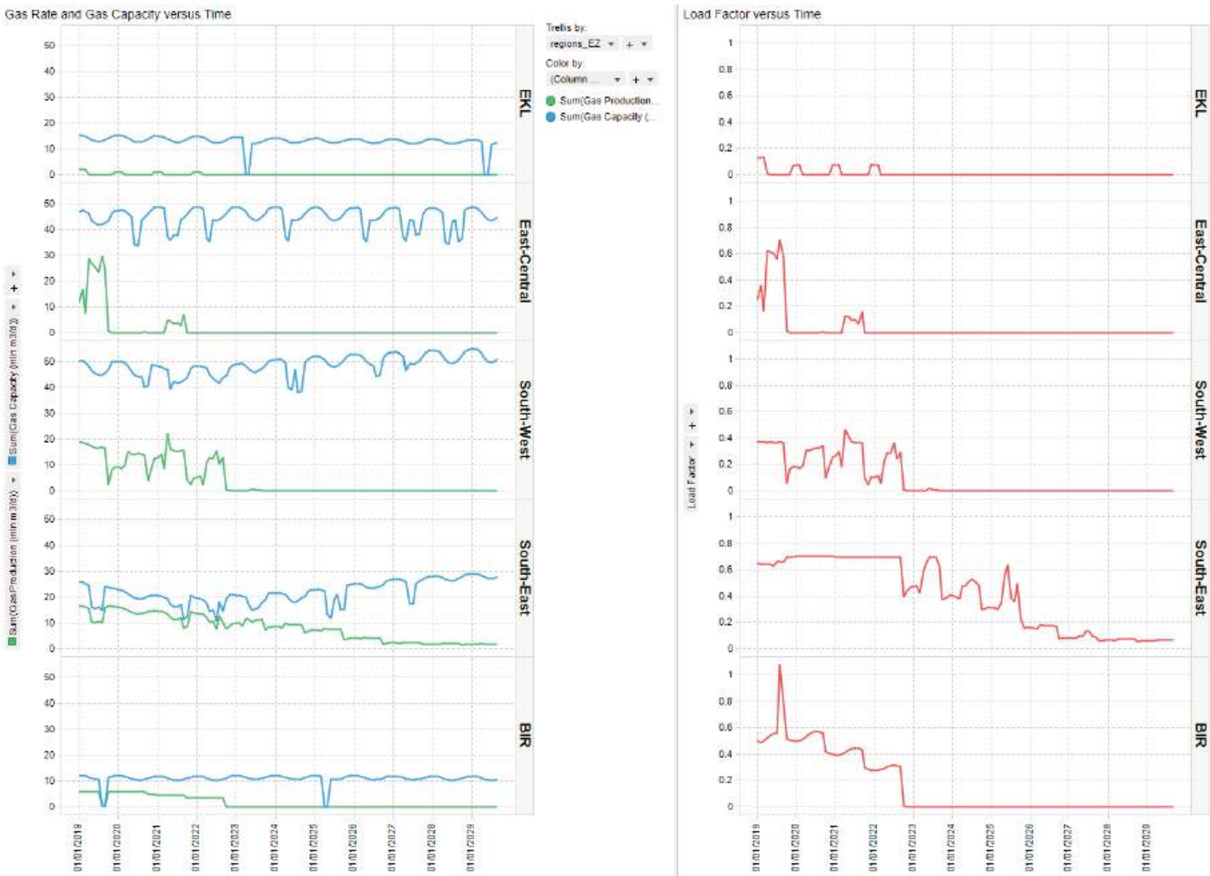



*Figure 3-20: Utilisation of the various production regions for the population weighted PGV, warm temperature year.*

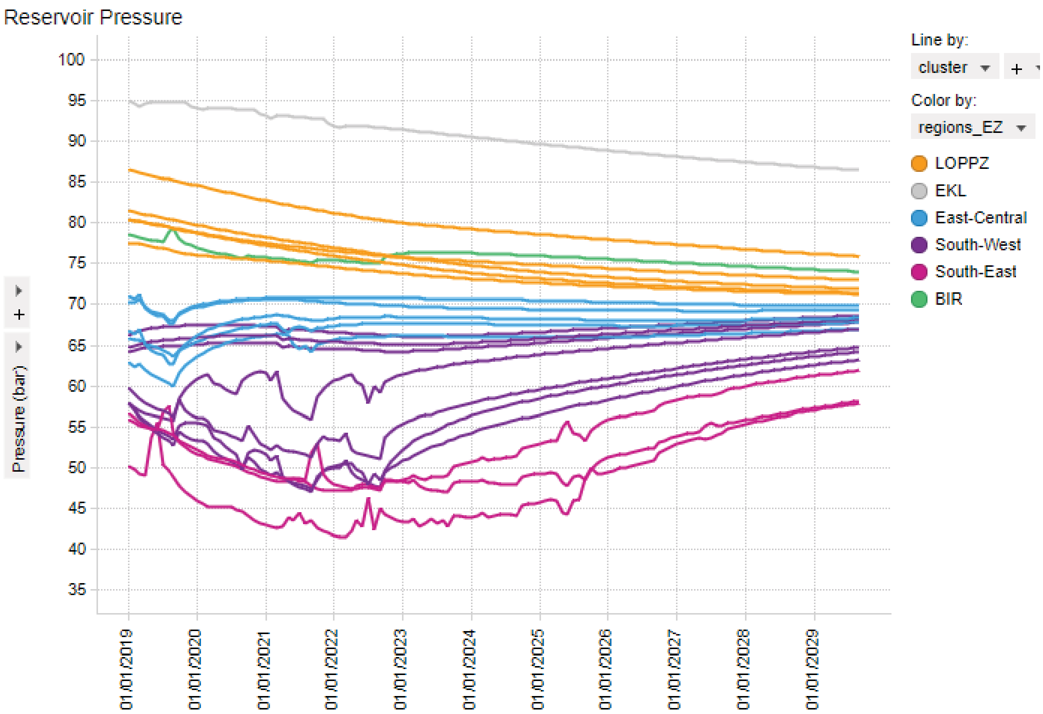



*Figure 3-21: Reservoir pressure at the production clusters for Strategy 1 (pwPGV), warm temperature year.*

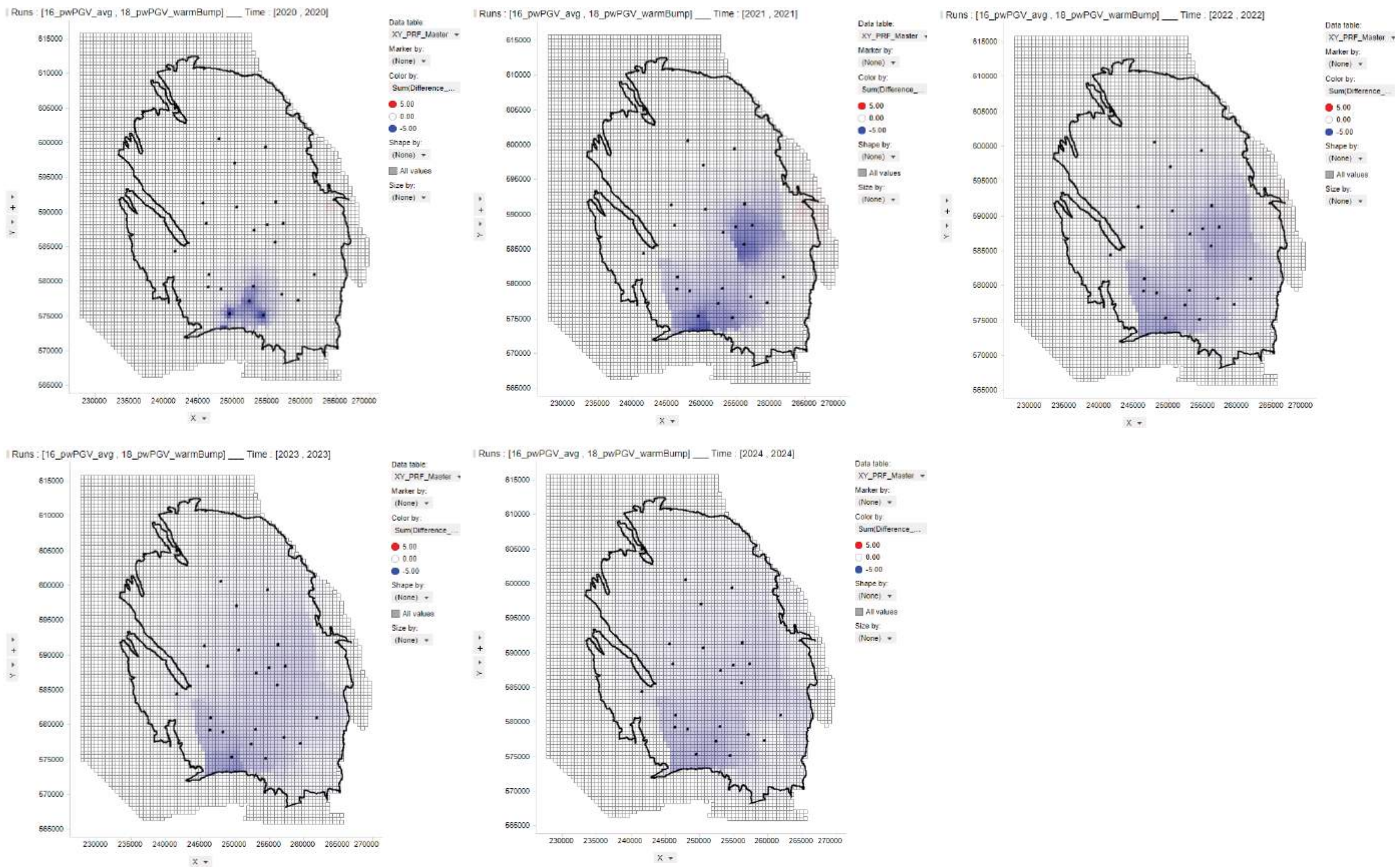



*Figure 3-22: Pressure slices comparing Strategy 1 (pwPGV) for the warm temperature year versus the average temperature profile.*

## Strategy 2 (Event count) – Average Temperature

Strategy 2 optimises for Event count, and targets production along the Southern area of the field, Figure 3-23. It starts production from the South-East and with increasing production demand gradually ramps up towards the South-West. The difference in production strategy clearly stands out from Figure 3-26, showing the increase in depletion in the South-West versus the reduction in depletion in the North-East as compared to Strategy 1 (both for average temperature production).

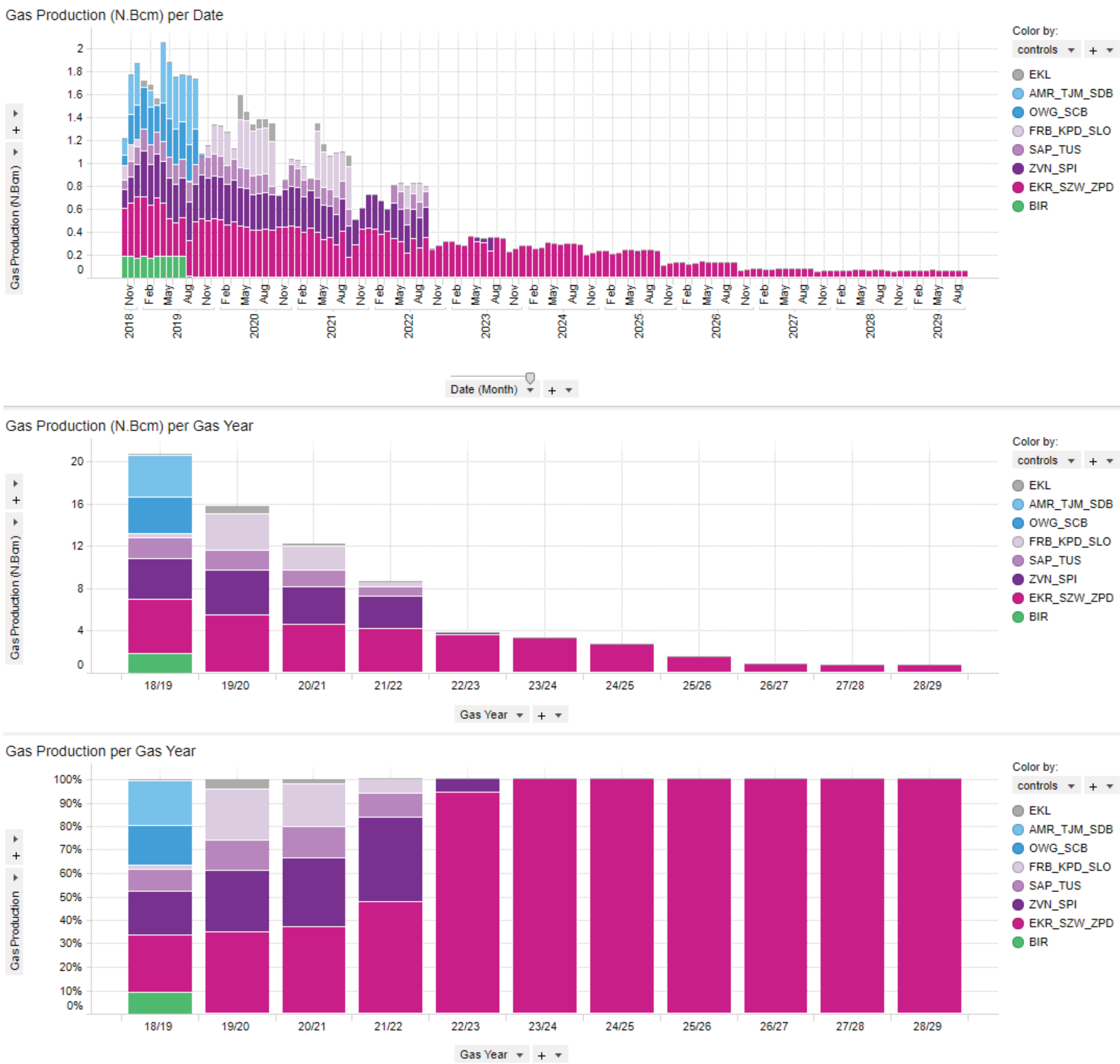



*Figure 3-23:* *Production distribution for Strategy 2 (Event count), average temperature.*

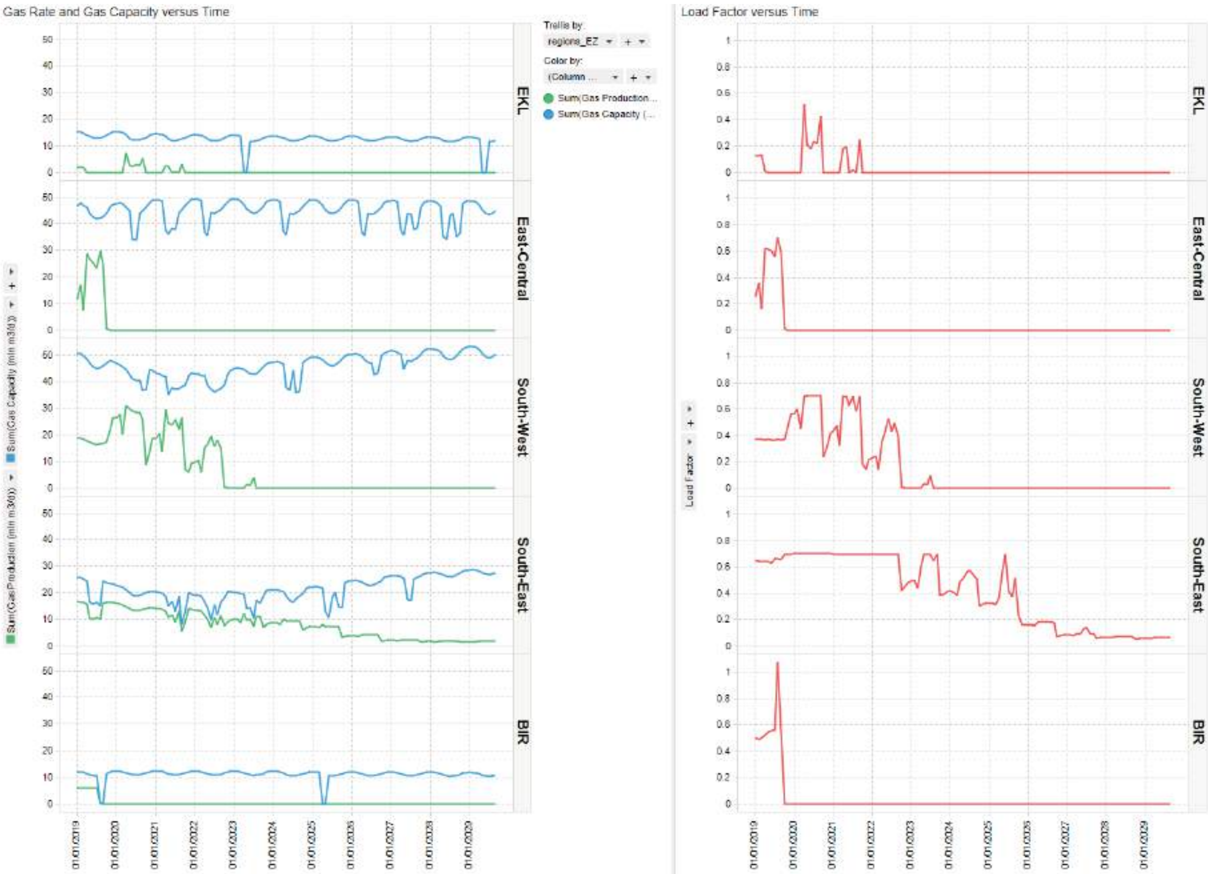



*Figure 3-24: Utilisation of the various production regions for Strategy 2 (Event count), average temperature.*

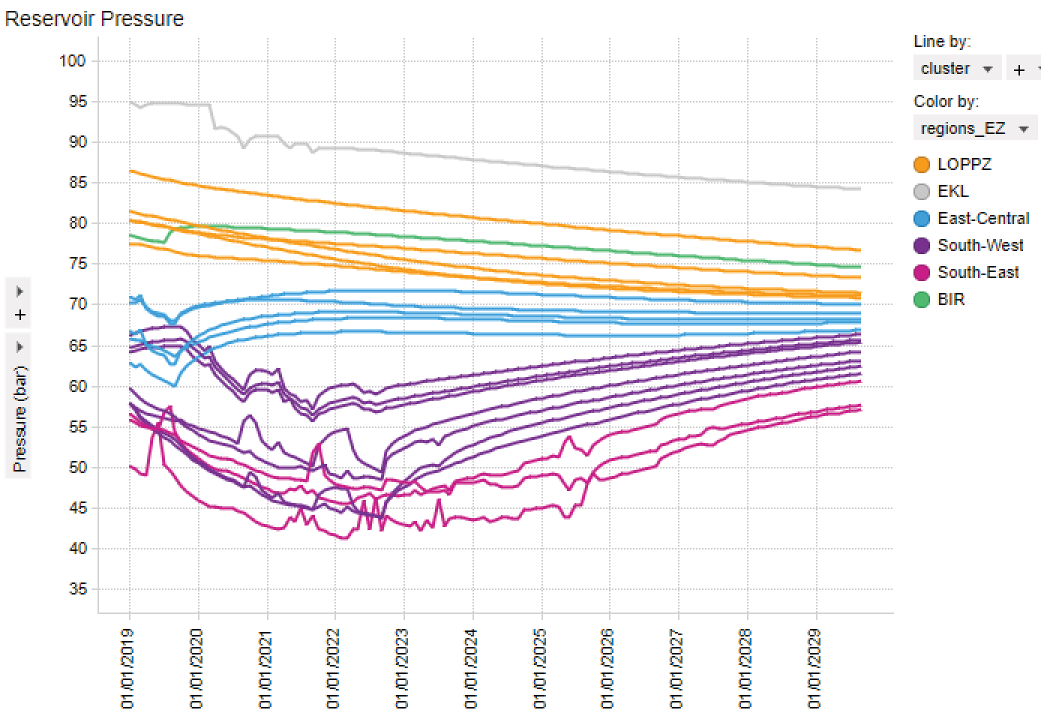



*Figure 3-25: Reservoir pressure at the production clusters for Strategy 2 (Event count), average temperature.*

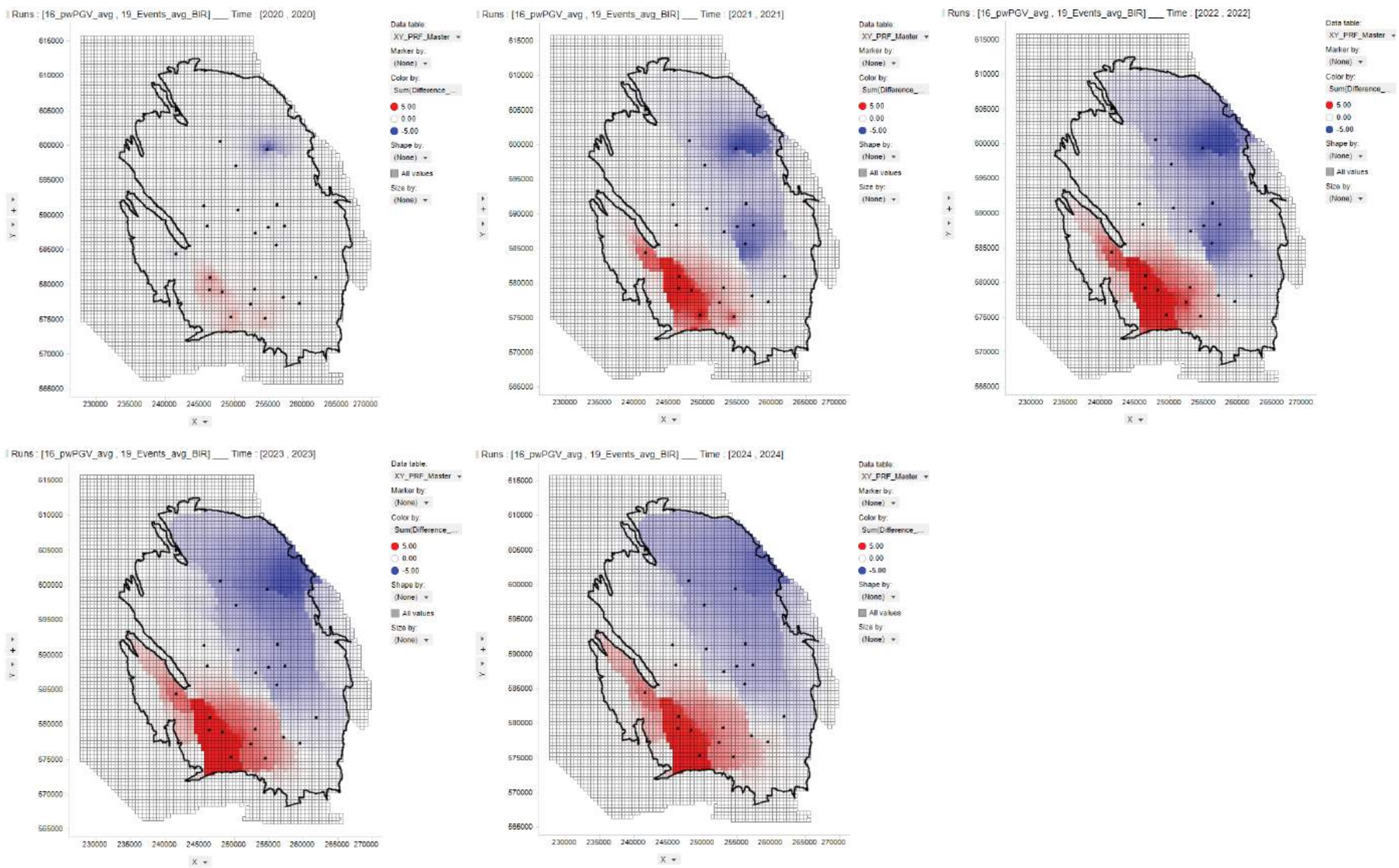



*Figure 3-26:* *Pressure slices comparing Strategy 2 (Event count optimised) to Strategy 1 (pwPGV optimised) for the average temperature production profile*

## Strategy 2 (Event count) – Cold temperature year

For the cold temperature profile, production from all Southern clusters is maximized up to the 70% load factor, after which the East-Central clusters are opened up (OWG/SCB). The differences in depletion with respect to Strategy 1 are quite distinct, see Figure 3-30. Especially the significant production from the Eemskanaal cluster yields some additional 5 bar of depletion in that area as compared to Strategy 1.

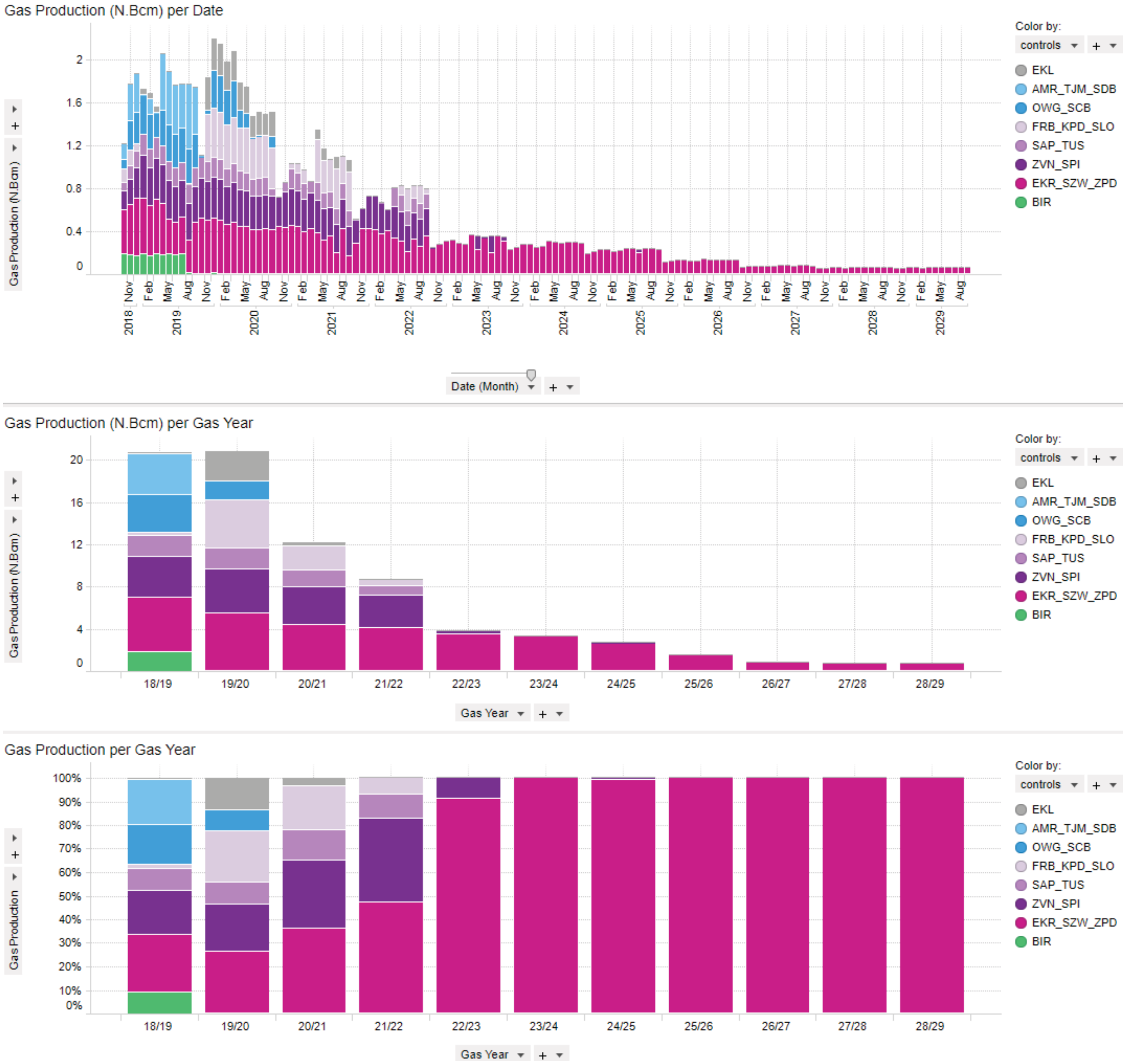



*Figure 3-27: Production distribution for Strategy 2 (Event count), cold temperature year*

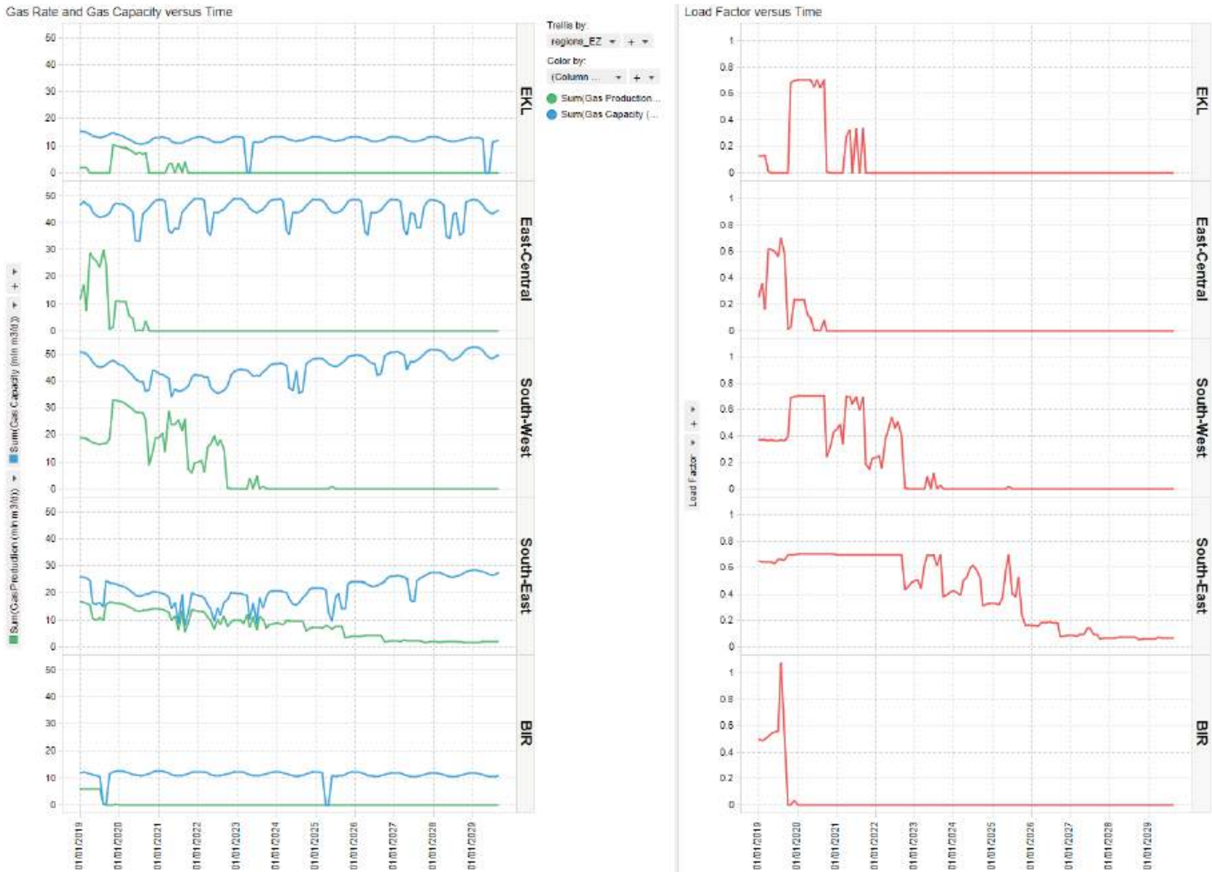



*Figure 3-28: Utilisation of the various production regions for Strategy 2 (Event count), cold temperature year.*

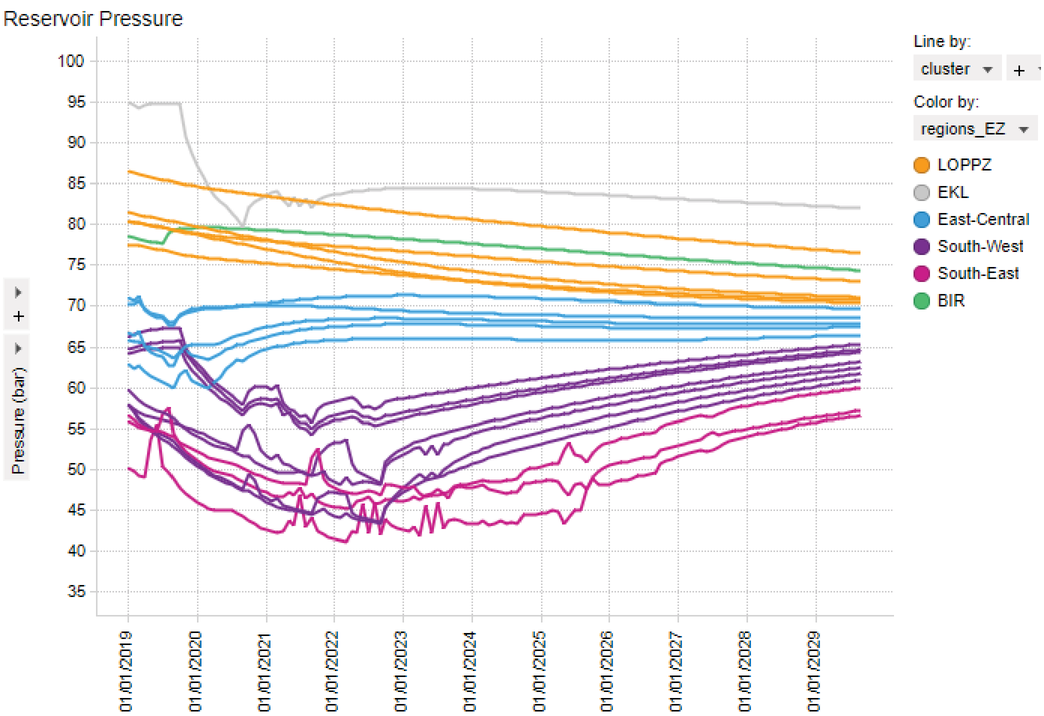



*Figure 3-29: Reservoir pressure at the production clusters for Strategy 2 (Event count), cold temperature year*

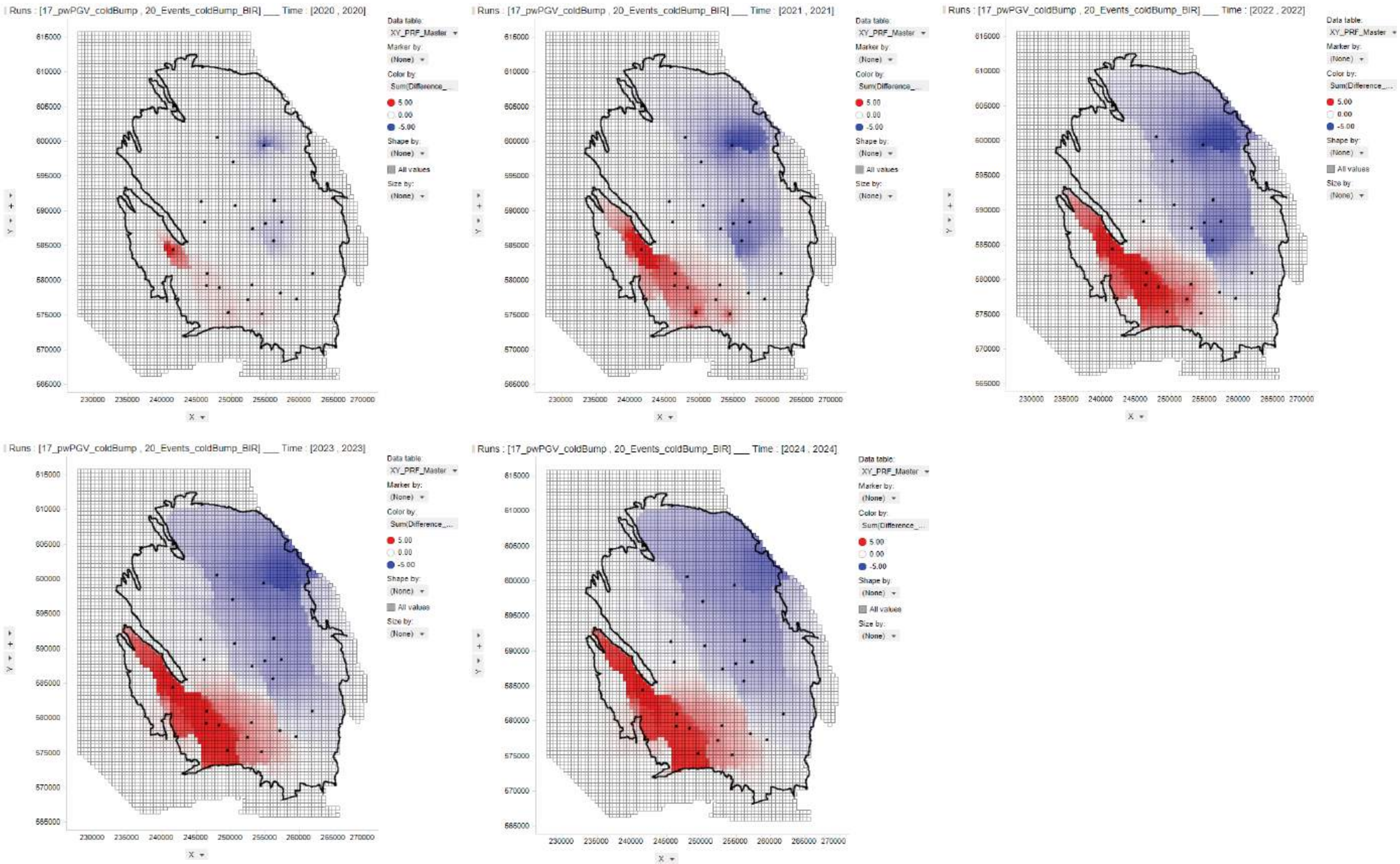



*Figure 3-30:* *Pressure slices comparing Strategy 2 (Event count optimised) to Strategy 1 (pwPGV optimised) for the cold spell temperature production profile.*

## Strategy 2 (Event count) – Warm temperature year

For the warm temperature year, the requested production rates do not require utilization beyond the western-most group of clusters within the South-West region from the start-up list, Figure 3-31. The Eemskanaal cluster is not produced, leaving the South-West Periphery unchanged with respect to Strategy 1, Figure 3-34.

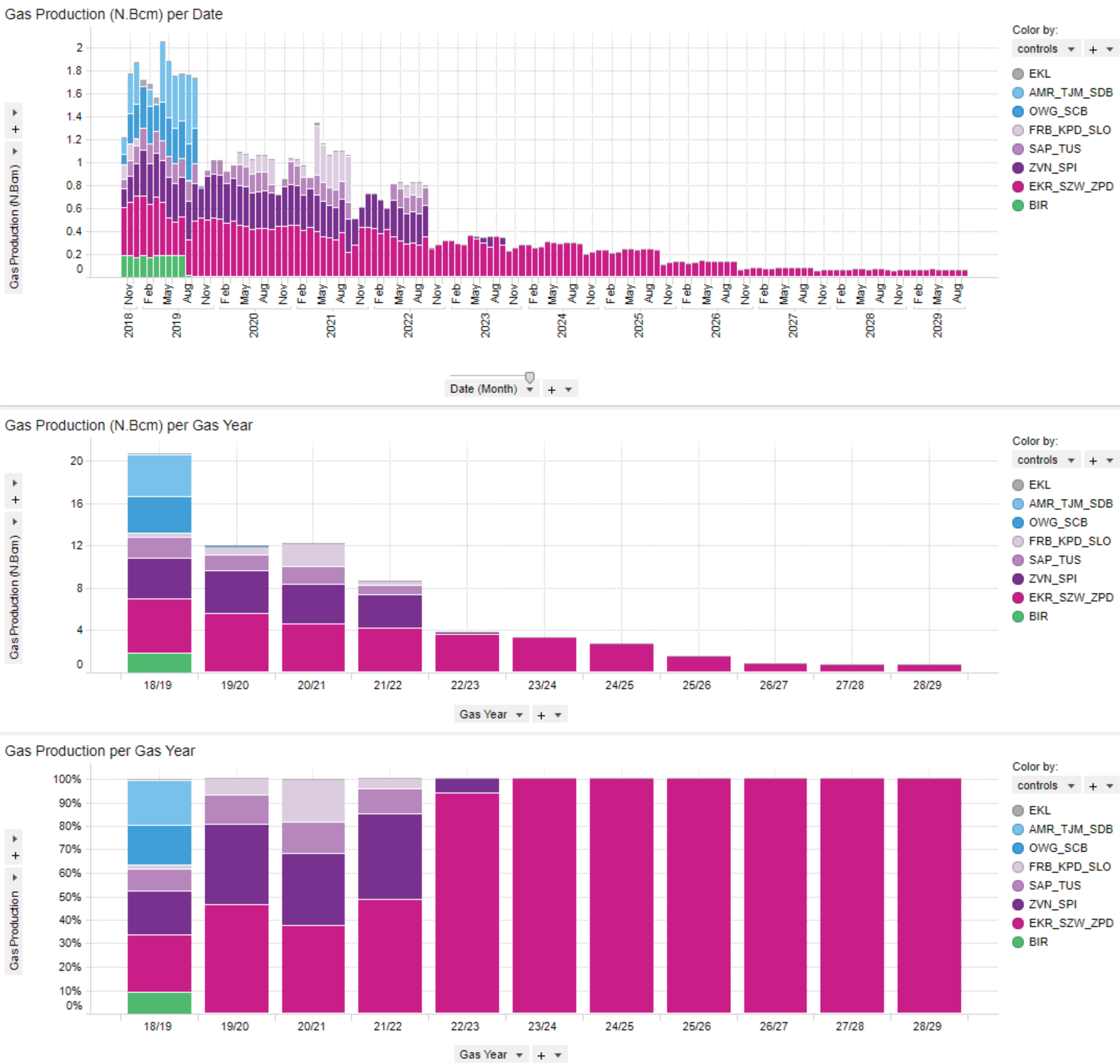



*Figure 3-31: Production distribution for Strategy 2 (Event count), warm temperature year*

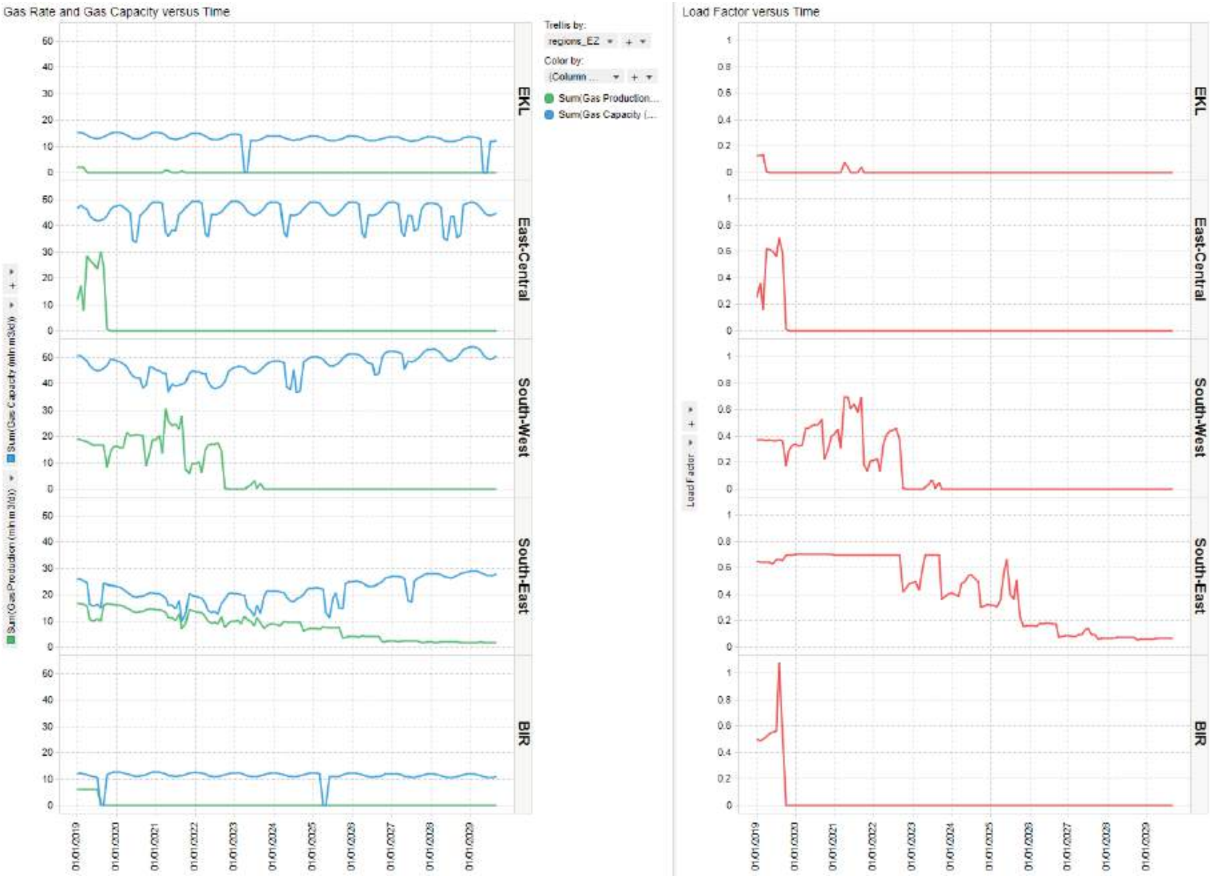



*Figure 3-32: Utilisation of the various production regions for Strategy 2 (Event count), warm temperature year.*

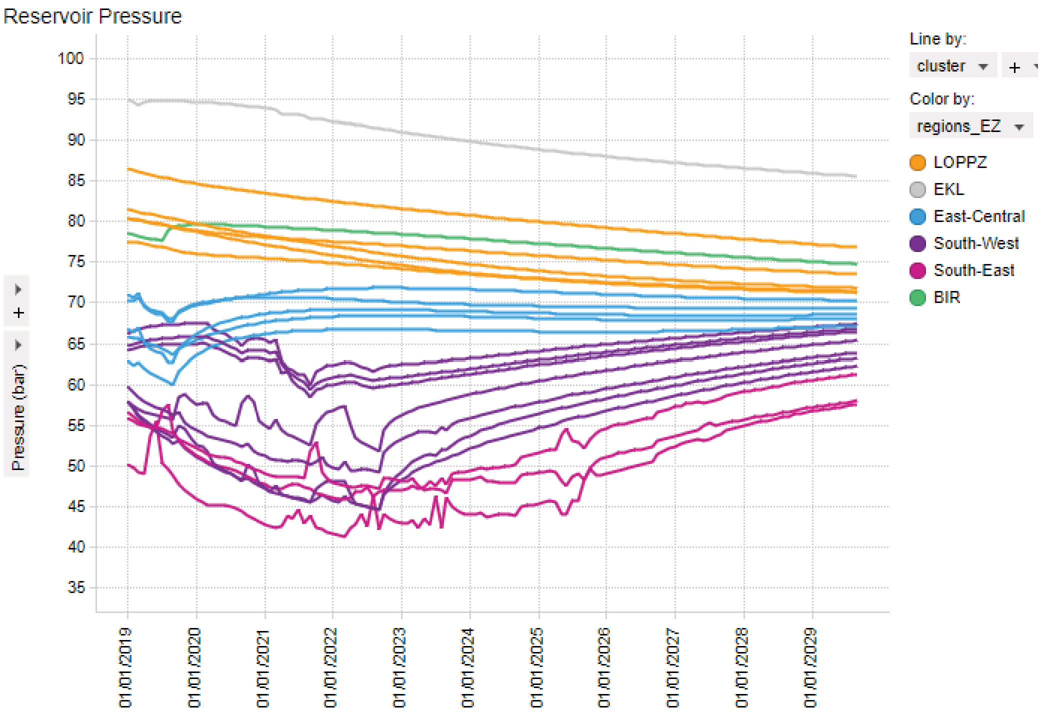



*Figure 3-33: Reservoir pressure at the production clusters for Strategy 2 (Event count), warm temperature year*

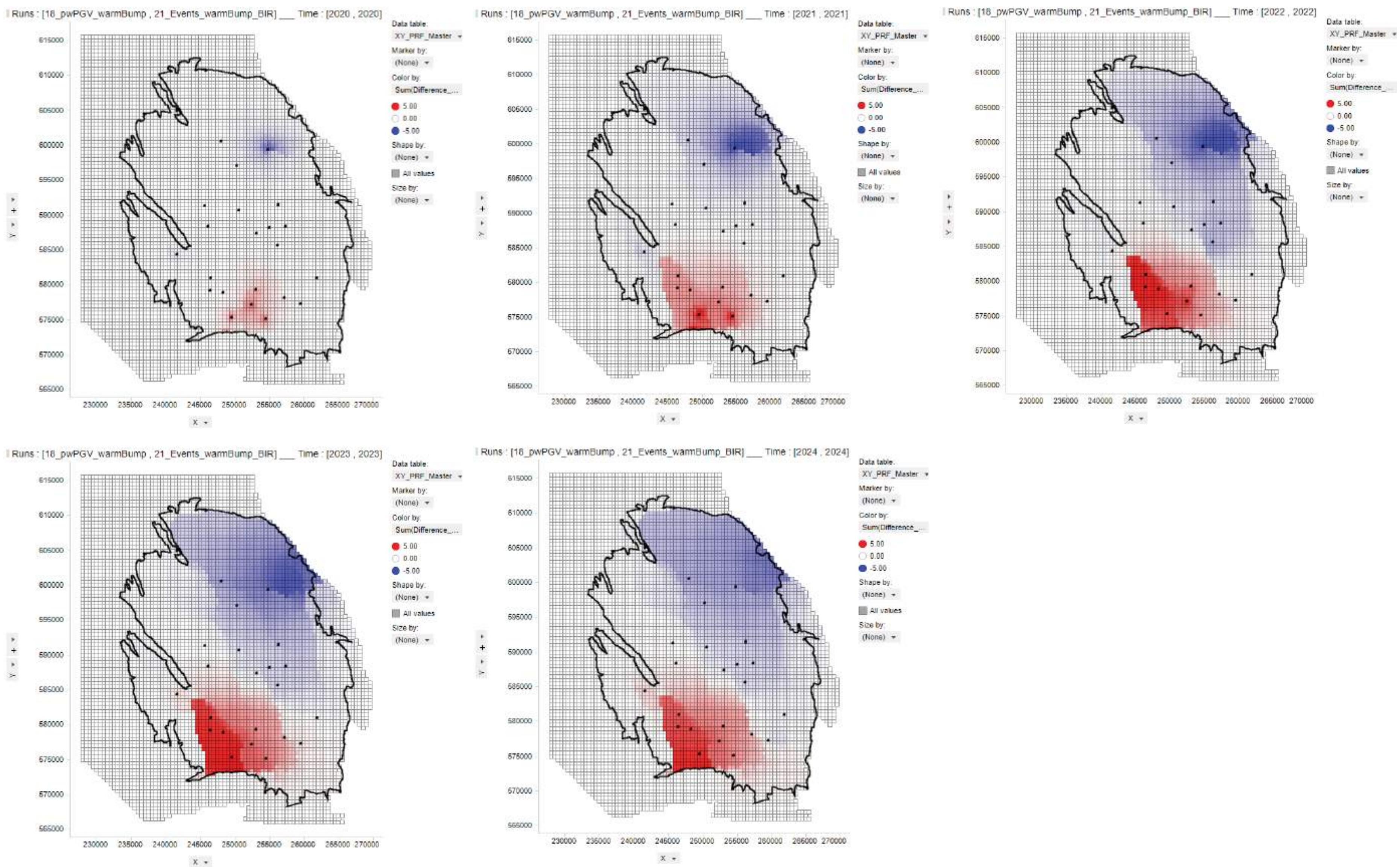



*Figure 3-34: Pressure slices comparing Strategy 2 (Event count optimised) to Strategy 1 (pwPGV optimised) for the warm spell temperature production profile.*

# 4 Event Rate and Hazard Assessment

## Event rate forecast

Based on the production profiles GTS-raming 2019, 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 “GTS-raming 2019” average temperature profile. After an initial plateau of about 16 earthquakes per year until 2020, the seismic activity rate starts to decline. This is a consequence of the decreasing gas production, which accelerates after the new nitrogen blending plant comes on stream.

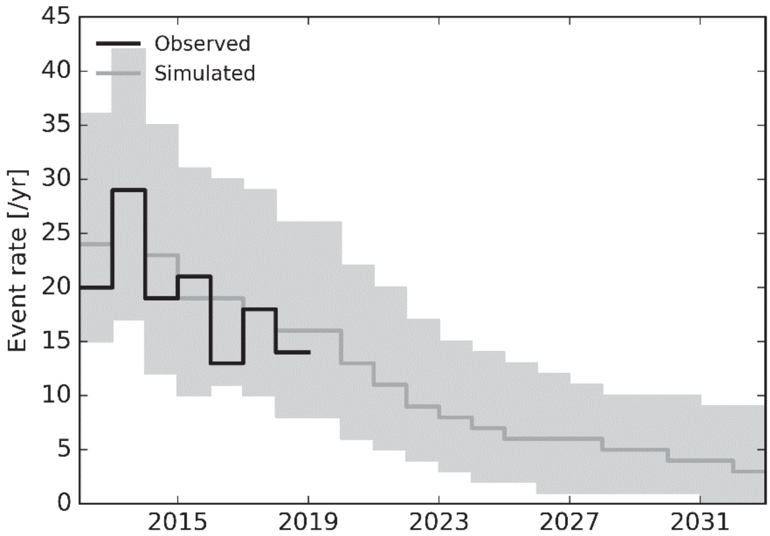



*Figure 4-1* *Seismic Activity Rate of earthquakes for the period 2012 to 2032 (production profile GTS-raming 2019 – average temperature year and production distribution optimisation based on minimisation of the event count). The dark grey line indicates the expected number of earthquakes in each year and the grey area the uncertainty band. This figure is based on the central branch of the Mmax distribution for the Average temperature profile.*

The seismic activity rate declines to an expected 3 earthquakes per year in 2032, with an uncertainty range of 0 to 9 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. 6).

The expected impact of temperature uncertainty is within the uncertainty band for event rate of the average temperature profile. In figure 4.2 the seismic activity rate for three profiles is shown; the average temperature profile, an average temperature profile with gas-year 2019-2020 a cold year and an average temperature profile with gas-year 2019-2020 a warm year. Especially in calendar year 2020 the activity rate is higher for the cold year profile (16 earthquakes) than for the average temperature profile (14 earthquakes) and lower for the warm year profile (12 earthquakes).

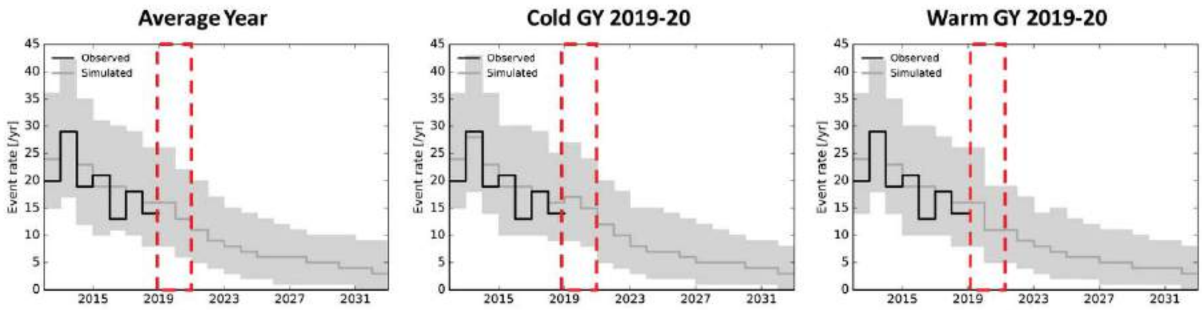



*Figure 4-2 The seismic activity rate for three production profiles; (left) the average temperature profile, (middle) an average temperature profile with gas-year 2018-2019 a cold year and (right) an average temperature profile with gas-year 2018-2019 a warm year.*
*These differences in seismic activity rate between the temperature profiles are smaller than the uncertainty band for the average temperature profile.*

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 2019 with a magnitude exceeding $M_L$=3.6 (the magnitude of the Huizinge earthquake) is equal to 13%.

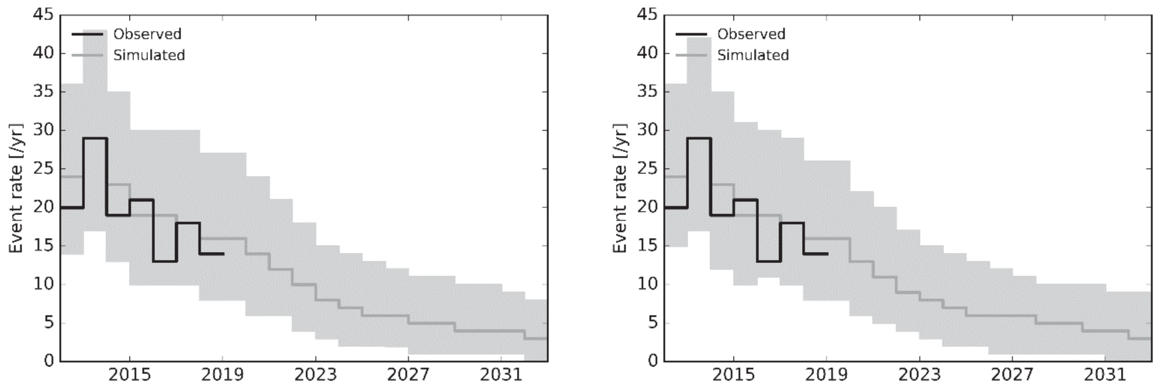
| Year | P(M>=3.6) | P(M>=4.0) | P(M>=4.5) | P(M>=5.0) |
|---|---|---|---|---|
| 2019 | 12.57% | 4.69% | 0.97% | 0.18% |
| 2020 | 10.62% | 3.93% | 0.86% | 0.15% |
| 2021 | 9.74% | 3.70% | 0.76% | 0.14% |
| 2022 | 7.84% | 3.01% | 0.64% | 0.14% |
| 2023 | 6.64% | 2.53% | 0.53% | 0.11% |
| 2024 | 6.01% | 2.24% | 0.48% | 0.08% |
| 2025 | 5.52% | 2.15% | 0.45% | 0.08% |
| 2026 | 4.94% | 1.90% | 0.40% | 0.08% |
| 2027 | 4.36% | 1.57% | 0.36% | 0.07% |
| 2028 | 4.21% | 1.56% | 0.32% | 0.07% |

*Table 4.1a Table with annual probabilities for occurrence of earthquakes exceeding a set magnitude. This table is for production profile GTS-raming 2019, average temperature and operational strategy 1.*

| Year | P(M>=3.6) | P(M>=4.0) | P(M>=4.5) | P(M>=5.0) |
|---|---|---|---|---|
| 2019 | 12.25% | 4.63% | 0.99% | 0.20% |
| 2020 | 9.99% | 3.78% | 0.77% | 0.13% |
| 2021 | 9.00% | 3.28% | 0.74% | 0.14% |
| 2022 | 7.62% | 2.86% | 0.65% | 0.12% |
| 2023 | 6.57% | 2.51% | 0.56% | 0.10% |
| 2024 | 6.11% | 2.24% | 0.48% | 0.09% |
| 2025 | 5.76% | 2.15% | 0.46% | 0.09% |
| 2026 | 5.09% | 1.88% | 0.42% | 0.09% |
| 2027 | 4.92% | 1.88% | 0.37% | 0.08% |
| 2028 | 4.52% | 1.72% | 0.38% | 0.05% |

*Table 4.1b Table with annual probabilities for occurrence of earthquakes exceeding a set magnitude. This table is for production profile GTS-raming 2019, average temperature and operational strategy 2.*

The event rate for both operational strategies are compared in figure 4.3. The mean event rate is very similar for both operational strategies. The uncertainty band around the mean event rate shows slight differences.




**Operational Strategy 1** **Operational Strategy 2**

*Figure 4.3* *The seismic event rate for the average temperature profile of GTS-raming 2019 for both operational strategies.*

# 5 Hazard Assessment

## Hazard metrics

Different metrics have been proposed to describe the hazard resulting from seismic activity. Most commonly used are the peak ground velocity (PGV) and peak ground acceleration (PGA). Because the focus of previous hazard studies was the assessment of risk, acceleration (PGA and spectral acceleration) was used as the prime metric for the hazard assessments. For the prediction of building damage, additional hazard metrics will be assessed (Ref. 5).

In the current report, the hazard assessment is based on Ground Motion Prediction Methodology (GMM) Version 5 (Ref. 36). This version of the GMM incorporates the minor comments from the assurance committee for ground motion prediction (see Table D.3 in Appendix D) on the previous release of the GMM version 4 (Ref. 37), which was prepared and assured May 2017.

### Risk Assessment

Peak Ground Acceleration (PGA) is a widely used metric for ground shaking intensity and was chosen as the most appropriate hazard metric for the seismic hazard assessment in support of the assessment of risk. Figure 5.1 shows the measured acceleration near the epicentre during the Huizinge earthquake of 16th August 2012. For the assessment of the response of a building to ground shaking spectral acceleration (SA) is used. This takes into account the response period of the building being considered. The duration of the seismic event is less important for the seismic risk. Ground Motion Prediction methods have therefore focused on prediction of PGA and spectral acceleration at several periods. These are the most important hazard parameters for the prediction of full or partial building collapse, failure of building elements and hence for personal risk.

### Building Damage Assessment

For the assessment of the potential to cause building damage at lower damage states (see section 7 of this report), velocity-based hazard metrics such as PGV (Peak Ground Velocity) are also important. Empirical evidence elsewhere has shown that building damage at lower damage states (damage states DS1 and DS2) correlates strongly with PGV. A Groningen-specific (induced) Ground Motion Prediction method to estimate the value of PGV at specific locations has therefore been developed as part of the Ground Motion Prediction Methodology Versions 4 and 5. The assessment of PGV is primarily in support of assessment of building damage due to historical earthquakes and expected future damage.

The official Dutch guidelines for assessing the impact of vibrations on buildings, as presented in the document “Building Damage: Measurement and Assessment” by the SBR (Ref. 38), are based on the ground velocity metric $V_{TOP}$. To ensure consistency with the SBR Guidelines, apart from the geometric mean velocity also a Ground Motion Prediction method for the $V_{TOP}$ parameter (the ‘maximum’ value of PGV in any direction) was developed.

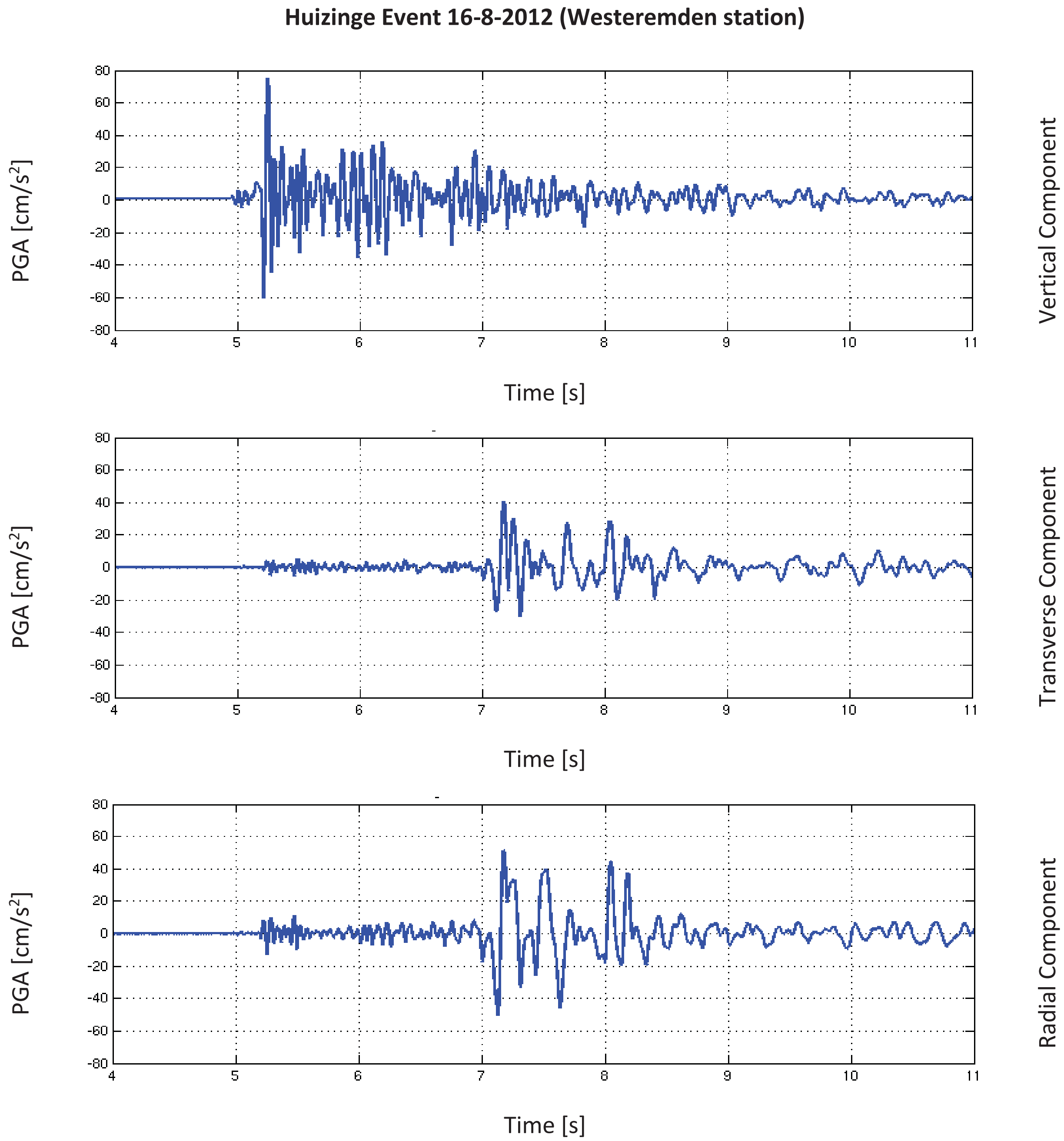



*Figure 5.1* *Accelerogram of the earthquake near Huizinge recorded at the 16th August 2012 by the accelerometer located near Westeremden (near the epicentre).*

## Hazard Map for Peak Ground Acceleration

For the probabilistic description of the ground accelerations (PGA, or generalised to Pseudo Spectral Acceleration, PSA), a hazard map is used. On this map for each location the acceleration is plotted that could occur, with a prescribed annualised probability of exceedance (exceedance level), during a prescribed analysis period. Hazard levels are shown using a gradual colour scale.

The hazard maps shown in this document were constructed according to the following procedure. Each location in the analysis area during the analysis period is subjected to ground motion accelerations resulting from induced earthquakes. At some locations at the centre of the field, e.g. near Loppersum, the chance of exceeding a given peak ground acceleration threshold is higher than at the periphery of the field, e.g. in Groningen city (Fig. 5.2).

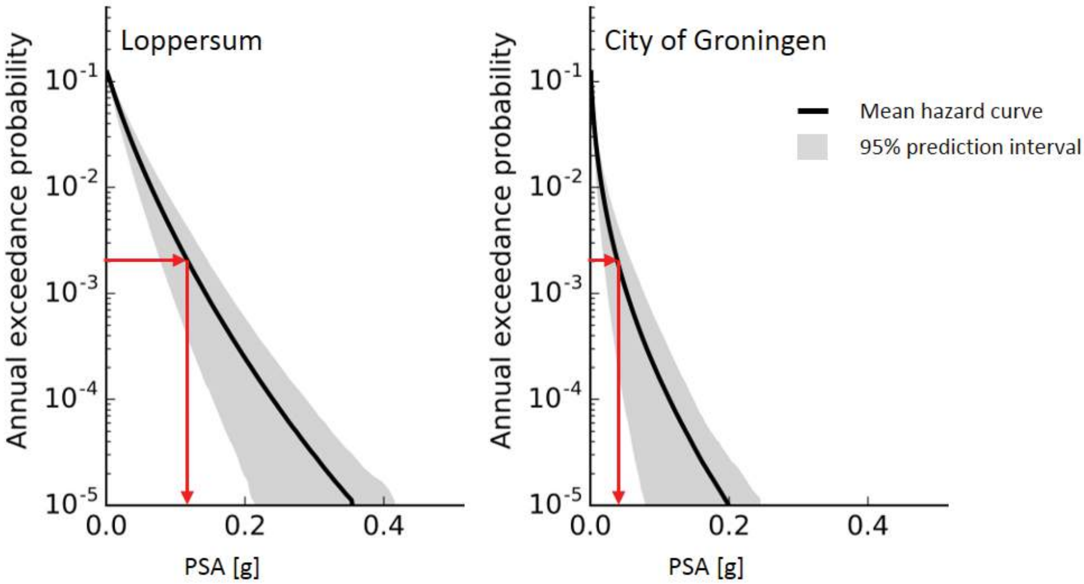



*Figure 5.2* *Hazard curves for two different locations in the Groningen area. Left for de village of Loppersum. Here the probability of being exposed to an acceleration exceeding larger than 0.1 g is 0.2% per year. On the right the hazard curve for the city of Groningen, the acceleration with an exposure of 0.2% per year is lower at 0.05 g.*

Equally, at any one location, the chance of exceeding some value of peak ground acceleration decreases with increasing peak ground acceleration. A set of hazard curves is shown for a number of locations in figure 5.3. Each declining line indicates the hazard curve for a single location in the field.

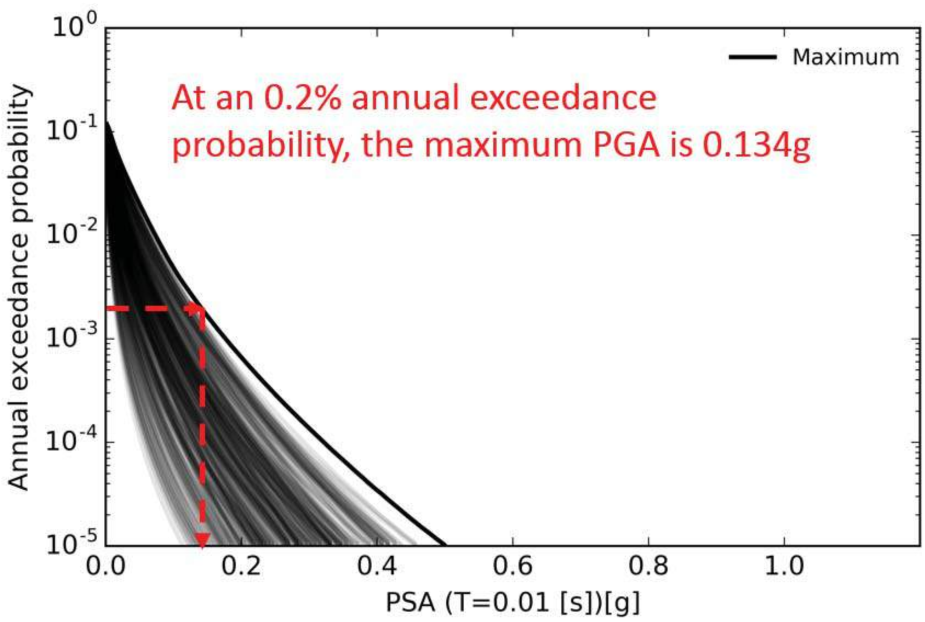



*Figure 5.3* *A set of hazard curves showing average annual exceedance rate for peak ground acceleration at different locations in the field. Each line corresponds to a location in the field. The bold line indicates the maximum PGA anywhere within the field for a given exceedance level (bounding envelope). In this figure, the red line indicates that for an exceedance level of 0.2%/year the highest PGA in the field is 0.134 g. This plot was prepared based on the average temperature production profile of GTS-raming 2019 for the period 2019 to 2024 and Operational Strategy 2.*

To prepare a hazard map, an exceedance level needs to be chosen. This is not a purely technical choice. However, inspired by Eurocode 8[6], part of the current technical standards for structural design in Europe, it has become common practice to prepare hazard maps for an exceedance level of 0.2%/year. This exceedance level is equivalent to a 475-year return period for stationary seismicity. The same exceedance level is also used by KNMI for their hazard maps, which allows for comparison of these hazard maps. The choice of the exceedance levels (or return period) is only for the representation of the hazard. This choice of exceedance level does not affect the subsequent assessment of risk. Hazard maps can also be prepared for spectral acceleration at a specified period. The standard PGA hazard map is the same as the spectral acceleration hazard map at shortest period, which for this assessment was chosen at 0.01 s.

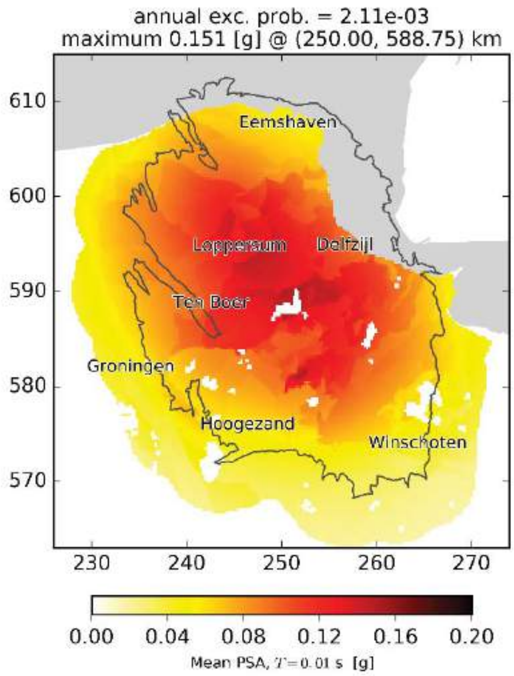
## Hazard Assessment

Hazard maps have been prepared for each year of the next ten calendar years and for the next two 5-year periods. Separate hazard maps are available for the "GTS-raming 2019" at average temperature profile, cold temperature profile and warm temperature profile.

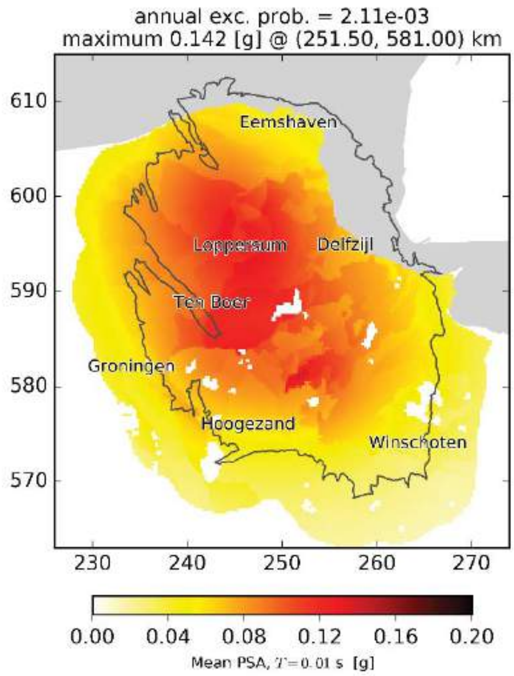
The hazard map for the average temperature profile for each year of the period 2019 to 2028 is shown in figure 5.4 a, b, c. The hazard is, as expected based on the declining gas production profile, also decreasing over this period. The trend in the largest PGA in these annual hazard maps is shown in figure 5.7. However, this reduction in PGA 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 profiles this effect (Ref. 6) has also been demonstrated.

The effect can also be seen in Figure 5.6 and 5.6, showing hazard maps of the "GTS-raming 2019" production profile for the next two 5-year periods (2019 to 2013 and 2013 to 2028 respectively), at a larger format.

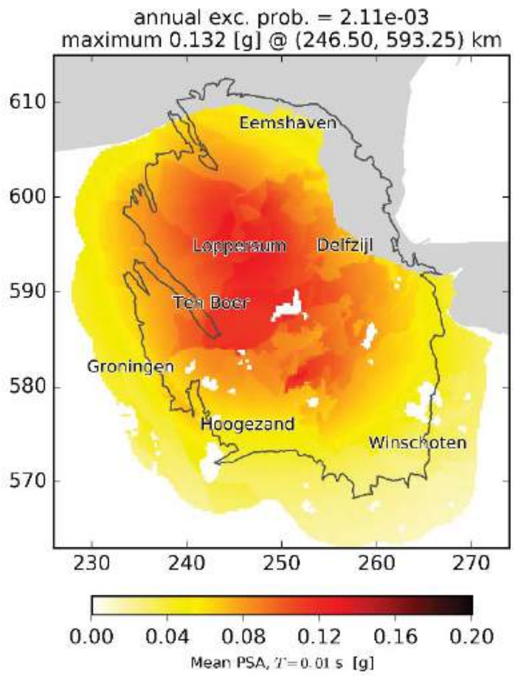
[6] The Eurocodes are the current technical standards for structural design in Europe, and it is now compulsory for the 28 countries in the Eurocode zone to adopt these. Eurocode 8 specifically deals with earthquake-resistant design of structures (CEN, 2006). Each country adopting Eurocode 8 must develop a National Annex to indicate how the code is implemented; the National Annex for the Netherlands is being developed. Eurocode 8 uses a standard practice to represent seismic hazard via PGA maps associated with ground motions having a 10% probability of exceedance during 50 years, equivalent to 0.2%/year for a stationary process, or a return period of 475-years.



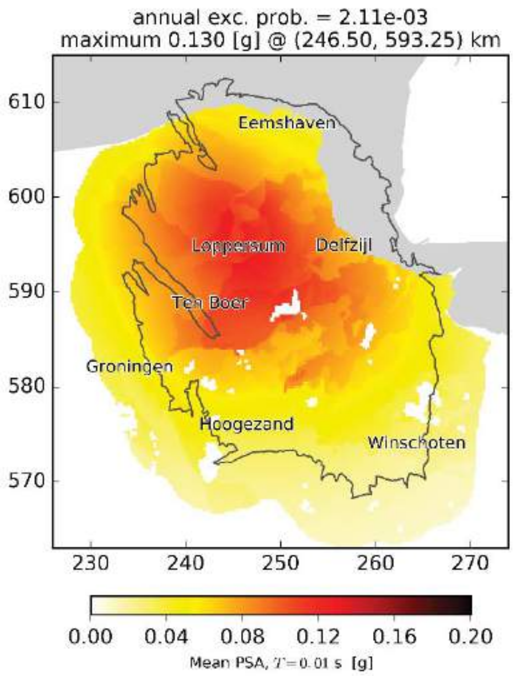

**2019**




**2020**

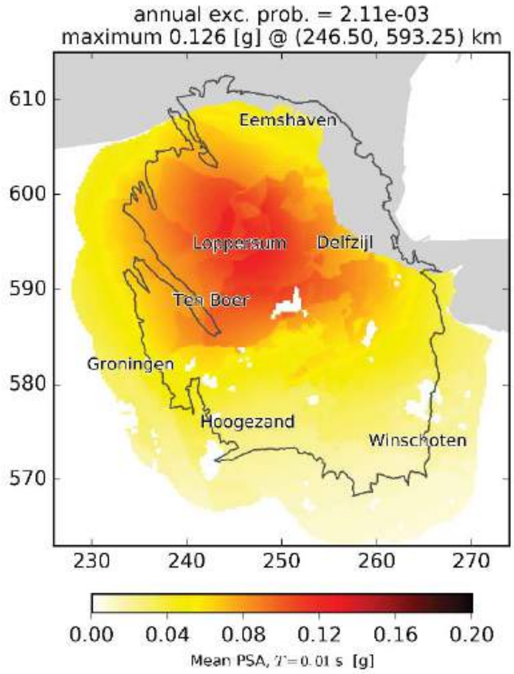



**2021**

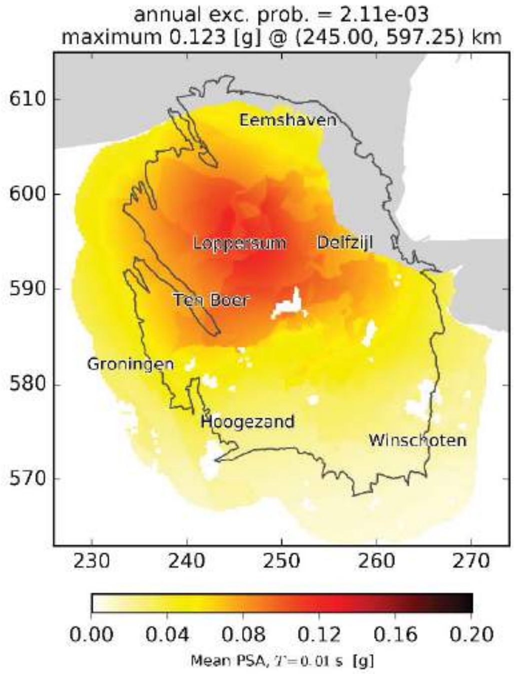



**2022**

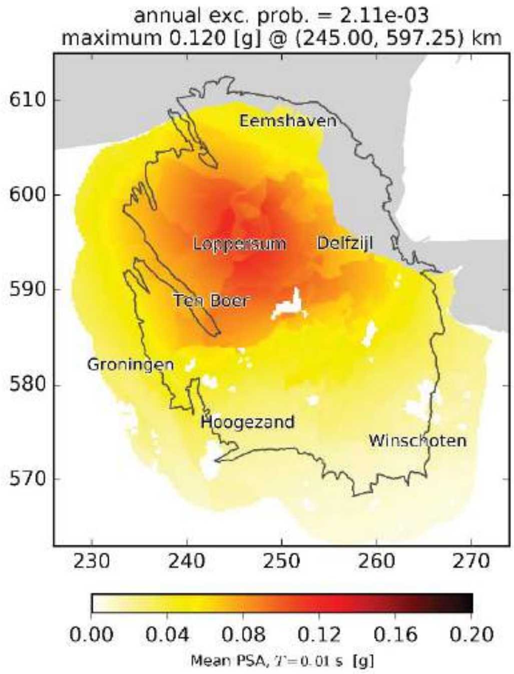
*Figure 5.4a* *Hazard Maps for the average temperature weather profile for the years 2019 (top – left), 2020 (top – right), 2021, (bottom – left) and 2022 (bottom – right). The production profile for these hazard maps is "GTS-raming 2019, for an average temperature year and optimisation of the distribution of the production to minimise the event count (Operational Strategy 2). Note that water-bodies, such as the Schildmeer, are masked in these hazard maps.*



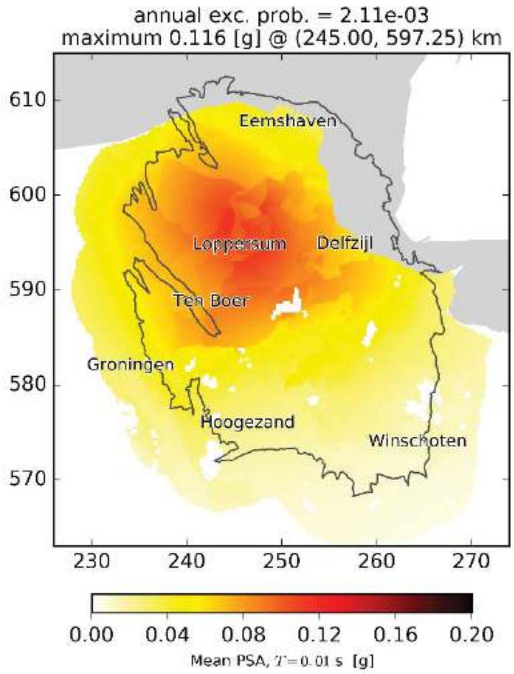

**2023**




**2024**

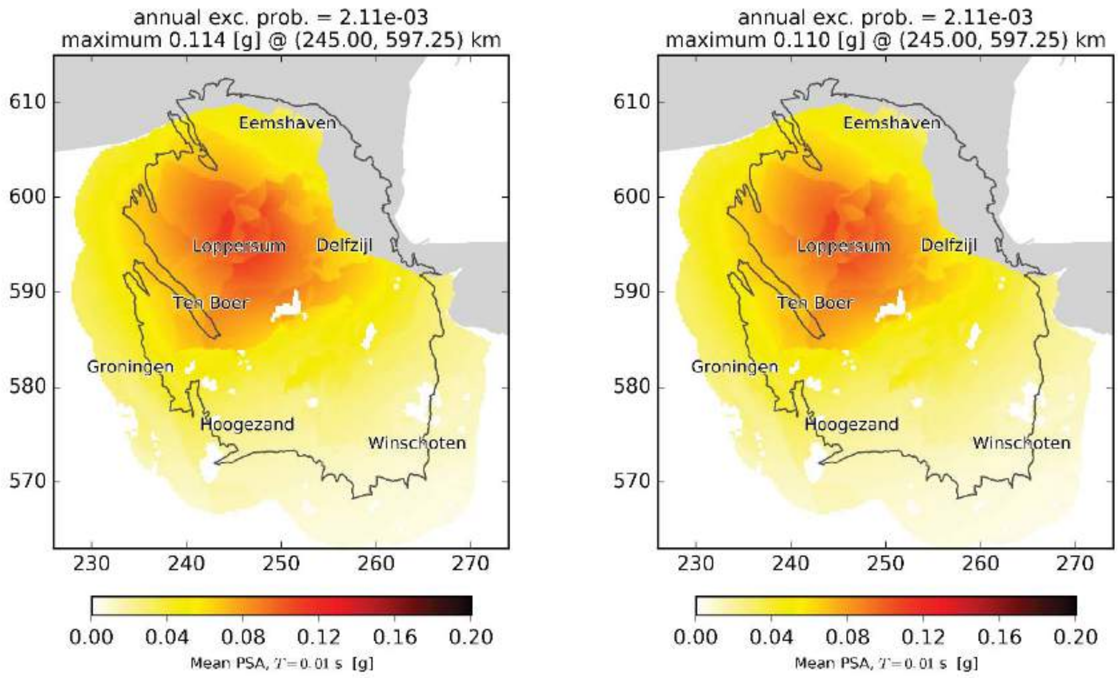



**2025**




**2026**

*Figure 5.4b* *Hazard Maps for the average temperature weather profile for the years 2022 (top – left), 2023 (top – right), 2024, (bottom – left) and 2025 (bottom – right). The production profile for these hazard maps is "GTS-raming 2019, for an average temperature year and optimisation of the distribution of the production to minimise the event count (Operational Strategy 2).*




**2027** **2028**

*Figure 5.4c* *Hazard Maps for the average temperature profile for the years 2022 (left), 2023 (right), 2024, (bottom – left) and 2025 (bottom – right). The production profile for these hazard maps is “GTS-raming 2019, for an average temperature year and optimisation of the distribution of the production to minimise the event count (Operational Strategy 2).*

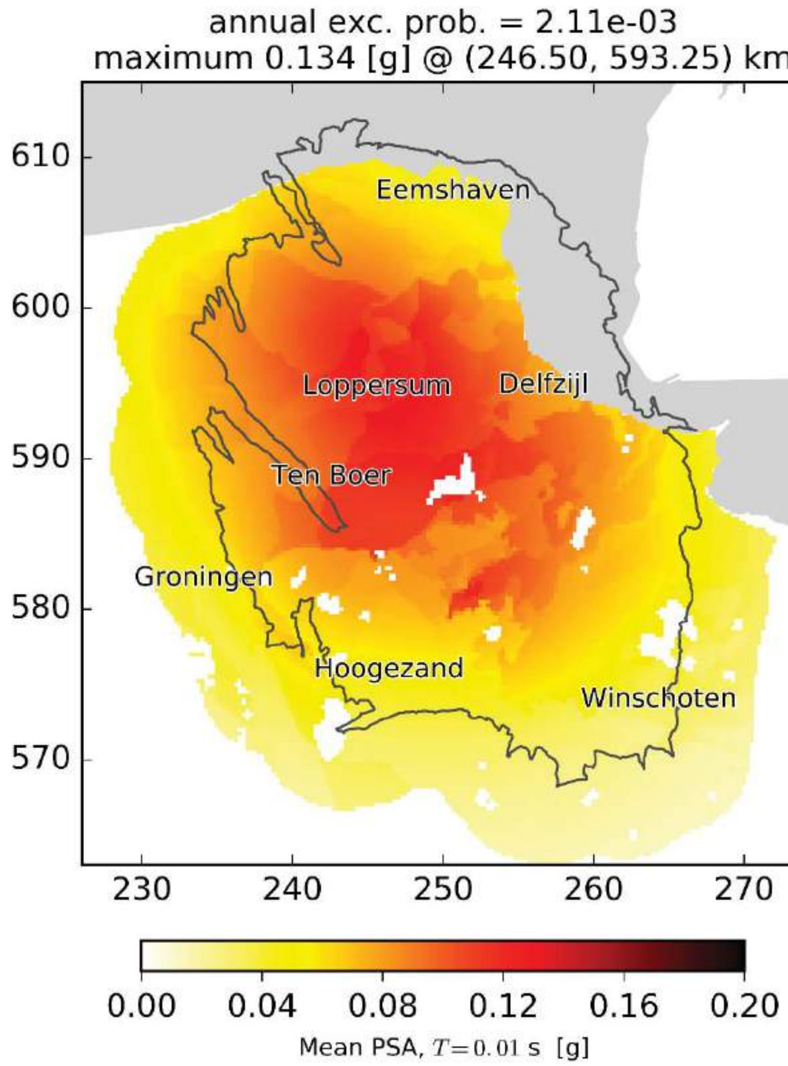



*Figure 5.5* *Hazard Maps for the average temperature weather profile for the period from 2019 to 2024. The production profile for these hazard maps is “GTS-raming 2019, for an average temperature year and optimisation of the distribution of the production to minimise the event count (Operational Strategy 2).*

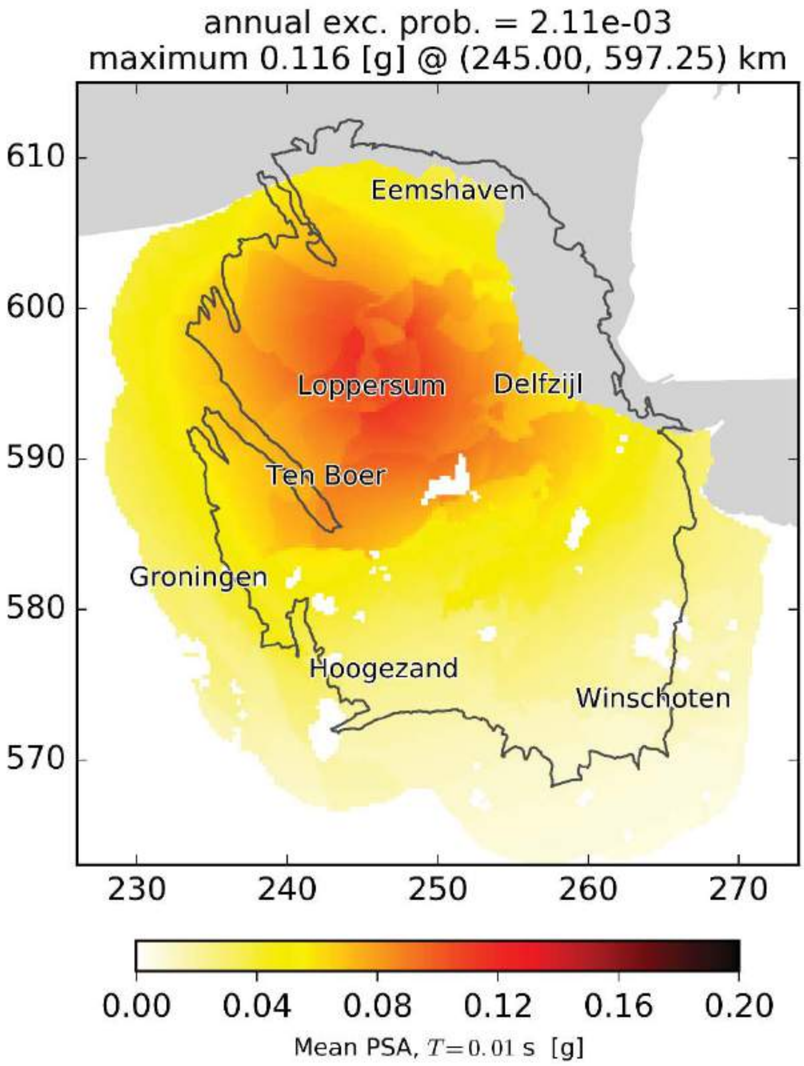



*Figure 5.6* *Hazard Maps for the average temperature weather profile for the period from 2024 to 2028. The production profile for these hazard maps is "GTS-raming 2019, for an average temperature year and optimisation of the distribution of the production to minimise the event count (Operational Strategy 2).*

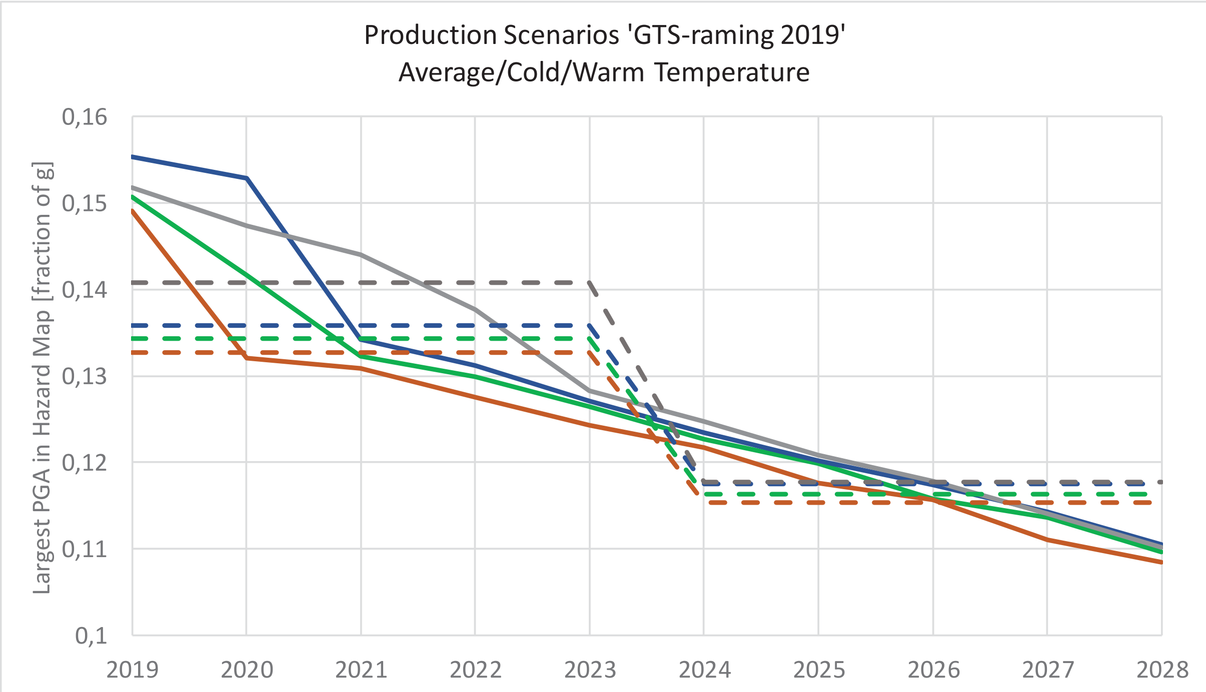
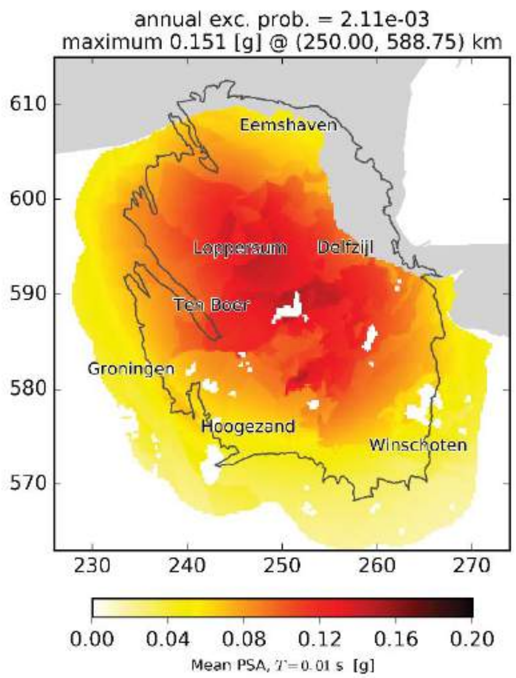
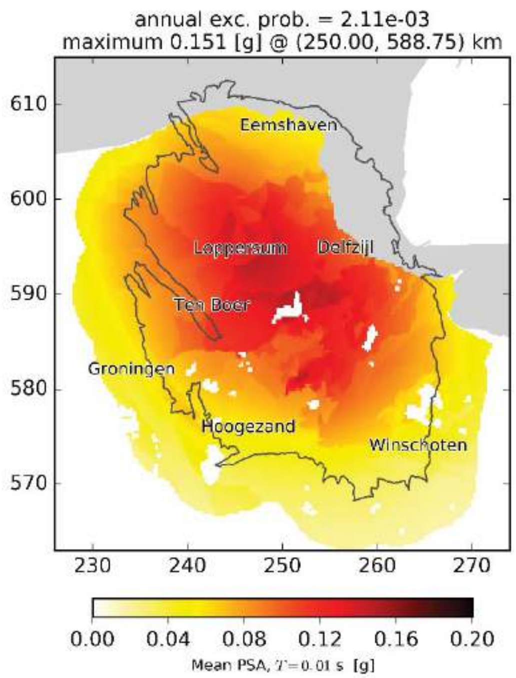



*Figure 5.7* *Development over time of the largest PGA in the hazard maps. The production profile for these hazard maps is "GTS-raming 2019 and optimisation of the distribution of the production to minimise the event count (Operational Strategy 2.*

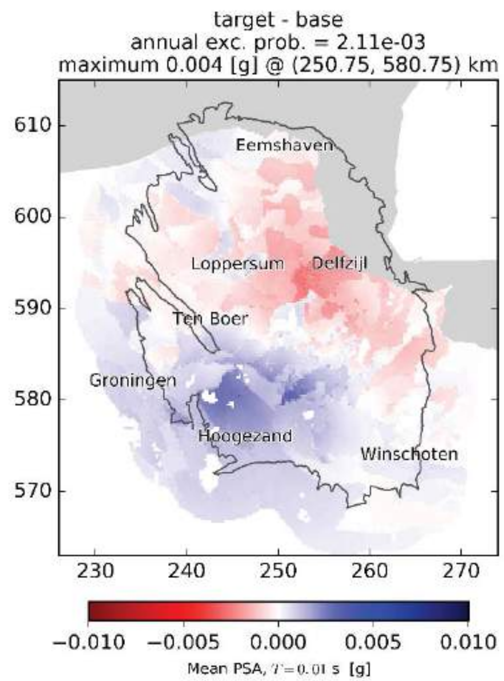
*The grey solid line denotes the largest PGA for each year in the hazard map for the reference profile.*
*The blue solid line denotes the largest PGA for each year in the hazard map for the GTS-raming 2019 cold temperature profile.*
*The green solid line denotes the largest PGA for each year in the hazard map for the GTS-raming 2019 average temperature profile.*
*The orange line denotes the largest PGA for each year in the hazard map for the GTS-raming 2019 warm temperature profile.*
*Hatched lines denote the five-year average of the largest PGA in the hazard map.*




**Operational Strategy 2** – Optimisation of the distribution of the gas production to minimise the event count

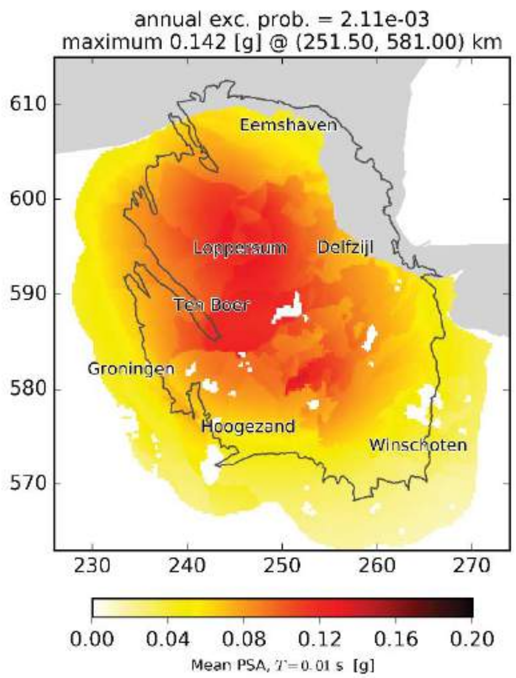



**Operational Strategy 1** – Optimisation of the distribution of the gas production based on population weighted PGV

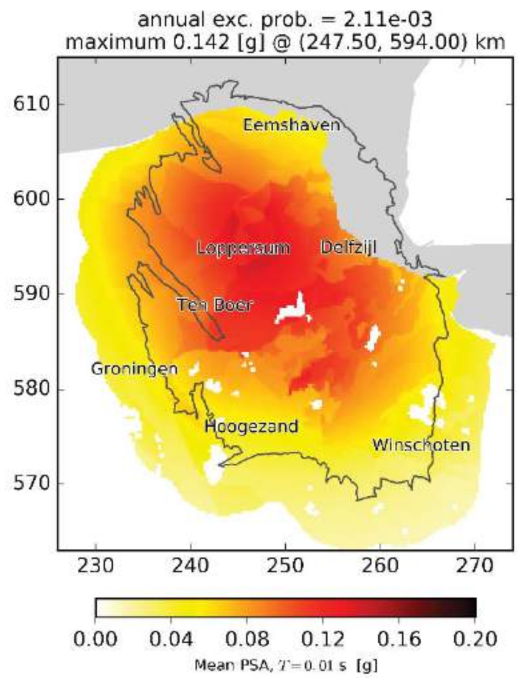



**Difference**
(Operational Strategy 2 – Operational Strategy 1)

**2019**

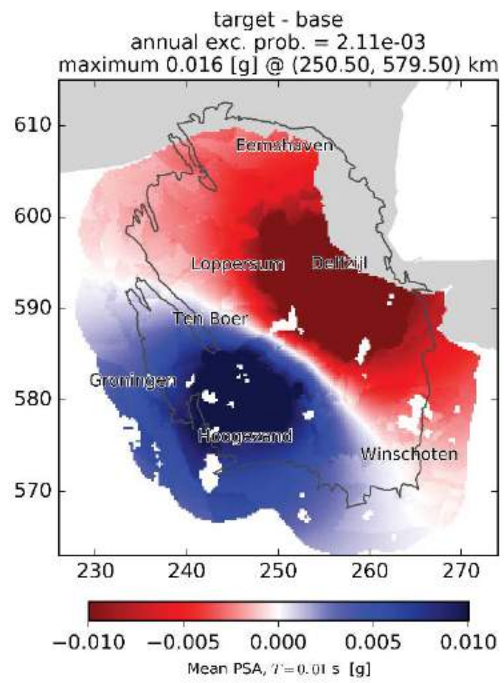



**Operational Strategy 2** – Optimisation of the distribution of the gas production to minimise the event count



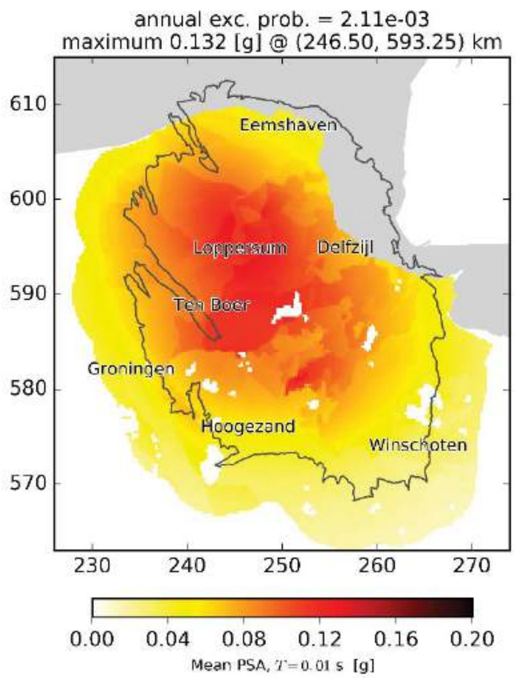

**Operational Strategy 1** – Optimisation of the distribution of the gas production based on population weighted PGV

**2020**

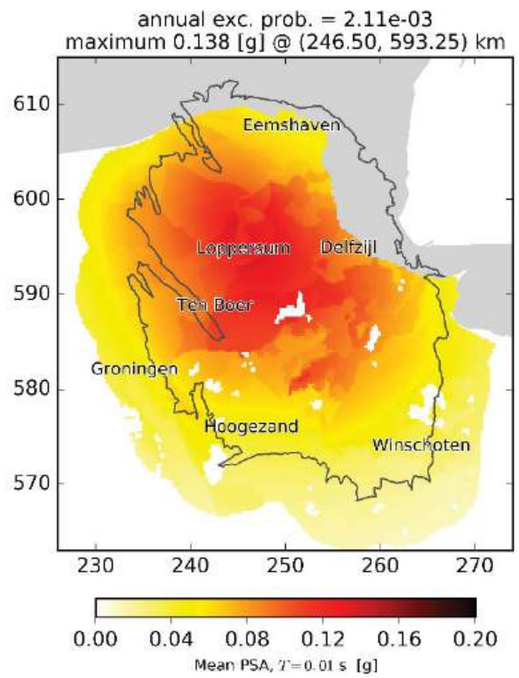



**Difference**

(Operational Strategy 2 – Operational Strategy 1)

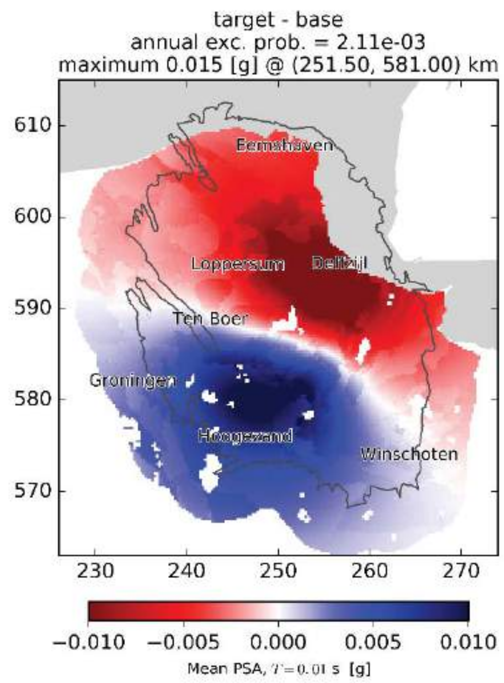



**Operational Strategy 2** – Optimisation of the distribution of the gas production to minimise the event count



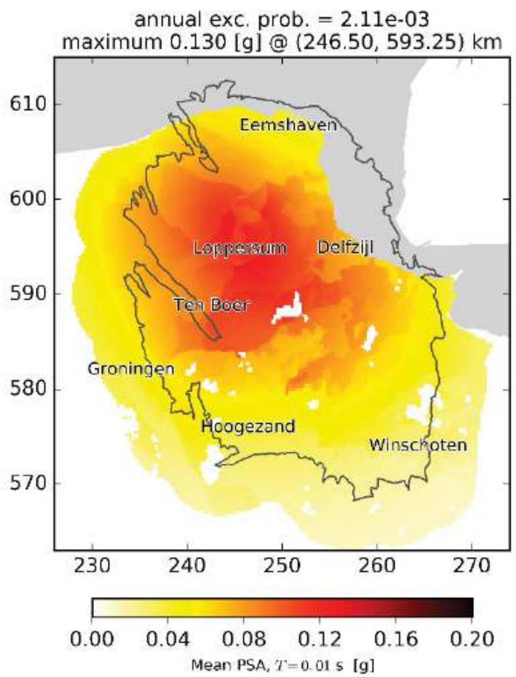

**Operational Strategy 1** – Optimisation of the distribution of the gas production based on population weighted PGV

**2021**

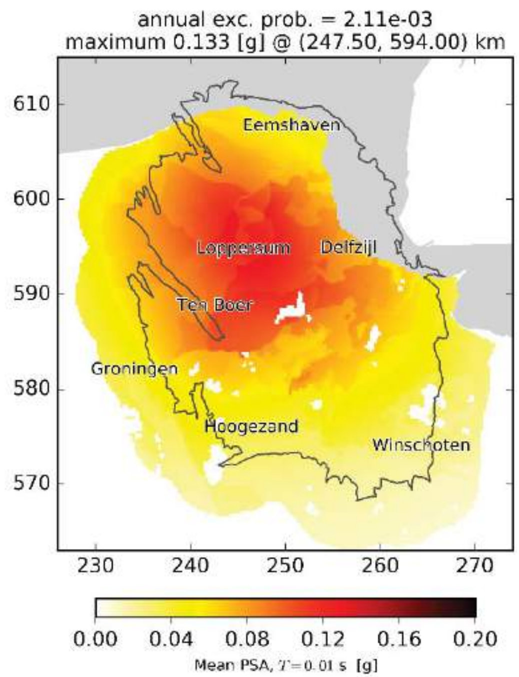



**Difference**

(Operational Strategy 2 – Operational Strategy 1)

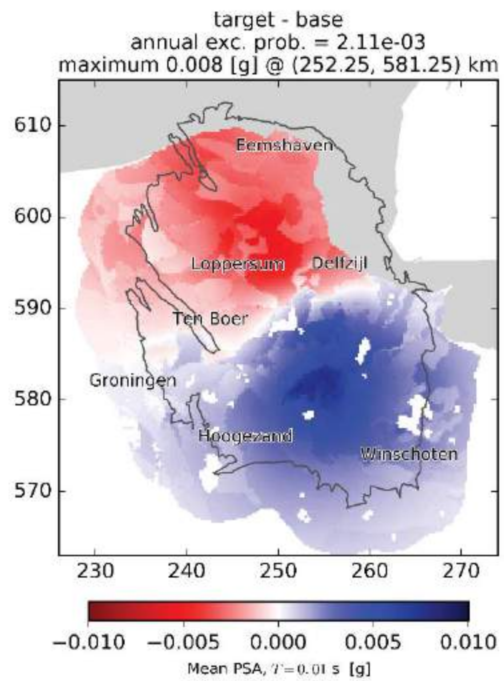



**Operational Strategy 2** – Optimisation of the distribution of the gas production to minimise the event count



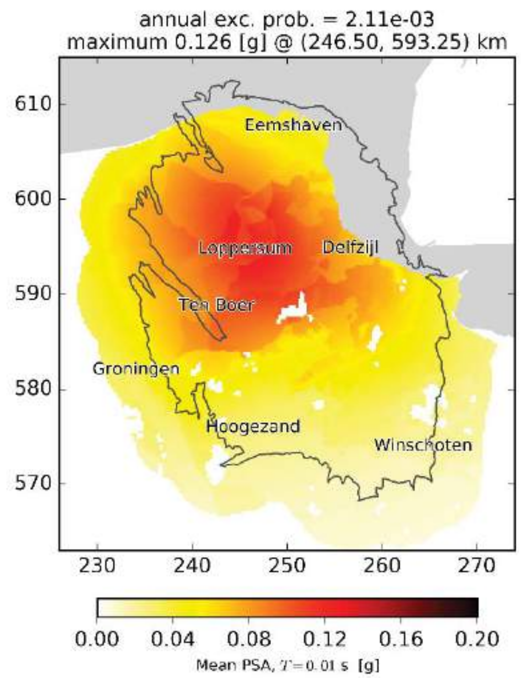

**Operational Strategy 1** – Optimisation of the distribution of the gas production based on population weighted PGV

**2022**

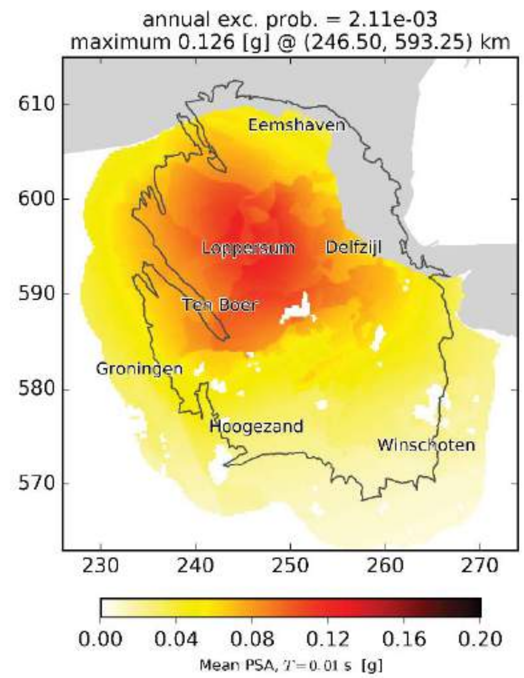



**Difference**

(Operational Strategy 2 – Operational Strategy 1)

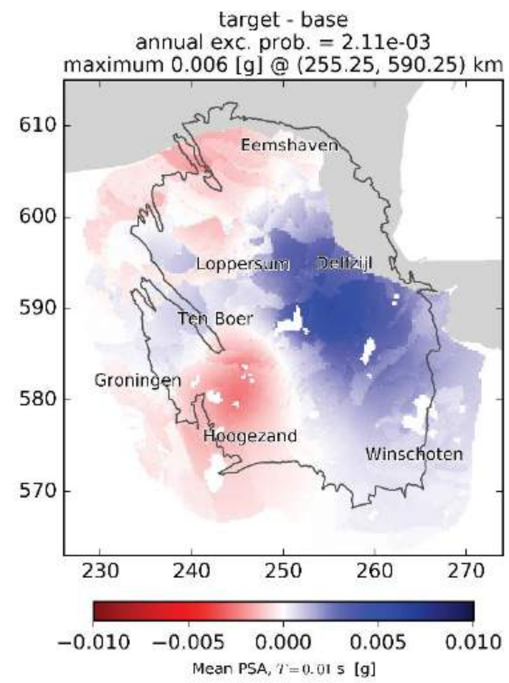



**Operational Strategy 2** – Optimisation of the distribution of the gas production to minimise the event count



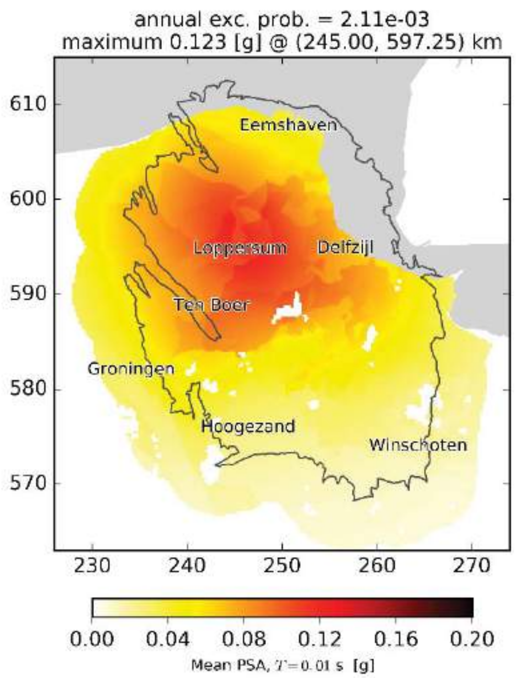

**Operational Strategy 1** – Optimisation of the distribution of the gas production based on population weighted PGV

**2023**

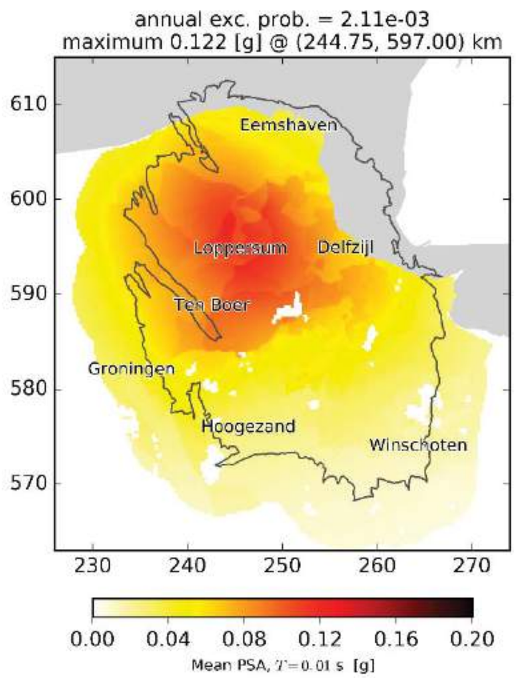



**Difference**

(Operational Strategy 2 – Operational Strategy 1)

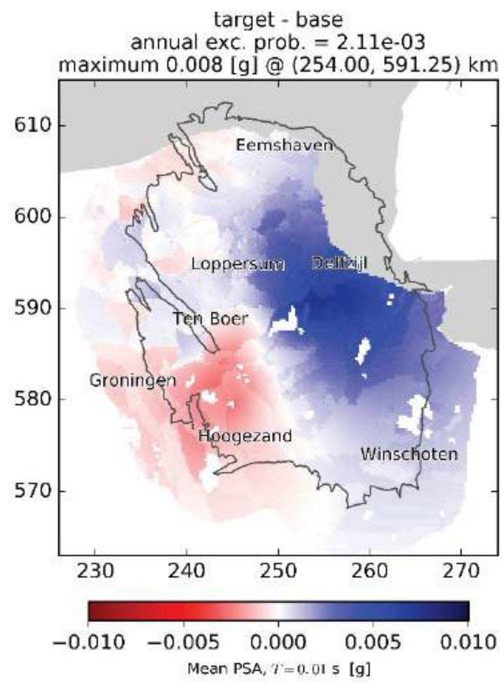



**Operational Strategy 2** – Optimisation of the distribution of the gas production to minimise the event count



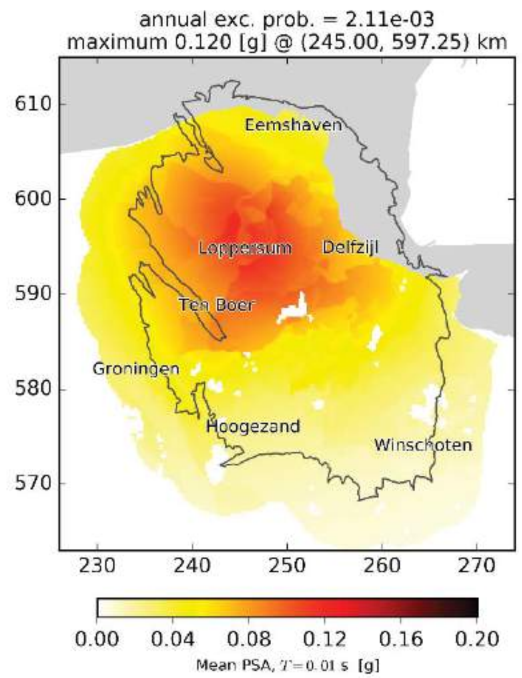

**Operational Strategy 1** – Optimisation of the distribution of the gas production based on population weighted PGV

**2024**

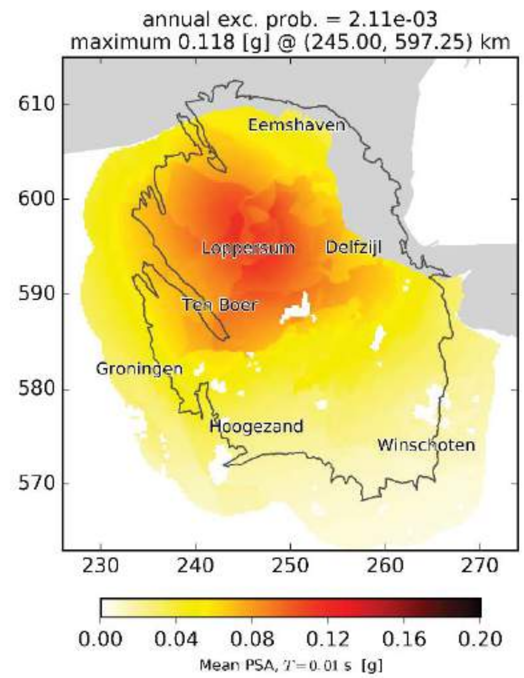



**Difference**

(Operational Strategy 2 – Operational Strategy 1)

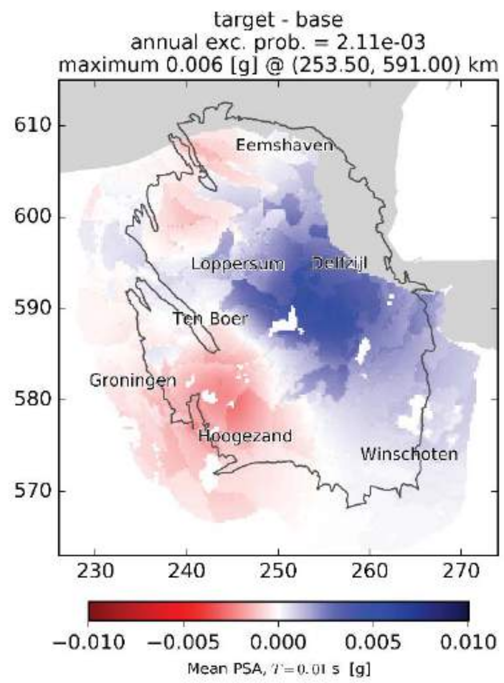



**Operational Strategy 2** – Optimisation of the distribution of the gas production to minimise the event count

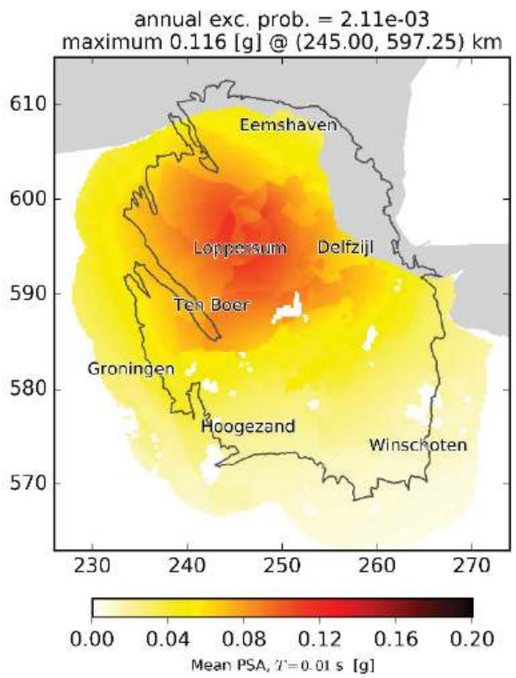



**Operational Strategy 1** – Optimisation of the distribution of the gas production based on population weighted PGV

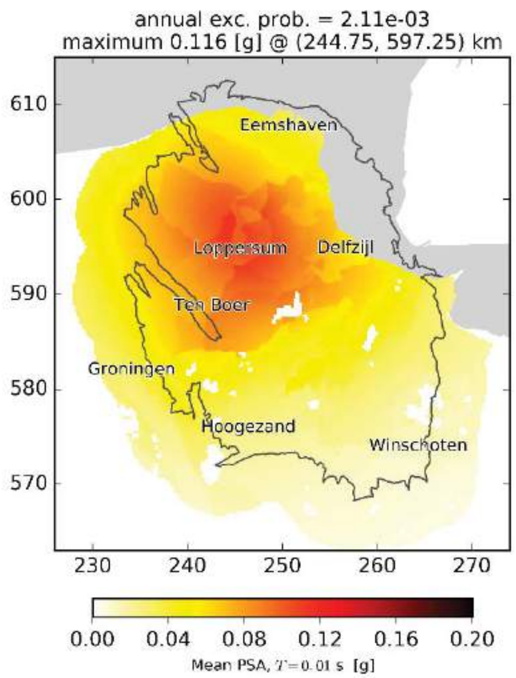
**2025**




**Difference**
(Operational Strategy 2 – Operational Strategy 1)

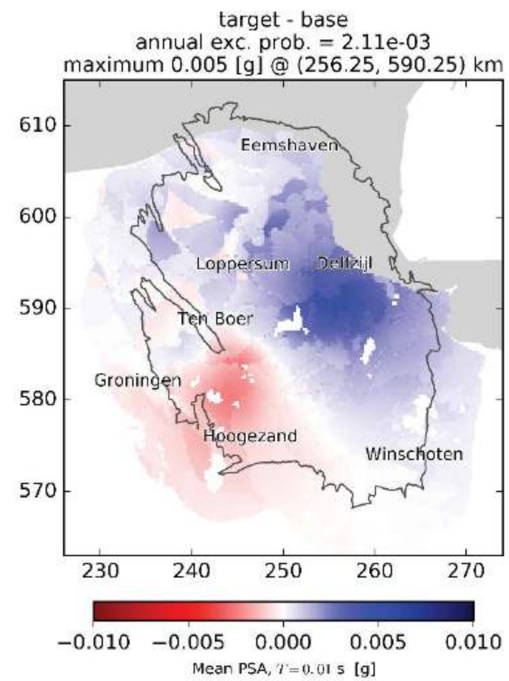



**Operational Strategy 2** – Optimisation of the distribution of the gas production to minimise the event count



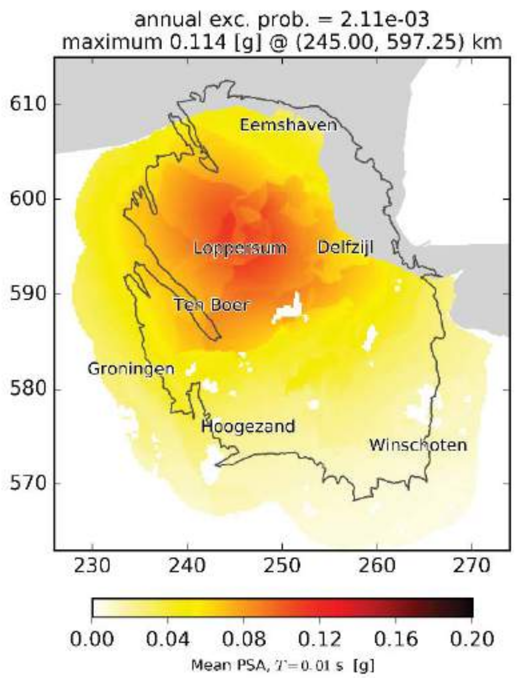

**Operational Strategy 1** – Optimisation of the distribution of the gas production based on population weighted PGV

**2026**

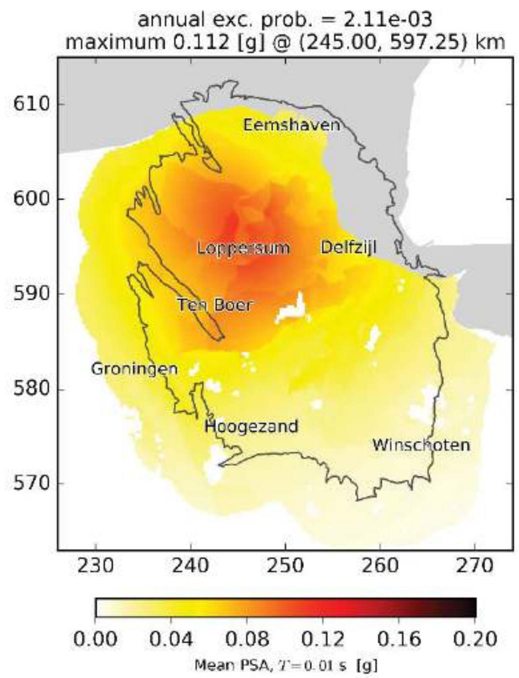



**Difference**

(Operational Strategy 2 – Operational Strategy 1)

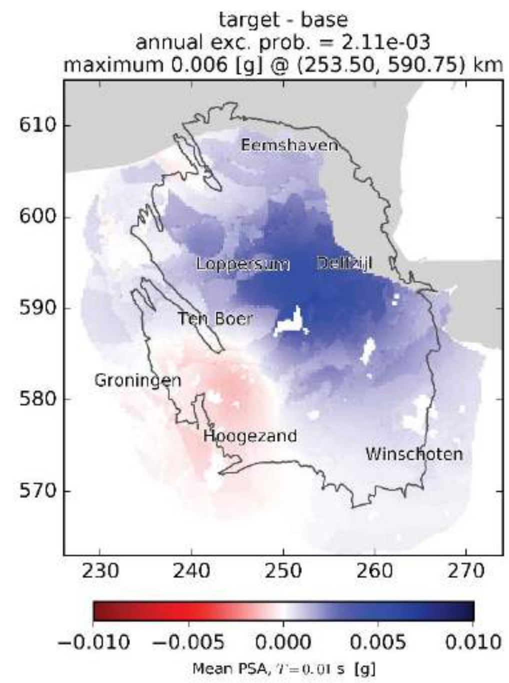



**Operational Strategy 2** – Optimisation of the distribution of the gas production to minimise the event count



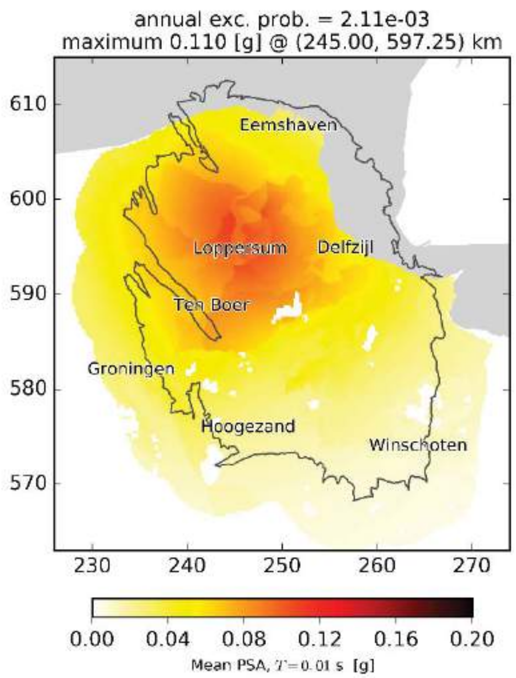

**Operational Strategy 1** – Optimisation of the distribution of the gas production based on population weighted PGV

**2027**

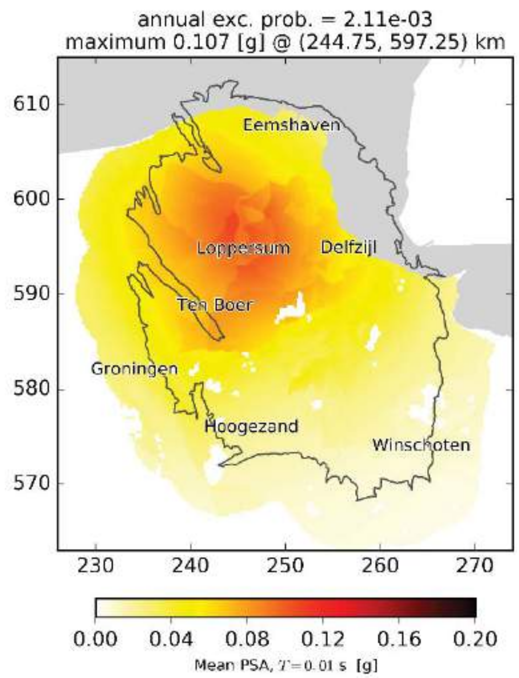



**Difference**

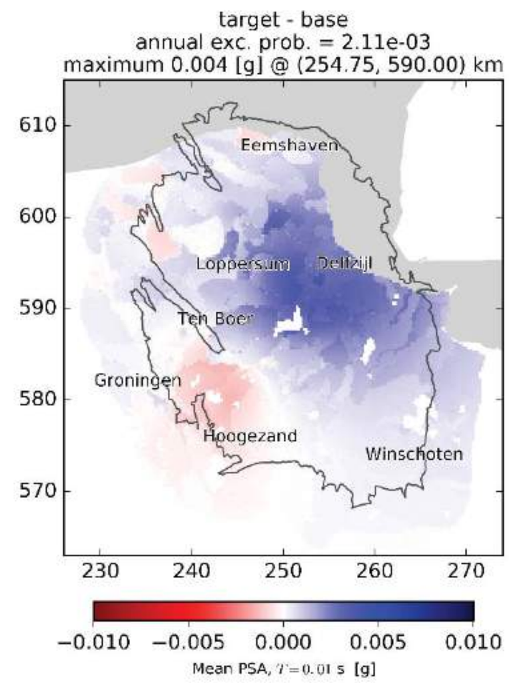
(Operational Strategy 2 – Operational Strategy 1)




**Operational Strategy 2** – Optimisation of the distribution of the gas production to minimise the event count



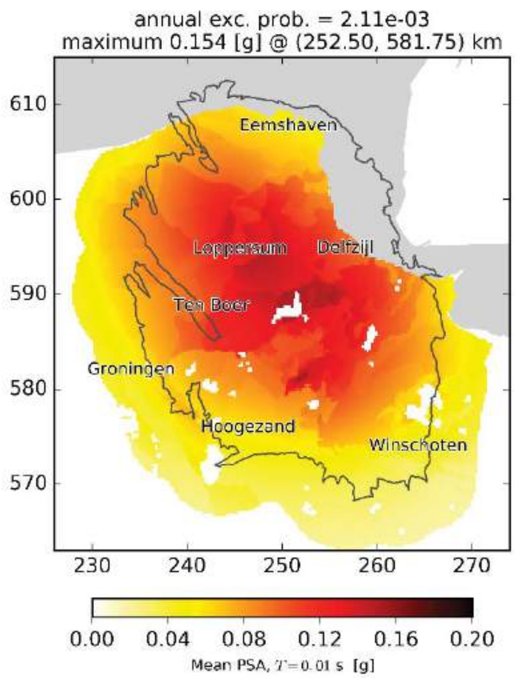

**Operational Strategy 1** – Optimisation of the distribution of the gas production based on population weighted PGV



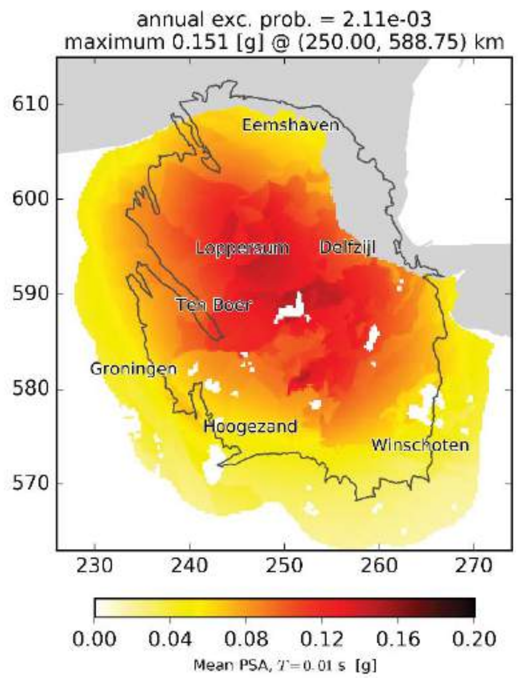

**Difference**
(Operational Strategy 2 – Operational Strategy 1)

**2028**

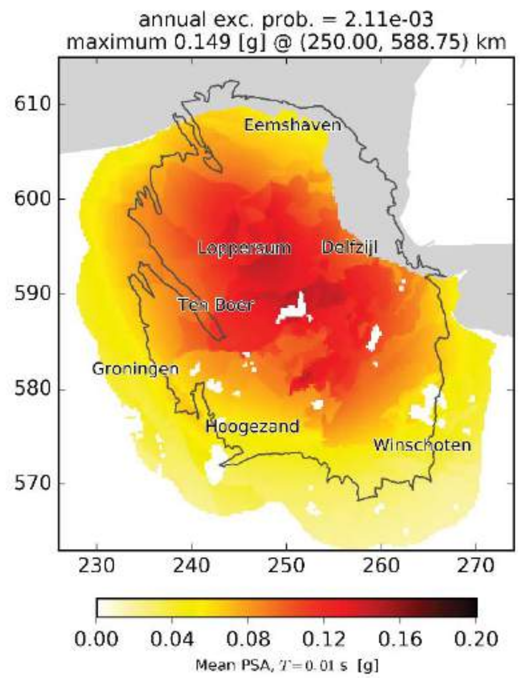
*Figure 5.8 Annual hazard maps for the two optimised Operational Strategies compared. These maps are based on the production profile “GTS-raming 2019” for an average temperature year.*



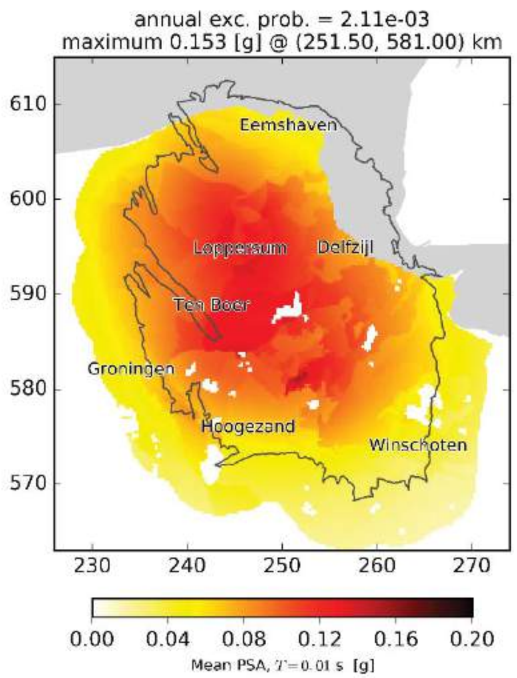

**Cold Temperature**



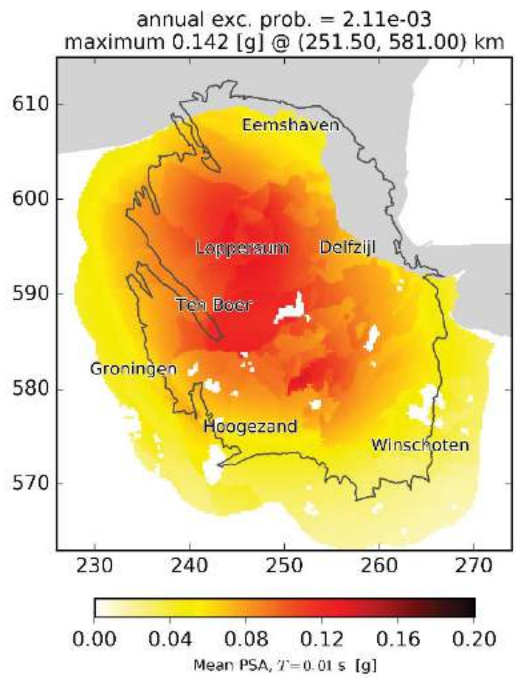

**Average Temperature 2019**



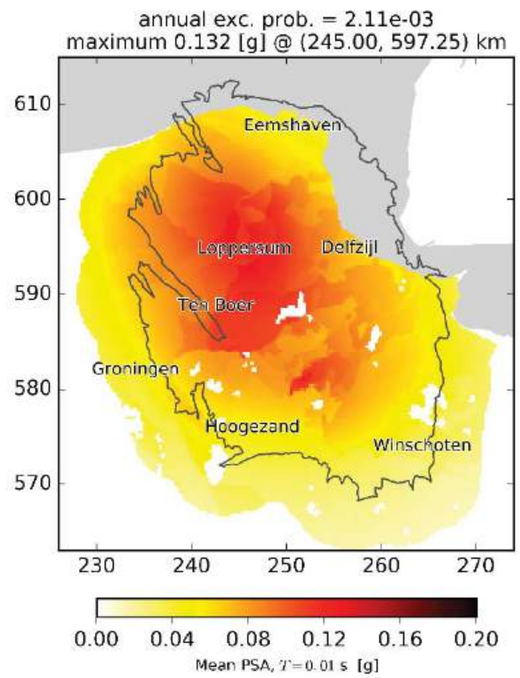

**Warm Temperature**



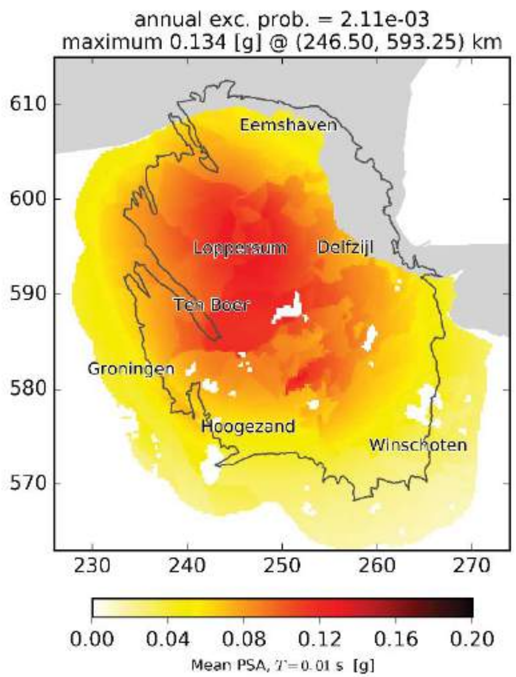

**Cold Temperature**



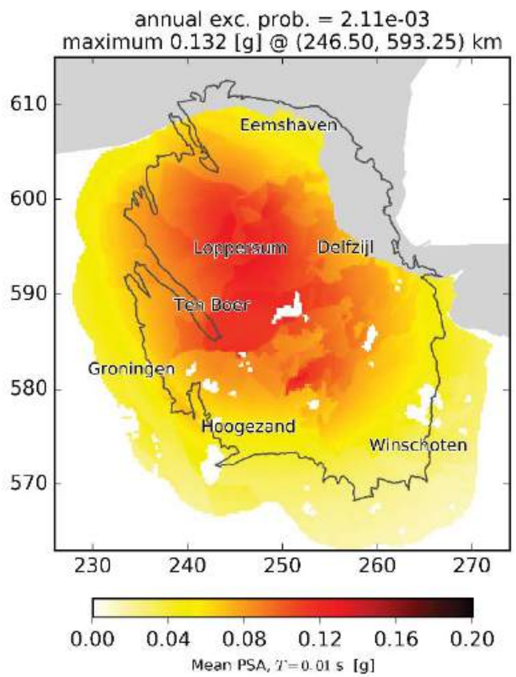

**Average Temperature 2020**



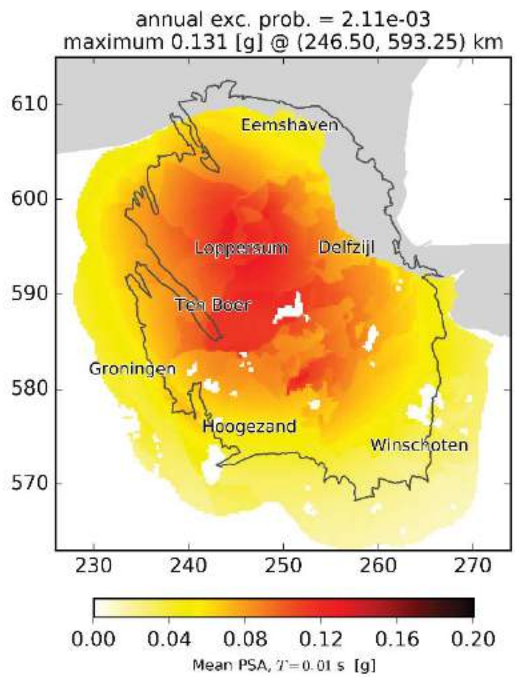

**Warm Temperature**



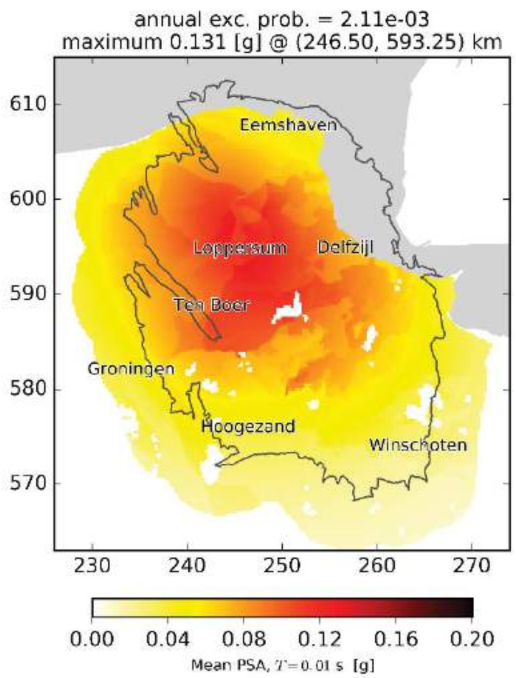

**Cold Temperature**



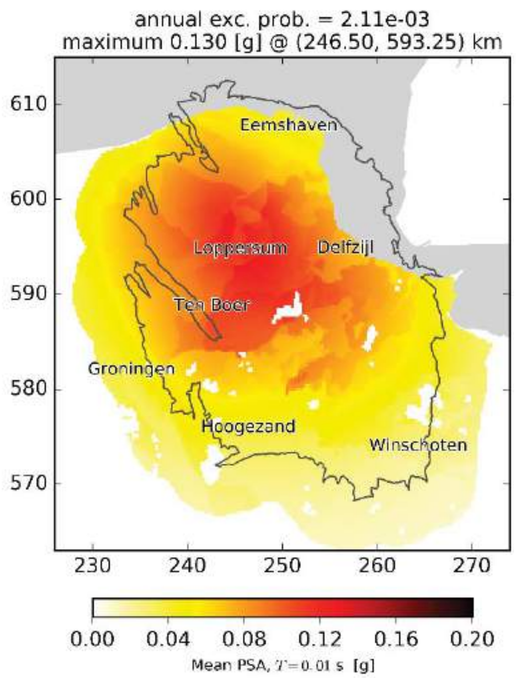

**Average Temperature**
**2021**



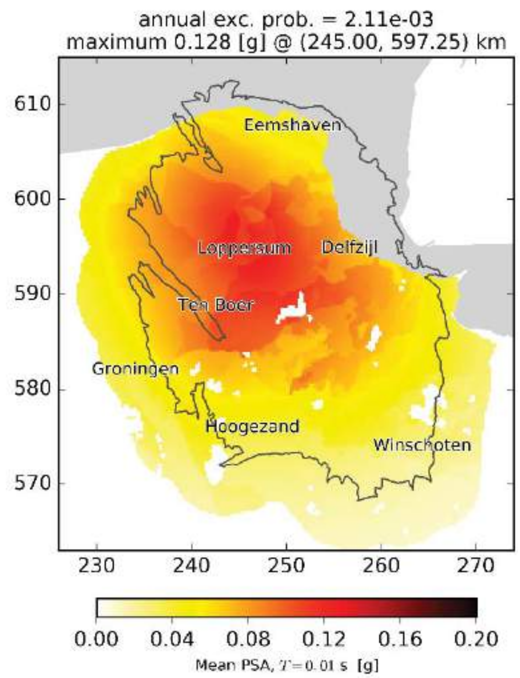

**Warm Temperature**



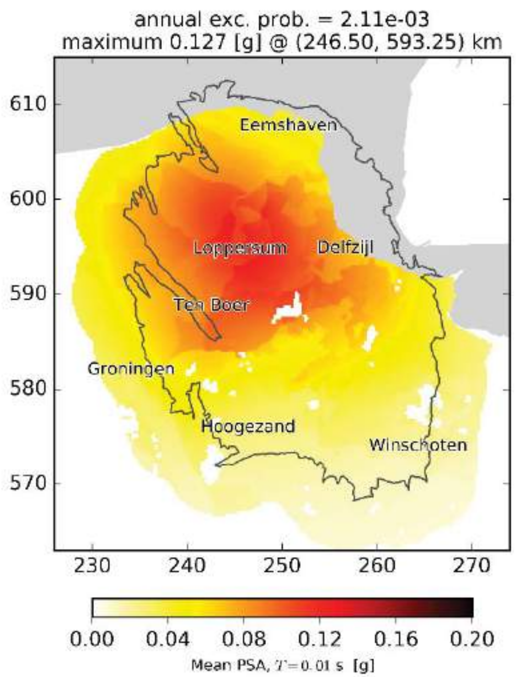

**Cold Temperature**



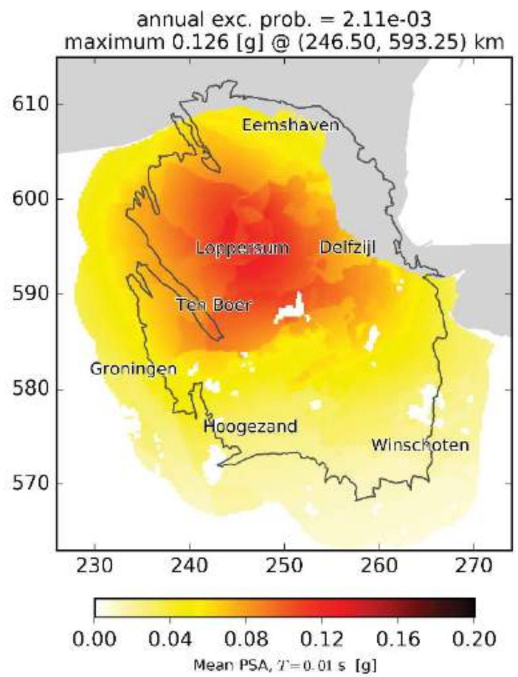

**Average Temperature**
**2022**



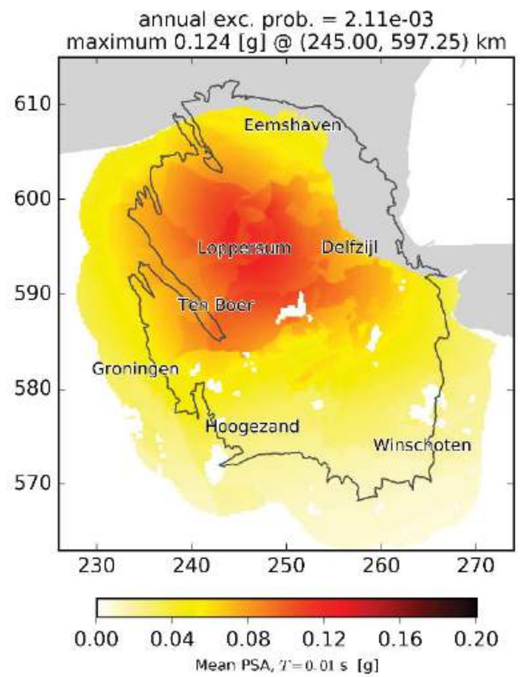

**Warm Temperature**



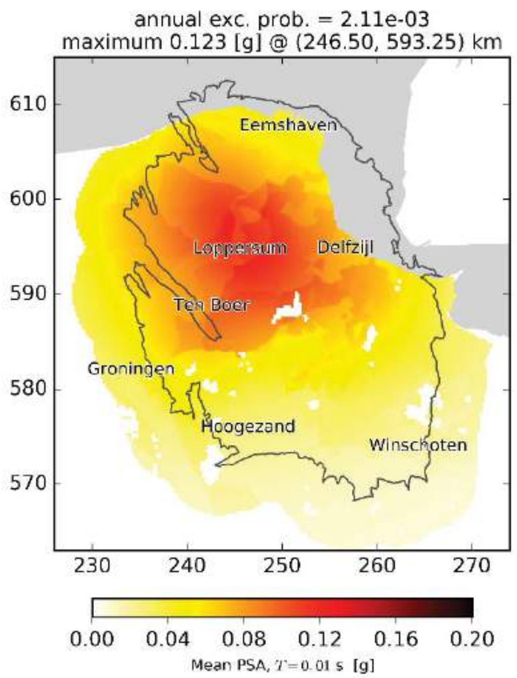

**Cold Temperature**



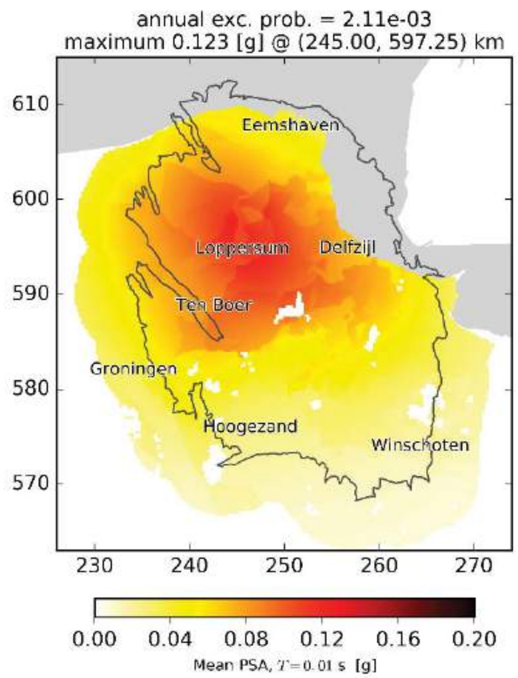

**Average Temperature 2023**



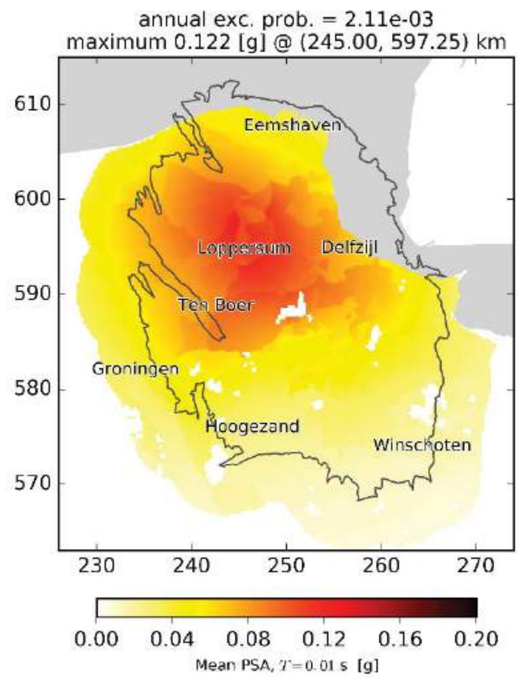

**Warm Temperature**



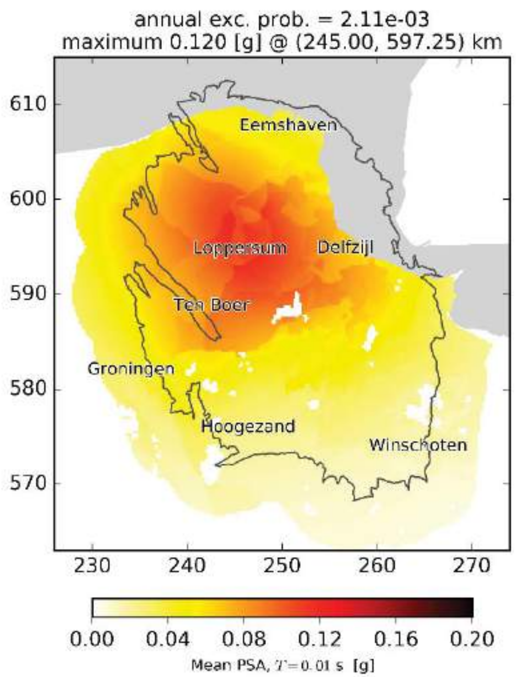

**Cold Temperature**



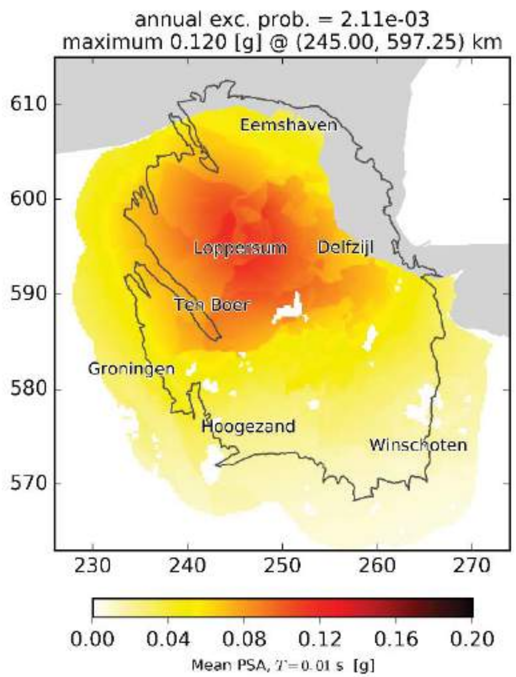

**Average Temperature**
**2024**



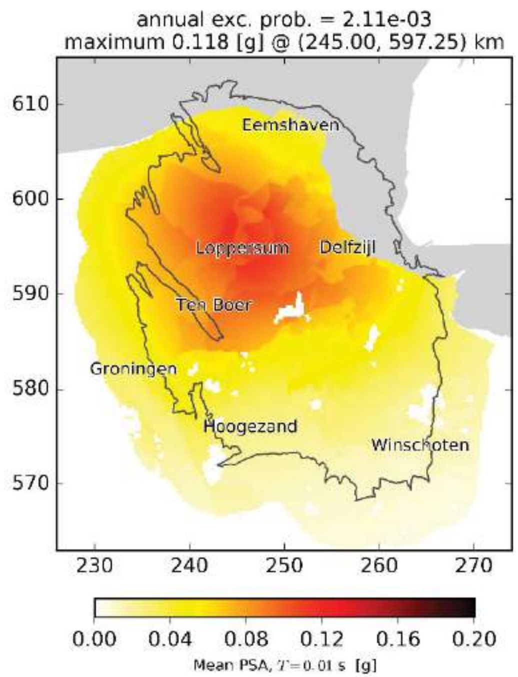

**Warm Temperature**



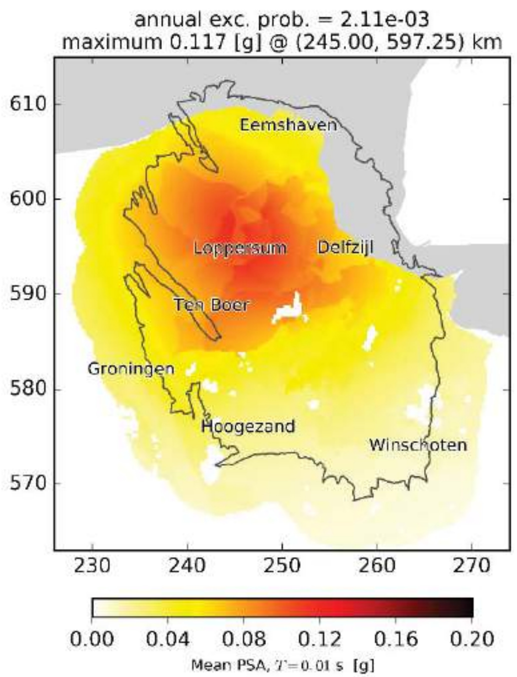

**Cold Temperature**



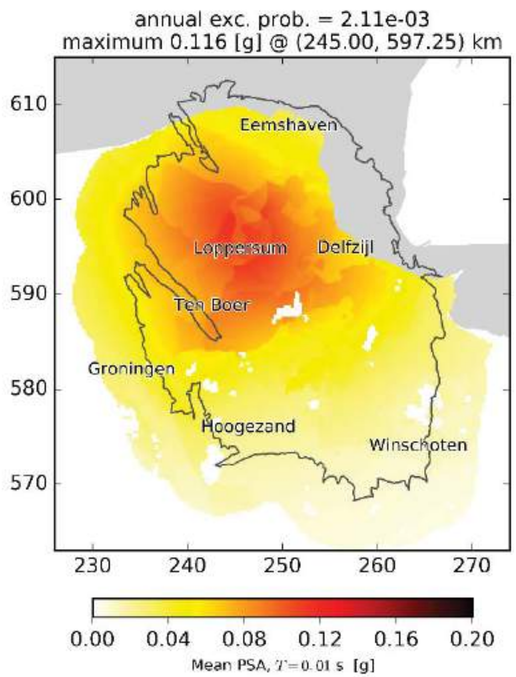

**Average Temperature**
**2025**



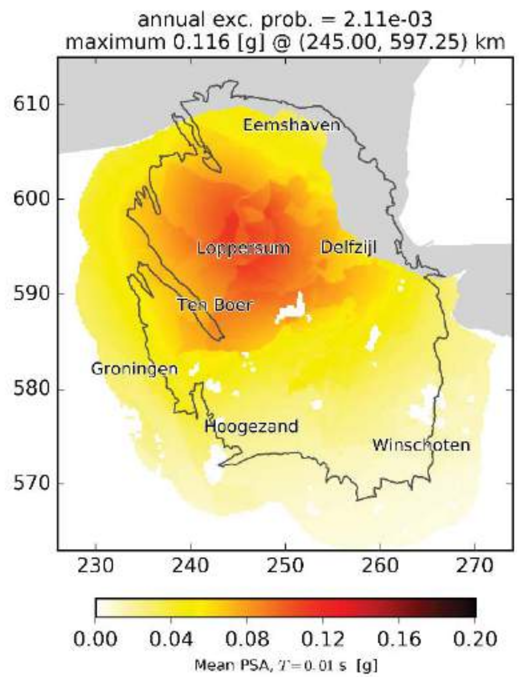

**Warm Temperature**



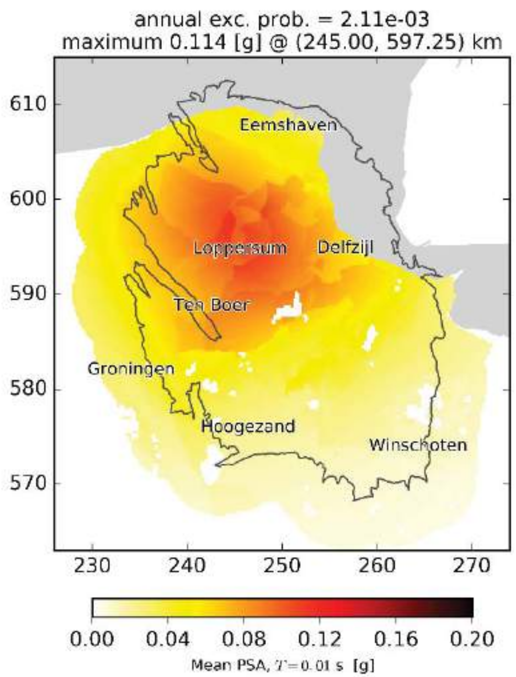

**Cold Temperature**



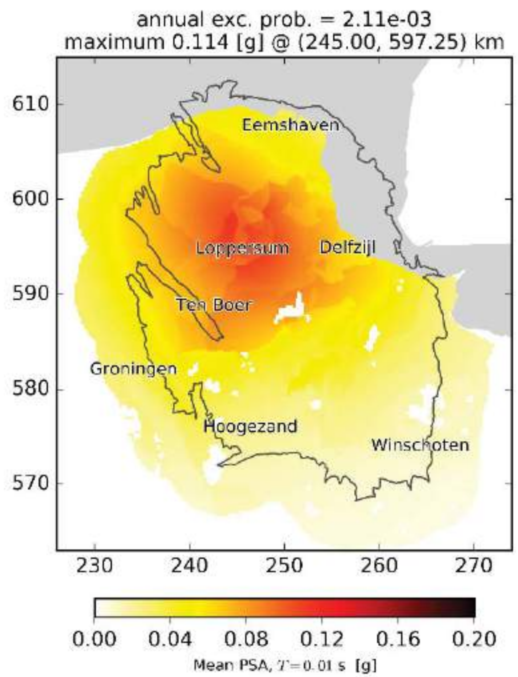

**Average Temperature 2026**



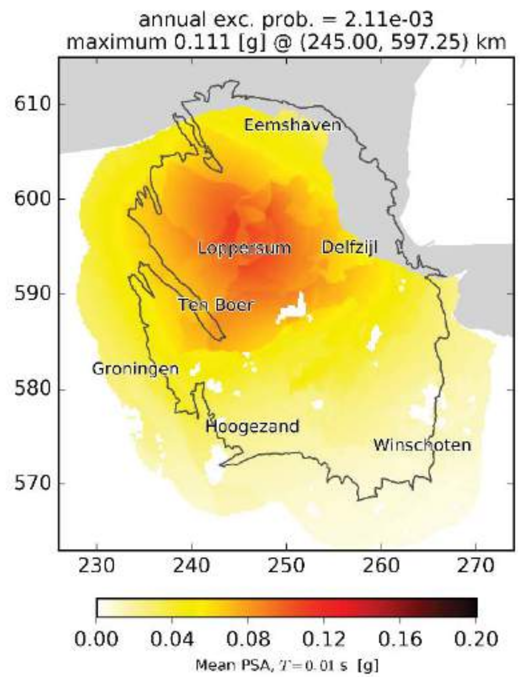

**Warm Temperature**



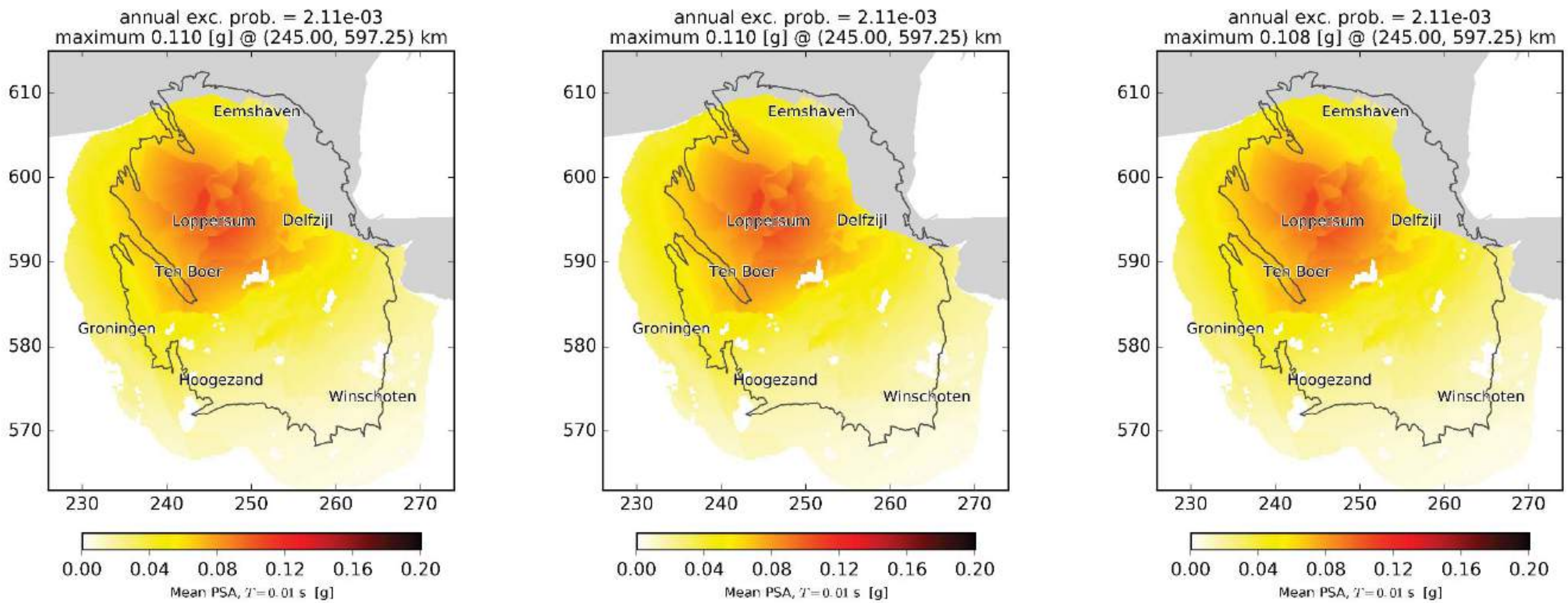

Cold Temperature




Average Temperature
2027




Warm Temperature

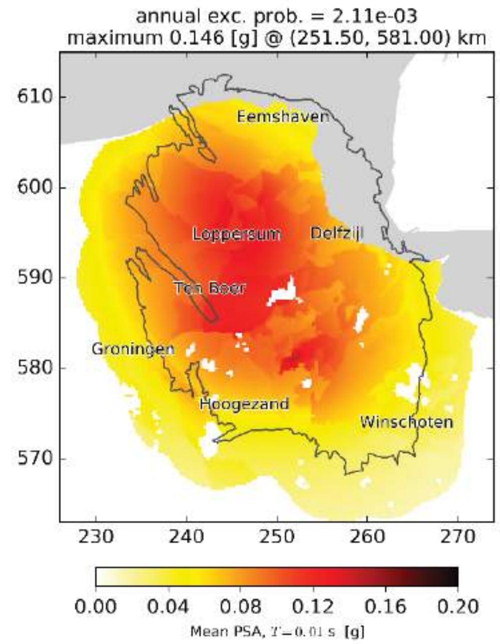



**Cold Temperature** | **Average Temperature 2028** | **Warm Temperature**

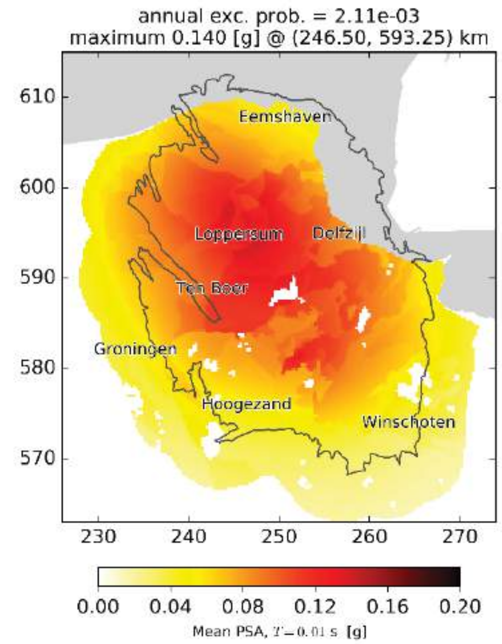
*Figure 5.9* *Annual hazard maps for the three temperature years compared. These maps are based on the production profile "GTS-raming 2019" for an optimisation of distribution of the gas production to minimise the event count (Operational Strategy 2).*

## Hazard for gas-year 2019 / 2020

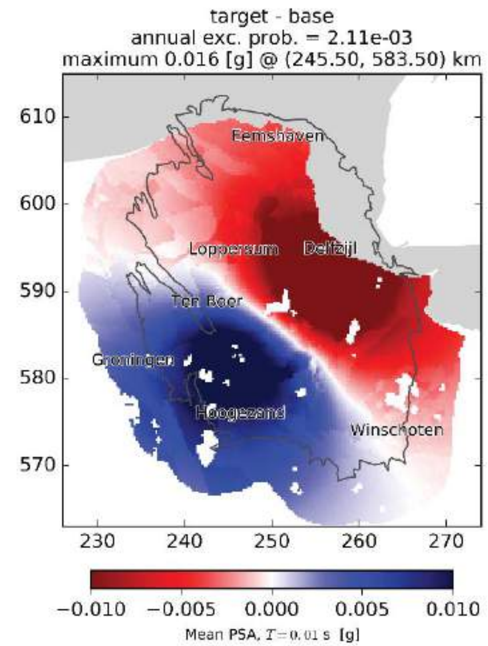
In this section the hazard for the gas-year 2019 – 2020 is presented. Figure 5.9 shows the hazard maps for both Operational Strategies together with a map of the difference between these strategies. This is shown for an average temperature year, a cold temperature year and a warm temperature year.




Operational Strategy 2

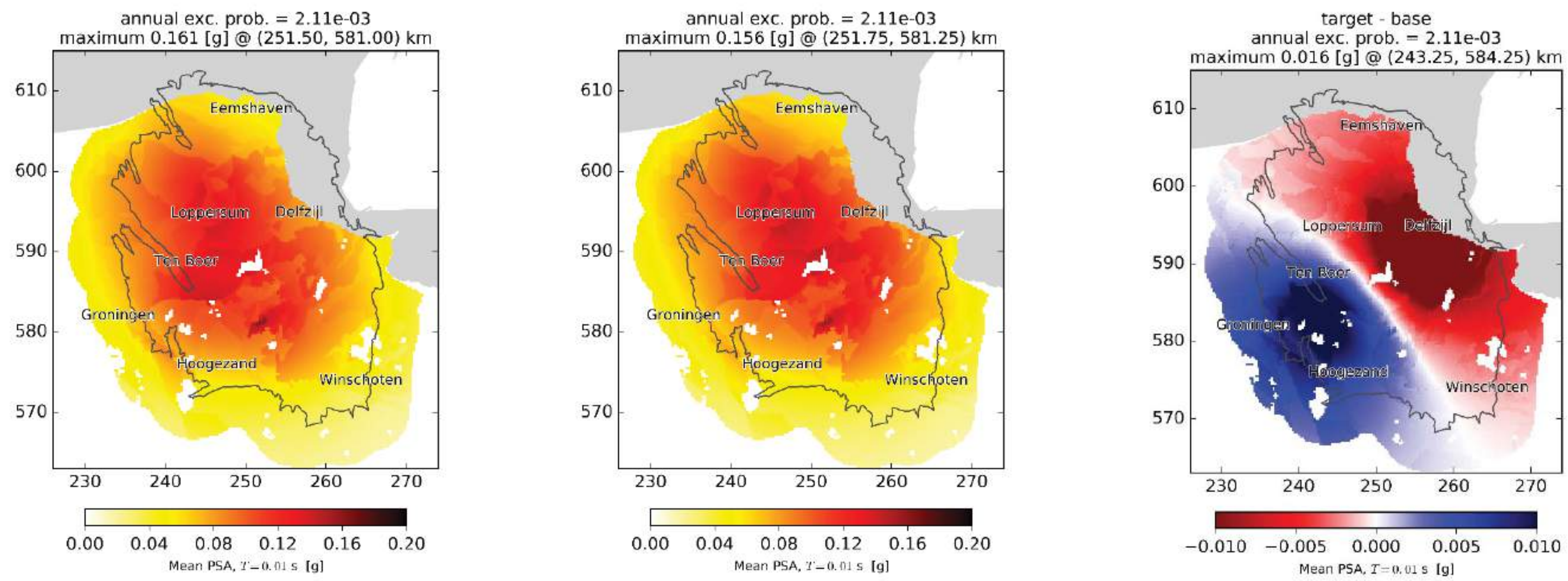



Operational Strategy 1



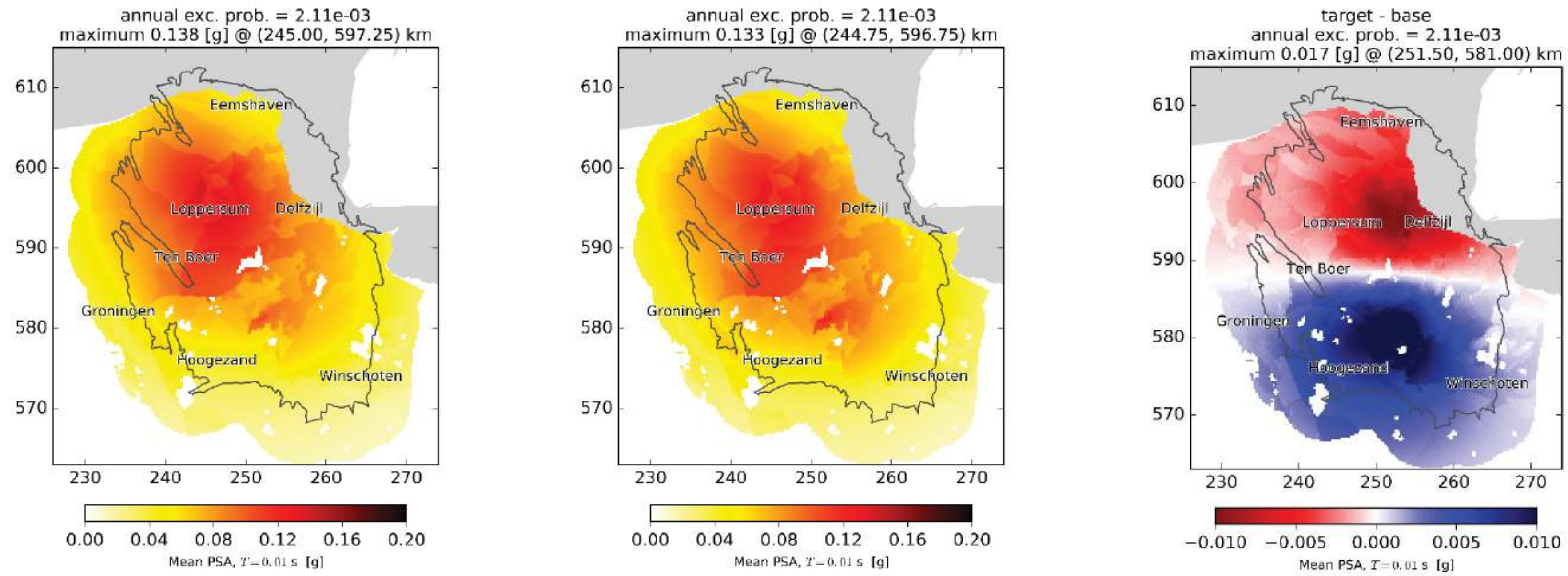

(Operational Strategy 2) – (Operational Strategy 1)

*Figure 5.9a* *Hazard maps for the production profile GTS-raming 2019 for the average temperature year. Both Operations Strategies and the difference between these strategies are shown.*




Operational Strategy 2 | Operational Strategy 1 | (Operational Strategy 2) – (Operational Strategy 1)

*Figure 5.9b* *Hazard maps for the production profile GTS-raming 2019 for the cold temperature year. Both Operations Strategies and the difference between these strategies are shown.*




Operational Strategy 2 | Operational Strategy 1 | (Operational Strategy 2) – (Operational Strategy 1)

*Figure 5.9c* *Hazard maps for the production profile GTS-raming 2019 for the warm temperature year. Both Operations Strategies and the difference between these strategies are shown.*

# 6 Risk Assessment

## Risk Metrics

The results from the probabilistic seismic Hazard and Risk Assessment (HRA) are summarised via risk metrics, which are related to the annualised probability of fatality for an individual person or for groups of people, taken as an average across the forecast period of the Hazard and Risk Assessment.

When assessing risk, it is important to select a risk metric that is appropriate given the purpose of the risk assessment. In many cases there is more than one option available as to which metric to use. An advisory committee, Commissie Meijdam, was established in early 2015 to advise the Minister of Economic Affairs and Climate Policy on risk policy related to Groningen earthquakes, including the selection and definition of the appropriate risk metrics. In December 2015, the Commissie Meijdam shared its third and final advice with the Minister of Economic Affairs (Ref. 9 to 11). The selection of risk metrics for this Hazard and Risk Assessment is based on the final advice published by Commissie Meijdam.

### Individual Risk Metrics

#### *Object-related Individual Risk and Individual Risk*

The Commissie Meijdam, introduced two individual risk metrics; Individual Risk (IR) and Object-related Individual Risk (OIA). Table 6.1 lists the definitions of the individual risk metrics used in the assessment of risk for induced seismicity in the Groningen field area. The fundamental principle of the advice of the Commission is that living and working in Groningen must be as safe as elsewhere in the Netherlands. In Groningen the same safety standards must apply as elsewhere in the Netherlands. Based on this principle the Committee Meijdam established the norm that Individual Earthquake Risk (IR) should be below $10^{-5}$/year.

For buildings with an OIA above $10^{-4}$/year, immediate action is required. In principle these buildings need to be strengthened immediately or vacated. Buildings with an OIA between $10^{-4}$/year and $10^{-5}$/year need to be strengthened within a reasonable period.

#### *Inside and Outside Local Personal Risk*

To perform the calculations, NAM uses as an intermediary result, the individual risk metric LPR (Local Person Risk) consisting of two components; Inside Local Personal Risk (ILPR) and Outside Local Personal Risk (OLPR). The use of LPR is analogous to safety assessment domains like those used for industrial activities and pipelines. “Local Personal Risk” (LPR) is generally defined as the annual probability of fatality for a fictional person, who is continuously present, without protection, at a specific at-risk location. For Groningen earthquakes, LPR is defined as follows: *“the probability of death of a fictional person who is permanently in or near a building”*. The location of the person within the building is uniformly and randomly distributed inside the building. This means that if 10% of the building collapses there is also a 10% probability that the fictional person will be in the collapsed part of the building.

| Risk Metric | Dutch Name | Definition | Purpose(s) |
| --- | --- | --- | --- |
| Object-related Individual Risk | Objectgebonden Individueel Aardbevingsrisico (OIA) | The Objectgebonden individual earthquake risk is the risk that an individual dies in a year due to collapse or falling objects (as a result of an earthquake) of a building in which or in the direct vicinity of which this person is present. The residence time in/around that building is therefore taken into consideration. | Local individual risk metric to measure fatality risk due to structural and non-structural collapse (LPR, see below), weighted by the average residence times of the individuals in/around the building (OIA), relative to norm of $10^{-5}$/year overall individual risk. Check if any buildings have occupants with an average OIA above $10^{-4}$/year (high priority for immediate action). |
| Individual Earthquake Risk | Individueel Aardbevingsrisico (IAR) | The individual earthquake risk is the annual risk that an individual is exposed to in the various structures in or near which this individual is present. | Individual risk metric that is not considered at present (as requires knowledge of the presence of all members of the Groningen community throughout the day, in order to sum up all their object-bound individual risks over a 24-hour period). |
| Inside Local Personal Risk (ILPR) | Plaatsgebonden Persoonlijk Risico Binnen | The probability of death of a fictional unprotected person who is permanently present in a building. | Local risk metric to measure fatality risk due to collapse of a given building and its non-structural elements both inside (ILPR) and outside (OLPR) the building, relative to the norm of $10^{-5}$/year overall individual risk.<br>Check if any buildings have Local Personal Risk above $10^{-4}$/year (high priority for immediate action). |
| Outside Local Personal Risk (OLPR) | Plaatsgebonden Persoonlijk Risico Buiten | The probability of death of a fictional unprotected person who is permanently present near a building. | |
| Local Personal Risk (LPR) | Plaatsgebonden Persoonlijk Risico | The probability of death of a fictional unprotected person who is permanently present in or near a building. This person is thought to be inside the building 99% of the time and outside near the building 1 % of the time. | |

*Table 6.1 Overview of the individual risk metrics used in the assessment of risk for induced seismicity in the Groningen field area.*

Inside Local Personal Risk is the probability of fatality for an individual continuously present in a building. It is associated with partial or full collapse of the building. Outside Local Personal Risk is the probability of fatality for an individual continuously present in the direct vicinity of a building. It is primarily associated with failure of non-structural elements, the so-called falling objects[7] (chimneys, balconies, parapets, etc.). In this context the vicinity of a building is taken as within 5 m from the building.

The Inside Local Personal Risk and Outside Local Personal Risk are aggregated to Local Personal Risk (LPR) assuming a *fictional person* is 99% of the time inside a building and 1% of the time outside the building, but in the direct vicinity of the building. The definition of these risk metrics is also listed in table 6.1.

As Local Personal Risk applies to a fictional unprotected person who is permanently present (everywhere) in a building, it is a property of this building. It is independent of the actual occupancy of the building; how many people are present in the building and the duration of their presence are not taken into account, when assessing the LPR of a building. LPR is presented as a cumulative distribution (of buildings versus risk level), which provides an estimate of the number of buildings that do not comply with the norm.

### *Current Practice in Risk Assessments*

However, the Meijdam-norm applies to Individual Risk. To assess Individual Risk for a person in a rigorous manner knowledge of the buildings the person visits during the day and the duration the person is present in these building is required. The Individual Risk of a person is the duration weighted sum of the LPR of the buildings visited during the day.

Typically, a person spends more than half her time in her house, some eight hours during week-days in an office (or workplace building), some time in shops or other public buildings and the remaining hours in the open air or in her car (where earthquake related risk is in general very low). Calculation of Individual Risk for all members of the full Groningen community using this method is not practically feasible as it requires, beside knowledge of all buildings in Groningen, also knowledge of the presence of all members of the Groningen community throughout the day. This detailed residence data, NAM does not have access to. Additionally, an assessment of IR for all members of the Groningen community does not directly suggest which buildings do not comply with the norm.

In previous risk assessments, NAM has therefore used a practical approach, whereby the number of buildings with a mean LPR above the norm level was evaluated and compared to the threshold safety levels of the Meijdam-norm. The underlying principle was that if all buildings have a mean LPR below the norm, no persons can be exposed to an IR above the norm. The LPR inherently assumes a full-time (100%) residency of the building. In the Hazard and Risk Assessment, the mean LPR is the primary metric used to compare against the $10^{-5}$/year individual risk norm (as recommended by Commissie Meijdam, which requires the individual risk for a person to be less than $10^{-5}$ per year). Note that individual risk metrics that account for the proportion of time a person spends in the building will yield a lower calculated individual risk (IR) than LPR (particularly for buildings occupied a small proportion of the time). The method used by NAM based on mean LPR instead of IR is conservative (over-estimates the number of buildings above the risk norm).

[7] Falling Objects are sometimes also referred to as High Risk Building Elements (HRBE) or Potential High Risk Building Elements (PRBE).

### *Proposed improvement of the Risk Assessment*

The panel of professors has pointed out that this is a conservative approach (Ref. 39 to 41), which inherently assumes that for each building individuals spend their full time there. The panel therefore proposed to assess OIA based on mean residence periods and compare this to the norm level set by the Committee Meijdam. This is a preferred implementation of the norm set by the Committee Meijdam and is less conservative.

The use of OIA to compare to the safety-norm inherently assumes that the time an individual spends in other buildings does not significantly add to his IR. Inspection of the list of buildings that do not meet the mean LPR norm (consisting of some 1,500 buildings) shows that it primarily contains buildings with a residence functionality and few office buildings, schools or other public buildings. Since the fraction of buildings exceeding the norm is relatively small compared to the total building stock, it is reasonable to take the LPR of a dwelling multiplied with the average residence time of the occupants as the IR of its occupants.

### *Residence Time Estimates*

To be able to implement the Object-related Individual Risk (OIA) including the residence times of the people living and present in a building, we need to know the mean residences times for the buildings. This depends on the usage of the building. The residence time for residential buildings will be most important as most buildings on the building risk ranking are residential buildings.

The report "Met het oog op de tijd" ("With an eye on the time") van het Social Planning Bureau (Ref. 42) provides information on how the Dutch spend their time. Based on the time spent on various activities, the time people spend in their own home can be estimated. Table 6.3 gives an overview of the time the Dutch engage in various activities during the week taken from this report. The report provides time estimates for the activities; *verplichte tijd, persoonlijk tijd en vrij tijd* (obligatory time, personal time and leisure time). These time estimates have been copied from the report (in the green section of the table). The references to the pages of the report are provided. The report also gives an overview of the time spent travelling to engage in these activities (also in green in the table). In the red section of the table the activities are allocated to a location; at home, at the workplace, at school and in the car and open space. In the blue section of the table time-fractions at these locations are calculated based on the time data. It shows that on average the residence time for a person in her/his own home is 75%.

For residential buildings, the mean OIA of the building will, when including the mean residence time, be 75% of the mean LPR.

Mean residence times for office buildings are more easily assessed. For a work place like an office building this is 24% based on a 40 hr per week work week. Working over-time is balanced by an average work-week of 36 hour per week for many people. This residence time is applied to all buildings with a usage associated with work; commercial business, agricultural, educational and industrial. Table 6.2 showing data on working hours from "Met het oog op de tijd" ("With an eye on the time", Ref. 42) shows this is a conservative approach.

| | Average hours spend working | Participation |
|---|---|---|
| Men | 39,6 | 83 % |
| Women | 25,6 | 72 % |
| Overall | 33,2 | 78 % |

*Table 6.2 Time spent working and participation.*

The residence time of Health Case buildings is set to 100% based on the presence of boarding patients. The residence time for religious buildings is 2% based on 3,5 hours religious practice in the religious building. Table 6.4 shows the mean residence time fractions for the different building usage categories.

| Building Use | Residence Time Fraction |
|---|---|
| Woonfunctie | 75% |
| Logiesfunctie | 50% |
| Industriefunctie | 24% |
| Winkelfunctie | 24% |
| Kantoorfunctie | 24% |
| Bijeenkomstfunctie | 24% |
| Overige gebruiksfunctie | 24% |
| Sportfunctie | 24% |
| Onderwijsfunctie | 24% |
| Celfunctie | 100% |
| Gezondheidszorgfunctie | 100% |
| <blank> -- anything unknown is assumed to be Residential | 75% |

*Table 6.4 Residence times for the building usage categories.*

Some buildings have both a primary and secondary building use. An example is a building with a shop (commercial business) at the ground floor and apartments on the first and higher floors (residential). In this case, a commercial business use combined with a residential use, the larger of the two residential time fractions will be assigned to the building. In general, the residence time fraction is the larger of the residence time for the primary and the secondary use.

## Number of buildings compared to the safety norm

In this section of the report, the number of houses where the risk exceeds one of the two risk safety levels of the Meijdam safety-norm is discussed, without addressing which of the two levels applies for an individual building, as such is the domain of the NCG, who currently directs the strengthening effort. Both mean LPR and mean OIA of a building will be calculated and reported. The mean OIA is calculated as the product of the LPR and the residence time fraction. These fractions are treated as fixed. Both in the cumulative LPR-plots and the cumulative OIA-plots uncertainty is indicated by a grey band.

### Assessment of Local Personal Risk (LPR)

Figures 6.1a and 6.1b show the number of buildings exceeding an annual mean Local Personal Risk (LPR) for each year of the 10-year period 2019 to 2028, based on the average temperature year and the optimised Operational Strategy to minimise the event rate. The grey bands in these LPR-graphs indicate the uncertainty range. Figure 6.2 shows the LPR-graphs for the two five-year periods 2019 to 2023, and 2024 to 2028. The impact of the buildings already strengthened to date has not been incorporated in this assessment.

| | Tijd (uren) | Tijd (uren) | Verwijzing in MHOODT | | Tijd (uren) | Verwijzing in MHOODT | | Huis | Kantoor | Buiten | School | Winkel | Totaal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Verplichte tijd** | 41,2 | | | | | | | | | | | | |
| huishouden + | | 17,9 | pg. 34 en 35 | thuis | 15,7 | | 100% huis | 12,7 | | | | 3 | |
| zorgtaken | | | | Huishouden + zorgtaken | | | | | | | | | |
| | | | | mobiliteit | 2,2 | | 100% buiten | | | 2,2 | | | |
| | | | | | 17,9 | | | | | | | | |
| betaald werk | | 19,6 | pg. 34 en 35 | op werk plek | 17 | | 100% werkplek | | 17 | | | | |
| | | | | verplichtetijdsmobiliteit | 2,6 | pg. 143 | 100% buiten | | | 2,6 | | | |
| | | | | | 19,6 | | | | | | | | |
| onderwijs | | 3,7 | pg. 34 en 35 | Op school | 3,2 | | 100% school | | | | 3,2 | | 41,2 |
| | | | | Onderwijs mobiliteit | 0,5 | | 100% buiten | | | 0,5 | | | |
| | | 41,2 | pg. 34 en 35 | | 3,7 | | | | | | | | |
| **Persoonlijke tijd** | 77,7 | | | | | | | | | | | | |
| slapen | | 59,5 | pg. 41 en 42 | | | | 100% huis | 59,5 | | | | | |
| eten/drinken | | 11,9 | pg. 41 en 42 | | | | 100% huis | 10,2 | 1,7 | | | | |
| persoonlijke verzorging | | 6,2 | pg. 41 en 42 | | | | 100% huis | 6,2 | | | | | 77,6 |
| | | 77,6 | | | | | | | | | | | |
| **Vrije tijd** | 47,8 | | | **Anders** | | | | | | | | | |
| media gebruik | | 20,9 | pg. 43 | binnenshuis | 32,1 | pg. 46 | 100% huis | 32,1 | | | | | |
| sociale contacten | | 7,2 | pg. 43 | uithuizig | 15,7 | pg. 46 | 100% buiten | | | 15,7 | | | 47,8 |
| recreatief + ontspanning | | 13,5 | pg. 43 | | 47,8 | | | 120,7 | 18,7 | 21 | 3,2 | 3 | 166,6 |
| maatschappelijke participatie | | 2,3 | pg. 43 | | | | | | | | | | |
| vrijetijdsmobiliteit | | 3,6 | pg. 43 | | | | | 72,4% | 11,2% | 12,6% | 1,9% | 1,8% | 100% |
| | | 47,5 | | | | | | | | | | | |
| **Gespecificeerd** | 166,7 | | pg. 34 | | | | | 74% | 9% | 13% | 2% | 2% | 100% |
| **Ongespecificeerd** | 1,3 | | pg. 34 | | | | | | | | | | |
| | 168 | | | | | | | | | | | | |
| **Onderweg tijd** | 9 | | | | | | | | | | | | |
| vrijetijdsmobiliteit | | 3,6 | pg. 143 | | | | | | | | | | |
| huishouden en zorgtaken | 2,2 | | pg. 143 | | | | | | | | | | |
| onderwijs | 0,5 | | pg. 143 | | | | | | | | | | |
| betaald werk | 2,6 | | pg. 143 | | | | | | | | | | |
| verplichtetijdsmobiliteit | | 5,3 | pg. 143 | | | | | | | | | | |
| | | 8,9 | | | | | | | | | | | |

*Table 6.3* *Table of time the Dutch spend on various activities. From this time data the mean residence time for her/his own home is estimated. The following assumptions are used (but these have only a small impact) (1) Care duties include 3 hours outside the home (i.e. shopping), (2) All worktime excluding travel is spent in an office and (3) Once a week people eat outside the home.*

The development of the mean LPR for the Groningen building stock over the period 2019 to 2028 is shown in figure 6.3. The number of buildings exceeding the Meijdam-norm of mean LPR $10^{-5}$/year shows a declining trend. This is particularly evident for the years 2019 to 2022 the number of buildings exceeding this norm declines noticeably. For each year in the period 2019 to 2028, tables 6.5a to 6.5d, show the number of buildings for four different probabilistic assessments:

- The number of buildings with LPR exceeding the $10^{-5}$/year level
- The number of buildings with LPR exceeding the $10^{-4}$/year level
- The number of buildings with OIA exceeding the $10^{-5}$/year level
- The number of buildings with OIA 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 826 in 2019 to about 208 in 2023 and less than one hundred in 2027, for production profile "GTS-raming 2019" for an average temperature profile and Operational Strategy 2.

The data captured in tables 6.5a to 6.5d is also shown in figures 6.4 and 6.5, which shows number of buildings where the LPR and OIA respectively exceeds the $10^{-4}$/year and $10^{-5}$/year, for different profiles.

The LPR results can be disaggregated to show the separate contributions of the different building typologies (shown in figure 6.6) as well as their collapse states contributing 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.

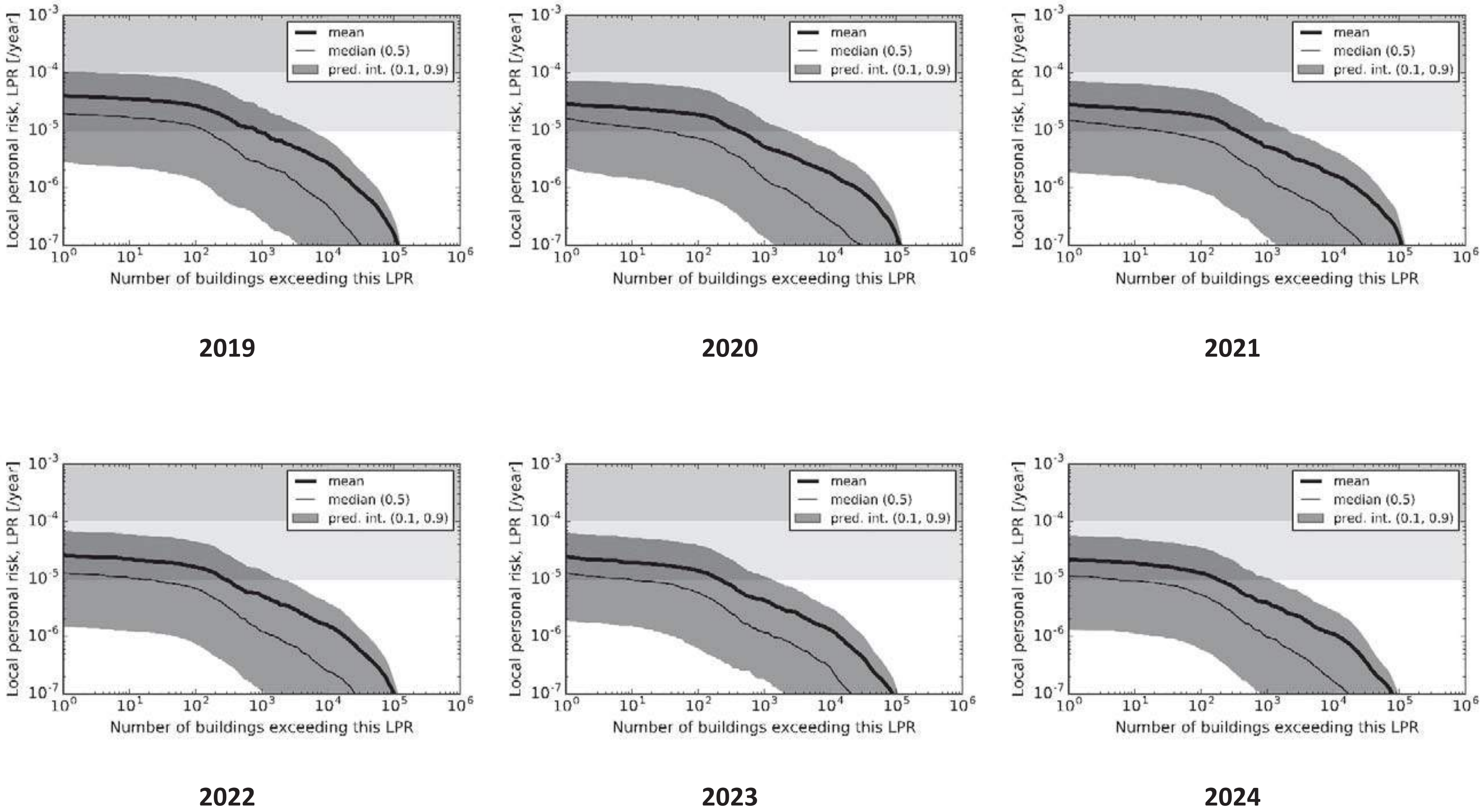
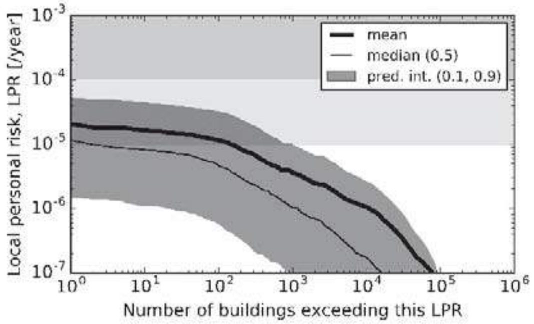
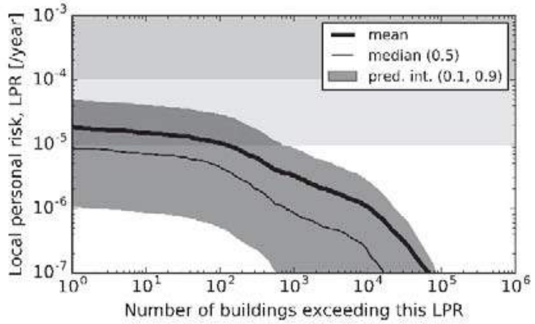


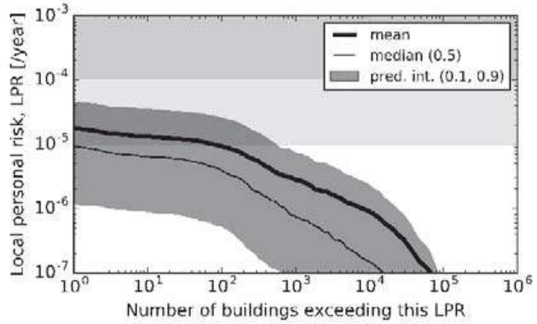

*Figure 6.1a* *Local Personal Risk graphs for the years 2019 to 2024. These show the number of houses that are exposed to a LPR. The black lines denote the mean and the dark grey areas the uncertainty bands. The two horizontal bands in light grey denote the LPR levels of the Meijdam-Norm.*



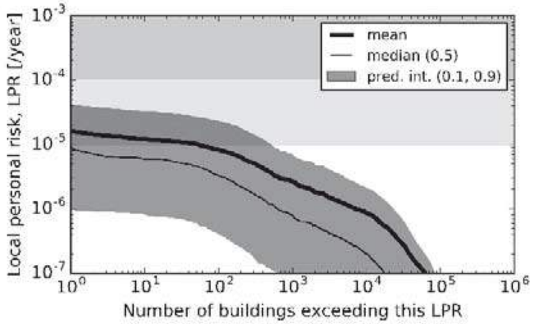

**2025**




**2026**

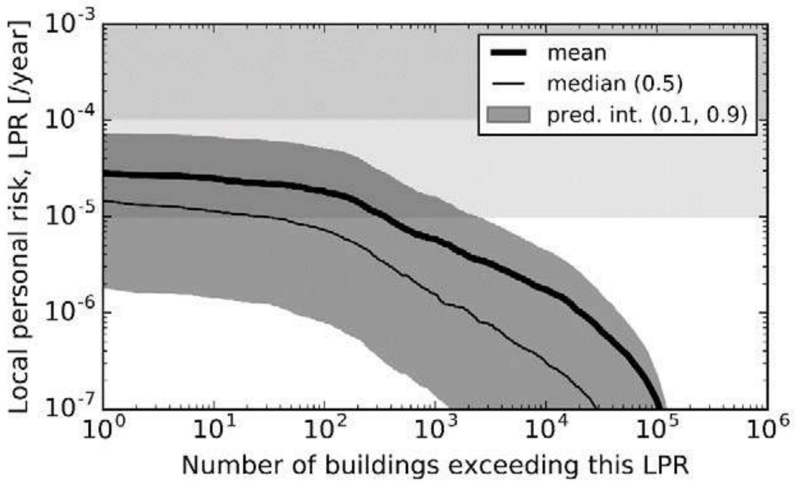



**2027**

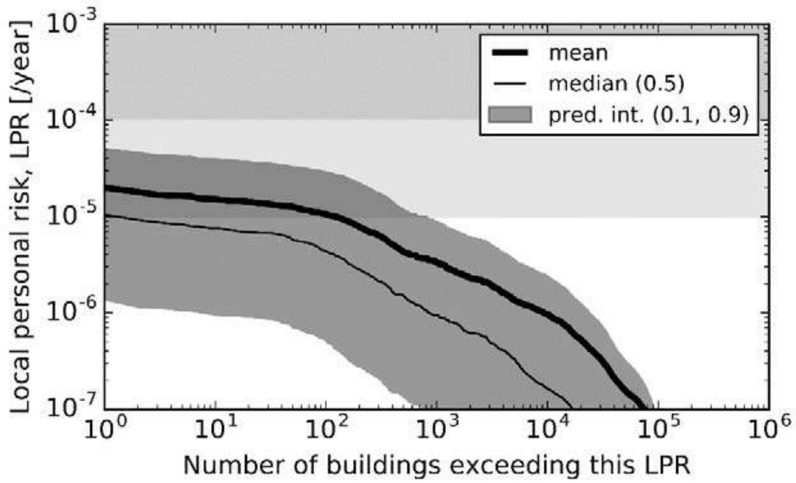



**2028**

*Figure 6.1b* *Local Personal Risk graphs for the years 2025 to 2028. 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. The assessment is based on production profile "GTS-raming 2019" for an average temperature year using the optimisation to minimise the event count (Operational Strategy 2).*




**2019 - 2023**




**2024 - 2028**

*Figure 6.2* *Local Personal Risk graphs for the two 5-year periods (2019 to 2023 and 2024 to 2028). 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. The assessment is based on production profile "GTS-raming 2019" for an average temperature year using the optimisation to minimise the event count (Operational Strategy 2).*

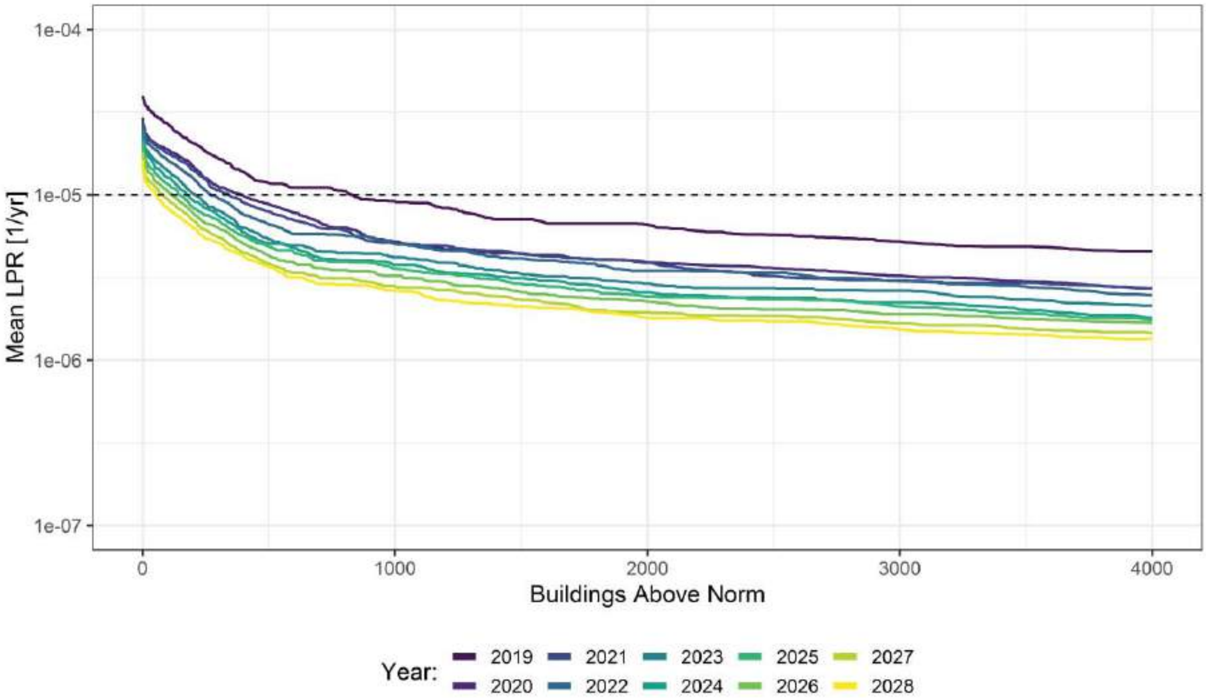



*Figure 6.3a* *Mean Local Personal Risk graphs for the years 2019 to 2028. These show the number of buildings that are exposed to an LPR. The uncertainty bands have been left out of this graph but are shown in figures 6.1a and 6.1b. The years are colour coded. The assessment is based on production profile "GTS-raming 2019" for an average temperature year using the optimisation to minimise the event count (Operational Strategy 2).*
*Note that the number of buildings exceeding the mean LPR norm of $10^{-5}$/year decreases over time.*

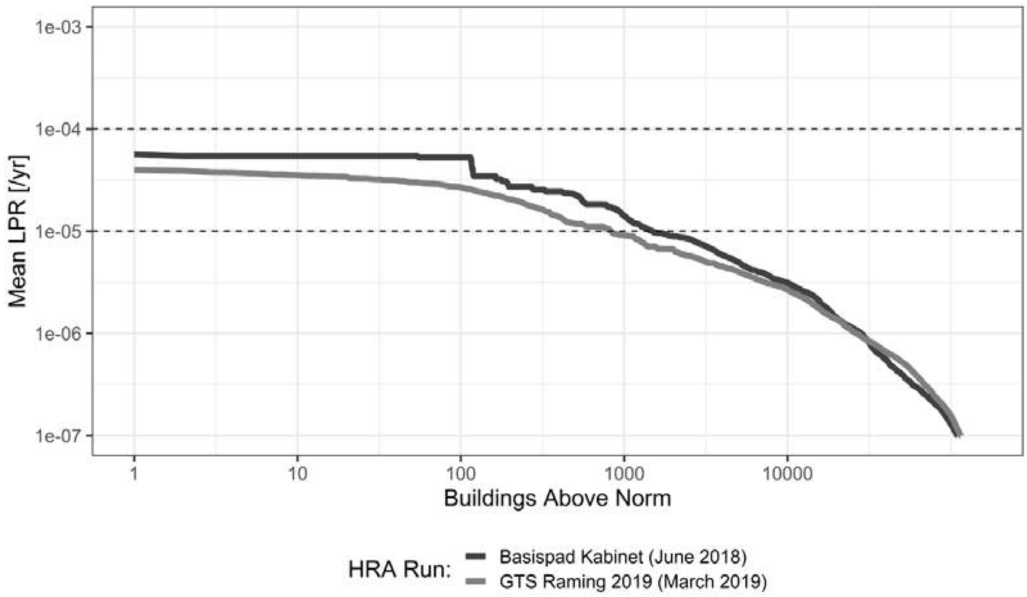



*Figure 6.3b* *Comparison of the mean Local Personal Risk graphs for the year 2019. Production profile "Basispad Kabinet" and "GTS-raming 2019" are shown.*

| Production Profile | Optimisation Profile | Temperature | Year | Mean OIA $10^{-5}$ /year | Mean OIA $10^{-4}$ /year | Mean LPR $10^{-5}$ /year | Mean LPR $10^{-4}$ /year |
|---|---|---|---|---|---|---|---|
| GTS-raming 2019 | Event rate | Average Year | 2019 | 402 | 0 | 780 | 0 |
| GTS-raming 2019 | Event rate | Average Year | 2020 | 224 | 0 | 385 | 0 |
| GTS-raming 2019 | Event rate | Average Year | 2021 | 211 | 0 | 338 | 0 |
| GTS-raming 2019 | Event rate | Average Year | 2022 | 169 | 0 | 265 | 0 |
| GTS-raming 2019 | Event rate | Average Year | 2023 | 108 | 0 | 204 | 0 |
| GTS-raming 2019 | Event rate | Average Year | 2024 | 80 | 0 | 171 | 0 |
| GTS-raming 2019 | Event rate | Average Year | 2025 | 53 | 0 | 143 | 0 |
| GTS-raming 2019 | Event rate | Average Year | 2026 | 33 | 0 | 113 | 0 |
| GTS-raming 2019 | Event rate | Average Year | 2027 | 6 | 0 | 77 | 0 |
| GTS-raming 2019 | Event rate | Average Year | 2028 | 4 | 0 | 52 | 0 |
| ReferenceCase (Basispad Kabinet) | | Average Year | 2019 | 420 | 0 | 916 | 0 |
| ReferenceCase (Basispad Kabinet) | | Average Year | 2020 | 382 | 0 | 788 | 0 |
| ReferenceCase (Basispad Kabinet) | | Average Year | 2021 | 296 | 0 | 434 | 0 |
| ReferenceCase (Basispad Kabinet) | | Average Year | 2022 | 216 | 0 | 345 | 0 |
| ReferenceCase (Basispad Kabinet) | | Average Year | 2023 | 115 | 0 | 213 | 0 |
| ReferenceCase (Basispad Kabinet) | | Average Year | 2024 | 84 | 0 | 173 | 0 |
| ReferenceCase (Basispad Kabinet) | | Average Year | 2025 | 59 | 0 | 152 | 0 |
| ReferenceCase (Basispad Kabinet) | | Average Year | 2026 | 25 | 0 | 117 | 0 |
| ReferenceCase (Basispad Kabinet) | | Average Year | 2027 | 11 | 0 | 77 | 0 |
| ReferenceCase (Basispad Kabinet) | | Average Year | 2028 | 6 | 0 | 57 | 0 |

*Table 6.5a* *Number of buildings with mean LPR exceeding $10^{-5}$/year and $10^{-4}$/year level for LPR, for different production and temperature profiles. See main text for further explanation. These are shown for each year of the period 2018 to 2027 for the production profile "GTS-raming 2019" for an average weather year and the reference case of "Basispad Kabinet".*

| Production Profile | Optimisation Profile | Temperature | Year | Mean OIA $10^{-5}$ /year | Mean OIA $10^{-4}$ /year | Mean LPR $10^{-5}$ /year | Mean LPR $10^{-4}$ /year |
|---|---|---|---|---|---|---|---|
| GTS-raming 2019 | Event rate | Cold Year | 2019 | 460 | 0 | 801 | 0 |
| GTS-raming 2019 | Event rate | Cold Year | 2020 | 304 | 0 | 547 | 0 |
| GTS-raming 2019 | Event rate | Cold Year | 2021 | 220 | 0 | 353 | 0 |
| GTS-raming 2019 | Event rate | Cold Year | 2022 | 170 | 0 | 282 | 0 |
| GTS-raming 2019 | Event rate | Cold Year | 2023 | 124 | 0 | 222 | 0 |
| GTS-raming 2019 | Event rate | Cold Year | 2024 | 90 | 0 | 188 | 0 |
| GTS-raming 2019 | Event rate | Cold Year | 2025 | 64 | 0 | 147 | 0 |
| GTS-raming 2019 | Event rate | Cold Year | 2026 | 51 | 0 | 137 | 0 |
| GTS-raming 2019 | Event rate | Cold Year | 2027 | 10 | 0 | 85 | 0 |
| GTS-raming 2019 | Event rate | Cold Year | 2028 | 6 | 0 | 62 | 0 |
| GTS-raming 2019 | Event rate | Warm Year | 2019 | 391 | 0 | 786 | 0 |
| GTS-raming 2019 | Event rate | Warm Year | 2020 | 171 | 0 | 281 | 0 |
| GTS-raming 2019 | Event rate | Warm Year | 2021 | 201 | 0 | 325 | 0 |
| GTS-raming 2019 | Event rate | Warm Year | 2022 | 153 | 0 | 249 | 0 |
| GTS-raming 2019 | Event rate | Warm Year | 2023 | 126 | 0 | 217 | 0 |
| GTS-raming 2019 | Event rate | Warm Year | 2024 | 66 | 0 | 161 | 0 |
| GTS-raming 2019 | Event rate | Warm Year | 2025 | 43 | 0 | 139 | 0 |
| GTS-raming 2019 | Event rate | Warm Year | 2026 | 28 | 0 | 105 | 0 |
| GTS-raming 2019 | Event rate | Warm Year | 2027 | 6 | 0 | 56 | 0 |
| GTS-raming 2019 | Event rate | Warm Year | 2028 | 2 | 0 | 31 | 0 |

*Table 6.5b Number of buildings with mean LPR exceeding $10^{-5}$/year and $10^{-4}$/year norm for LPR, for different production and temperature profiles. See main text for further explanation. These are shown for each year of the period 2018 to 2027 for the production profile "GTS-raming 2019" for cold weather and warm weather years.*

| Production Profile | Optimisation Profile | Temperature | Year | Mean OIA $10^{-5}$ /year | Mean OIA $10^{-4}$ /year | Mean LPR $10^{-5}$ /year | Mean LPR $10^{-4}$ /year |
|---|---|---|---|---|---|---|---|
| GTS-raming 2019 | pwPGV | Average Year | 2019 | 403 | 0 | 796 | 0 |
| GTS-raming 2019 | pwPGV | Average Year | 2020 | 277 | 0 | 434 | 0 |
| GTS-raming 2019 | pwPGV | Average Year | 2021 | 234 | 0 | 373 | 0 |
| GTS-raming 2019 | pwPGV | Average Year | 2022 | 185 | 0 | 286 | 0 |
| GTS-raming 2019 | pwPGV | Average Year | 2023 | 112 | 0 | 213 | 0 |
| GTS-raming 2019 | pwPGV | Average Year | 2024 | 66 | 0 | 169 | 0 |
| GTS-raming 2019 | pwPGV | Average Year | 2025 | 45 | 0 | 146 | 0 |
| GTS-raming 2019 | pwPGV | Average Year | 2026 | 17 | 0 | 97 | 0 |
| GTS-raming 2019 | pwPGV | Average Year | 2027 | 5 | 0 | 59 | 0 |
| GTS-raming 2019 | pwPGV | Average Year | 2028 | 2 | 0 | 43 | 0 |

*Table 6.5c* *Number of buildings with mean LPR exceeding $10^{-5}$/year and $10^{-4}$/year level for LPR, for different production and temperature profiles. See main text for further explanation. These are shown for each year of the period 2018 to 2027 for the production profile "GTS-raming 2019" for an average weather year and the reference case of "Basispad Kabinet".*

| Production Profile | Optimisation Profile | Temperature | Year | Mean OIA $10^{-5}$ /year | Mean OIA $10^{-4}$ /year | Mean LPR $10^{-5}$ /year | Mean LPR $10^{-4}$ /year |
|---|---|---|---|---|---|---|---|
| GTS-raming 2019 | pwPGV | Cold Year | 2019 | 457 | 0 | 975 | 0 |
| GTS-raming 2019 | pwPGV | Cold Year | 2020 | 395 | 0 | 879 | 0 |
| GTS-raming 2019 | pwPGV | Cold Year | 2021 | 244 | 0 | 370 | 0 |
| GTS-raming 2019 | pwPGV | Cold Year | 2022 | 172 | 0 | 284 | 0 |
| GTS-raming 2019 | pwPGV | Cold Year | 2023 | 111 | 0 | 203 | 0 |
| GTS-raming 2019 | pwPGV | Cold Year | 2024 | 65 | 0 | 163 | 0 |
| GTS-raming 2019 | pwPGV | Cold Year | 2025 | 52 | 0 | 133 | 0 |
| GTS-raming 2019 | pwPGV | Cold Year | 2026 | 25 | 0 | 103 | 0 |
| GTS-raming 2019 | pwPGV | Cold Year | 2027 | 7 | 0 | 66 | 0 |
| GTS-raming 2019 | pwPGV | Cold Year | 2028 | 2 | 0 | 25 | 0 |
| GTS-raming 2019 | pwPGV | Warm Year | 2019 | 385 | 0 | 790 | 0 |
| GTS-raming 2019 | pwPGV | Warm Year | 2020 | 195 | 0 | 312 | 0 |
| GTS-raming 2019 | pwPGV | Warm Year | 2021 | 218 | 0 | 363 | 0 |
| GTS-raming 2019 | pwPGV | Warm Year | 2022 | 177 | 0 | 291 | 0 |
| GTS-raming 2019 | pwPGV | Warm Year | 2023 | 91 | 0 | 191 | 0 |
| GTS-raming 2019 | pwPGV | Warm Year | 2024 | 55 | 0 | 155 | 0 |
| GTS-raming 2019 | pwPGV | Warm Year | 2025 | 34 | 0 | 129 | 0 |
| GTS-raming 2019 | pwPGV | Warm Year | 2026 | 10 | 0 | 76 | 0 |
| GTS-raming 2019 | pwPGV | Warm Year | 2027 | 3 | 0 | 53 | 0 |
| GTS-raming 2019 | pwPGV | Warm Year | 2028 | 2 | 0 | 17 | 0 |

*Table 6.5d* *Number of buildings with mean LPR exceeding $10^{-5}$/year and $10^{-4}$/year norm for LPR, for different production and temperature profiles. See main text for further explanation. These are shown for each year of the period 2018 to 2027 for the production profile “GTS-raming 2019” for cold weather and warm weather years.*

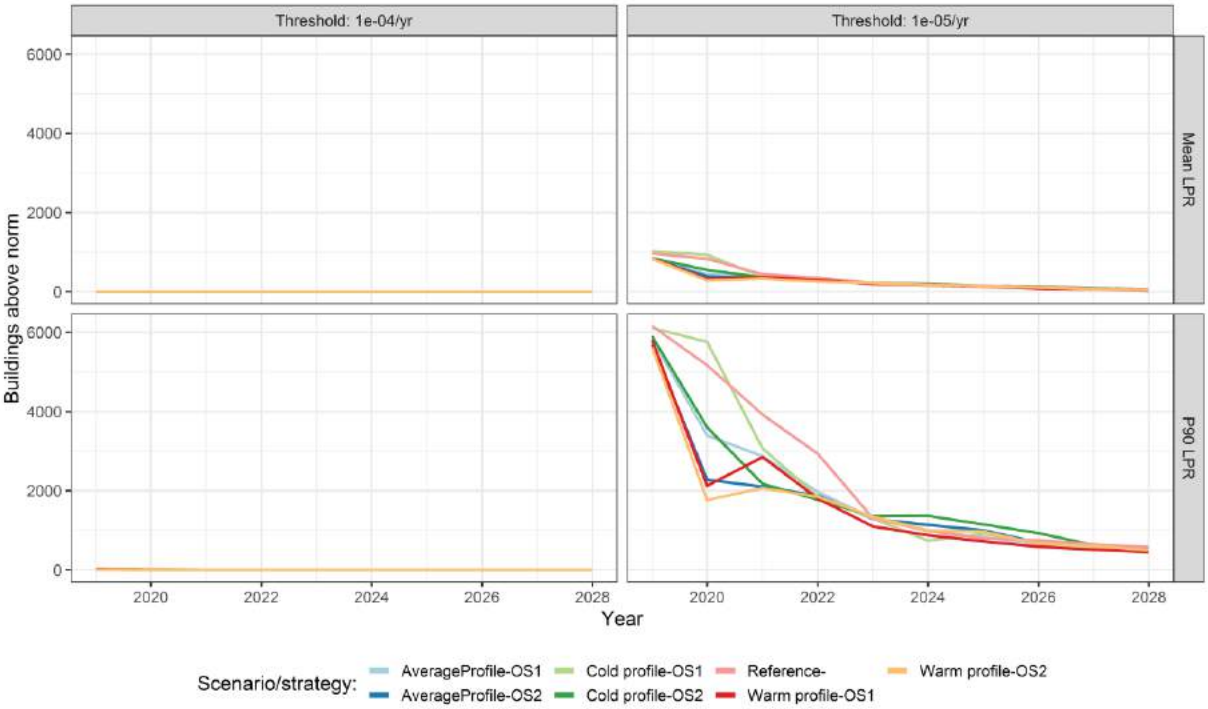
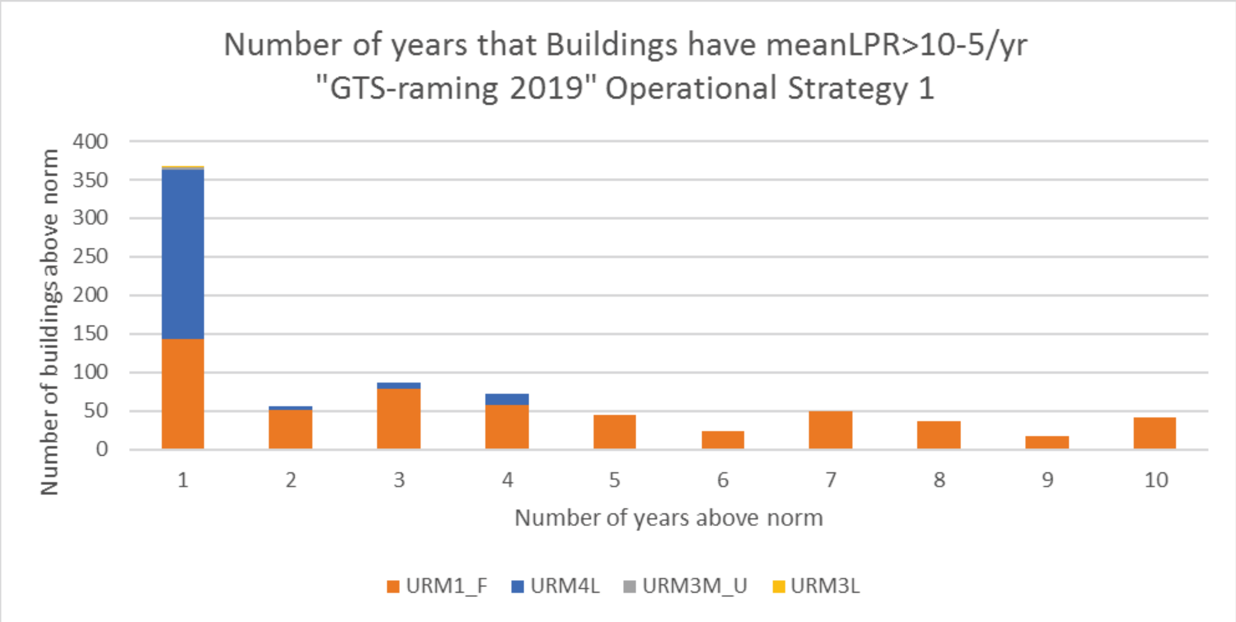



*Figure 6.4* *Graphs show the Local Personal Risk associated with the production profile "GTS-raming 2019" for average, cold weather and warm weather years, and the Reference Profile (Basispad Kabinet – 2 mei 2018), and for the period 2019 to 2028.*

| | |
|---|---|
| *Right graphs:* | *number of buildings exceeding the norm LPR larger than $10^{-5}$/year* |
| *Left graphs:* | *number of buildings exceeding the norm LPR larger than $10^{-4}$/year* |
| *Top graphs:* | *number of buildings exceeding the norm for mean LPR* |
| *Bottom graphs:* | *number of buildings exceeding the norm for P90 LPR* |

## Number of years above the norm

Figure 6.5 gives, for buildings above the norm in 2019, an overview of the duration that these buildings remain above the norm. For about half of them this duration is 1 year. All URM4L will drop below the norm within 4 years and 3 years respectively. Because URM1_F is most fragile, buildings of this type will remain above the norm for a longer period.



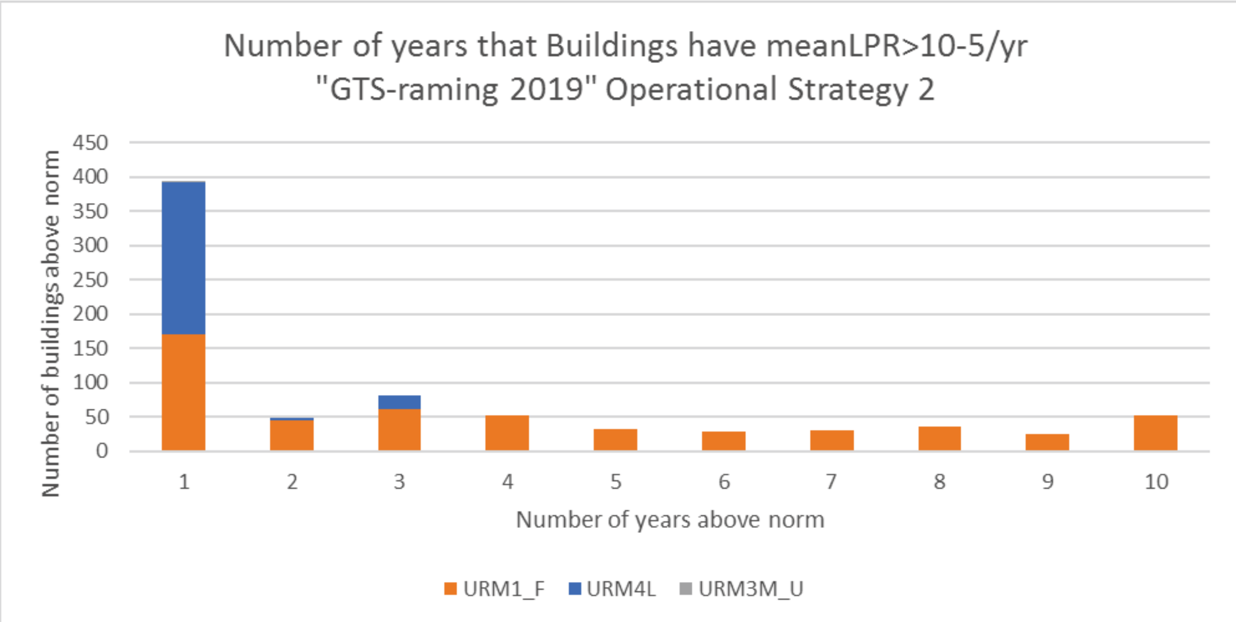




*Figure 6.5 Overview of the duration that these buildings remain above the norm for buildings above the norm in 2019, shown for Operational Strategy 1 above and Operational Strategy 2 below.*

## Individual Earthquake Risk (OIA)

As discussed in the previous section hazard metrics, a panel of professors has in three advises to the Minister (Ref. 39 to 41) pointed out that the use of mean LPR is a conservative interpretation of the Meijdam Norm (Ref. 9 to 11). In this section of the report the number of buildings not meeting the safety norm levels based on Individual Earthquake Risk are reported. For brevity, only the final results will be reported.

## Assessment of Object-related Individual Risk

The OIA of a building will be calculated as the product of the LPR and the residence time fraction. These fractions are treated as fixed. Both in the cumulative LPR-plots and the cumulative-OIA plots uncertainty is indicated by a grey band.

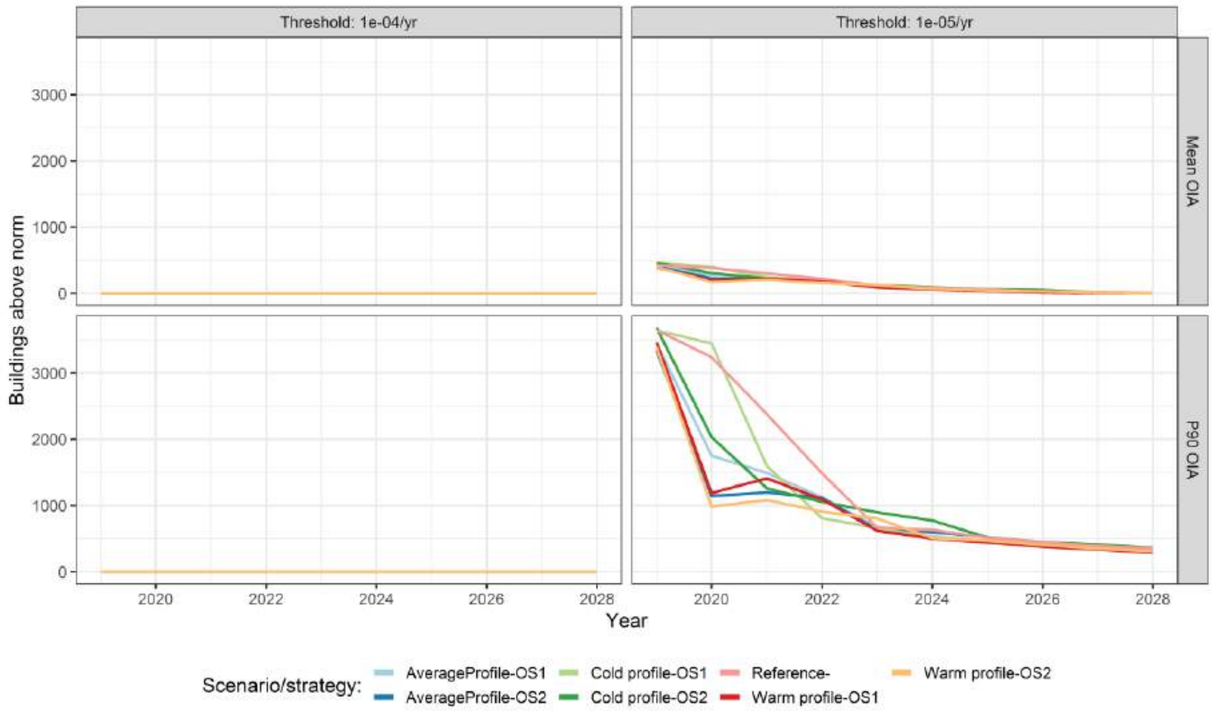
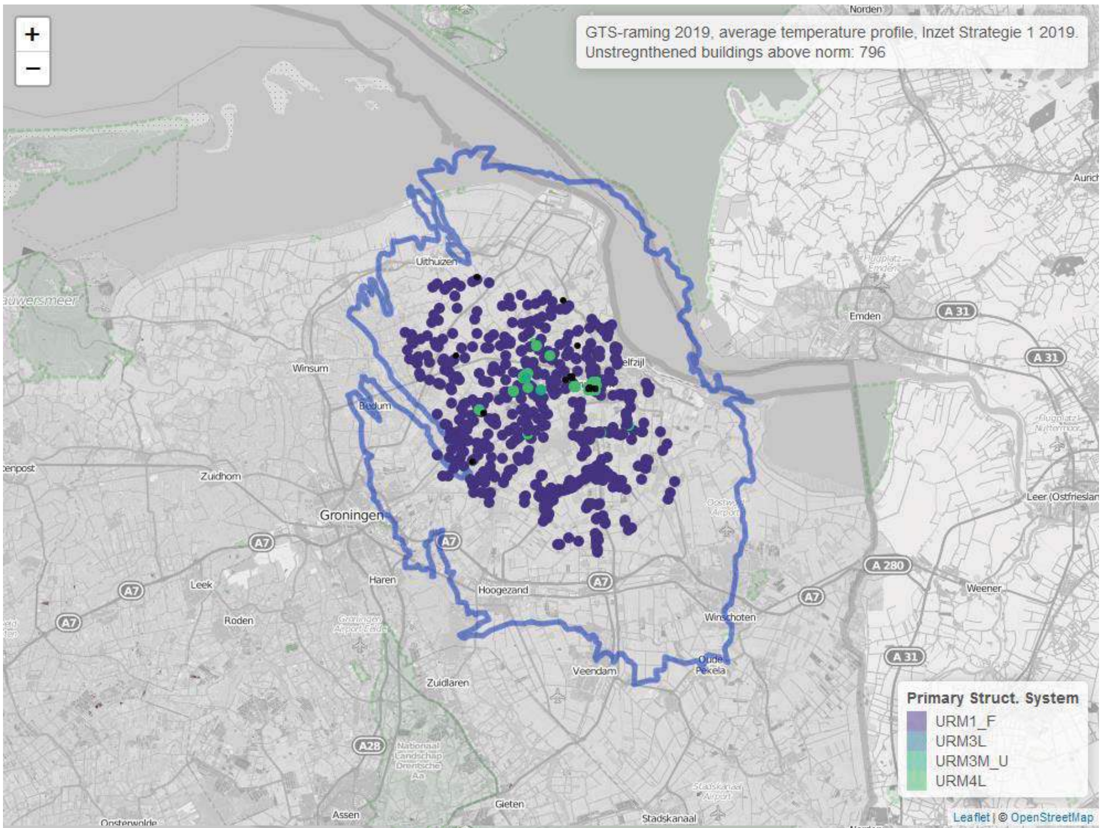


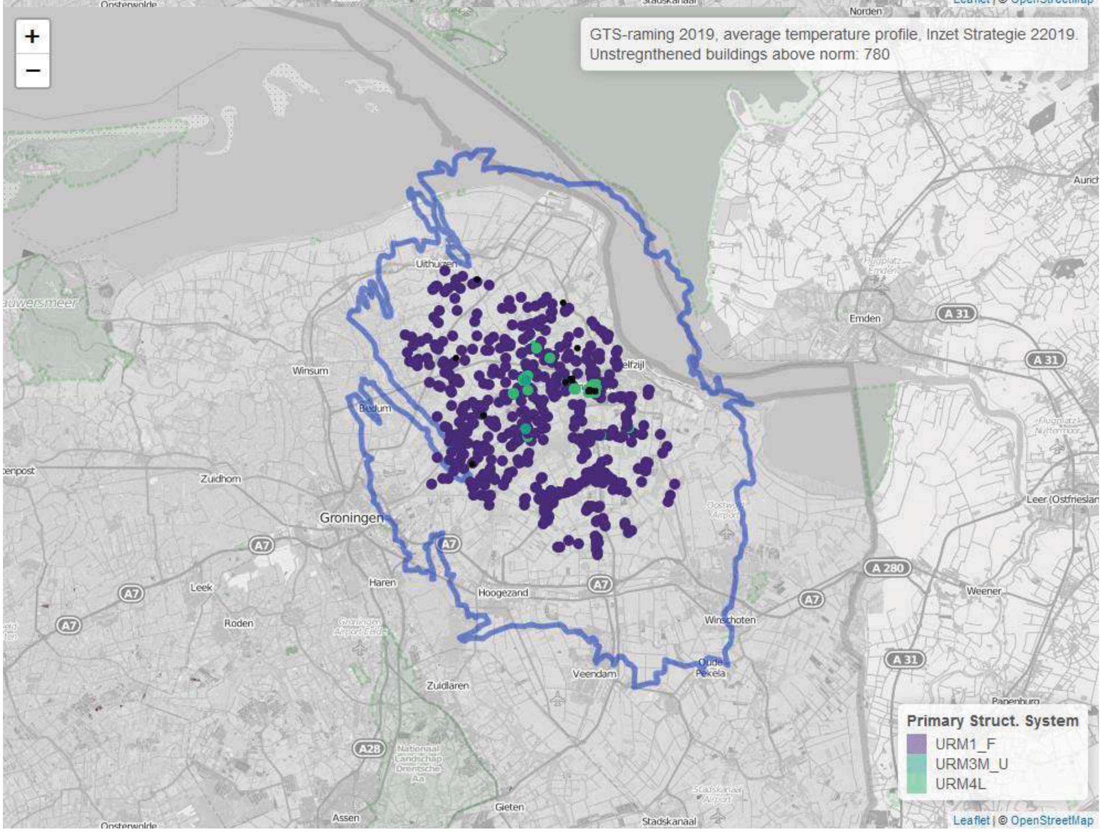

*Figure 6.6* *Graphs show the Individual Earthquake Risk associated with the production profile "GTS-raming 2019" for average, cold weather and warm weather years, and the Reference Profile (Basispad Kabinet – 2 mei 2018), and for the period 2019 to 2028.*

*Right graphs:* *number of buildings exceeding the norm OIA larger than $10^{-5}$/year*
*Left graphs:* *number of buildings exceeding the norm OIA larger than $10^{-4}$/year*
*Top graphs:* *number of buildings exceeding the norm for mean OIA*
*Bottom graphs:* *number of buildings exceeding the norm for P90 OIA*

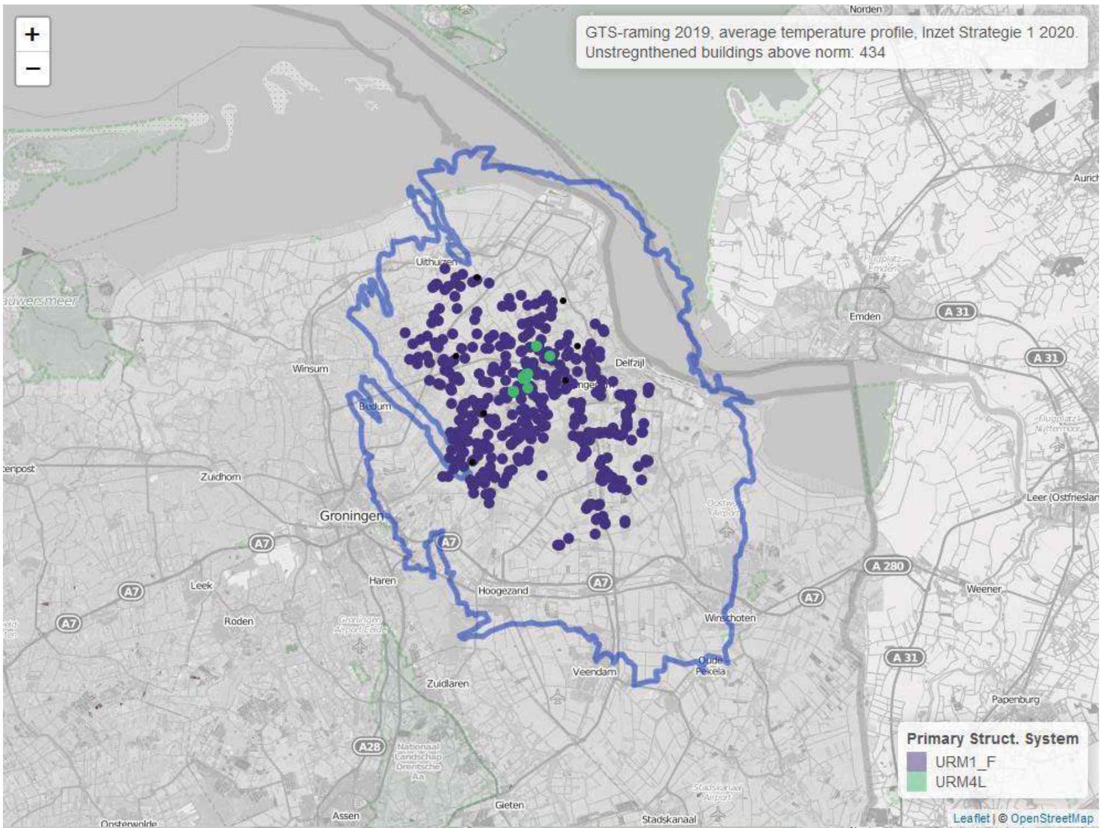
## Maps of Buildings compared to the Meijdam-Norm Risk Levels

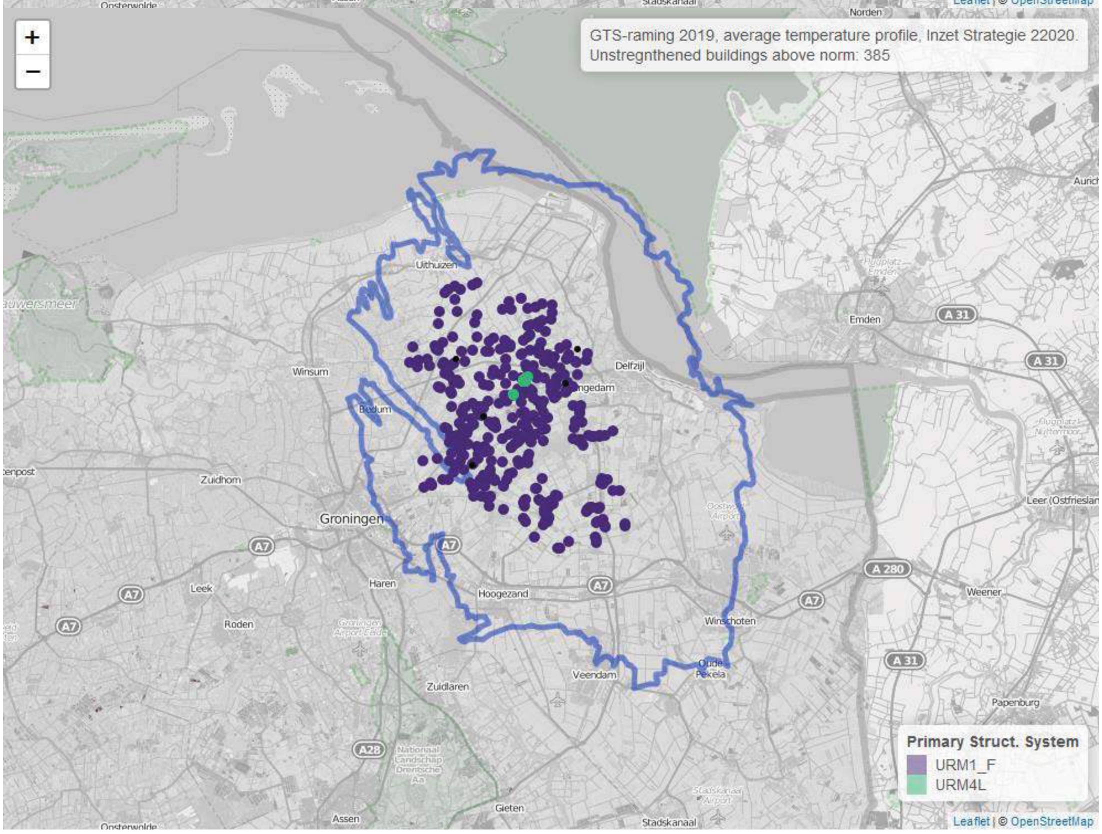
The maps of figure 6.7 show all buildings exceeding mean LPR>$10^{-5}$/year for the years between 2019 and 2028. Different colours represent different dominant building typologies. For the purpose of this risk assessment, the Groningen building stock has not been adjusted for the ongoing strengthening operations. The maps are shown for the production profile “GTS-raming 2019” with the average temperature profile and the Operational Strategy for the optimisation of the areal distribution of the gas production.


GTS-raming 2019, average temperature profile, Inzet Strategie 1 2019.
Unstregnthened buildings above norm: 796
Primary Struct. System
URM1_F
URM3L
URM3M_U
URM4L
Leaflet | © OpenStreetMap

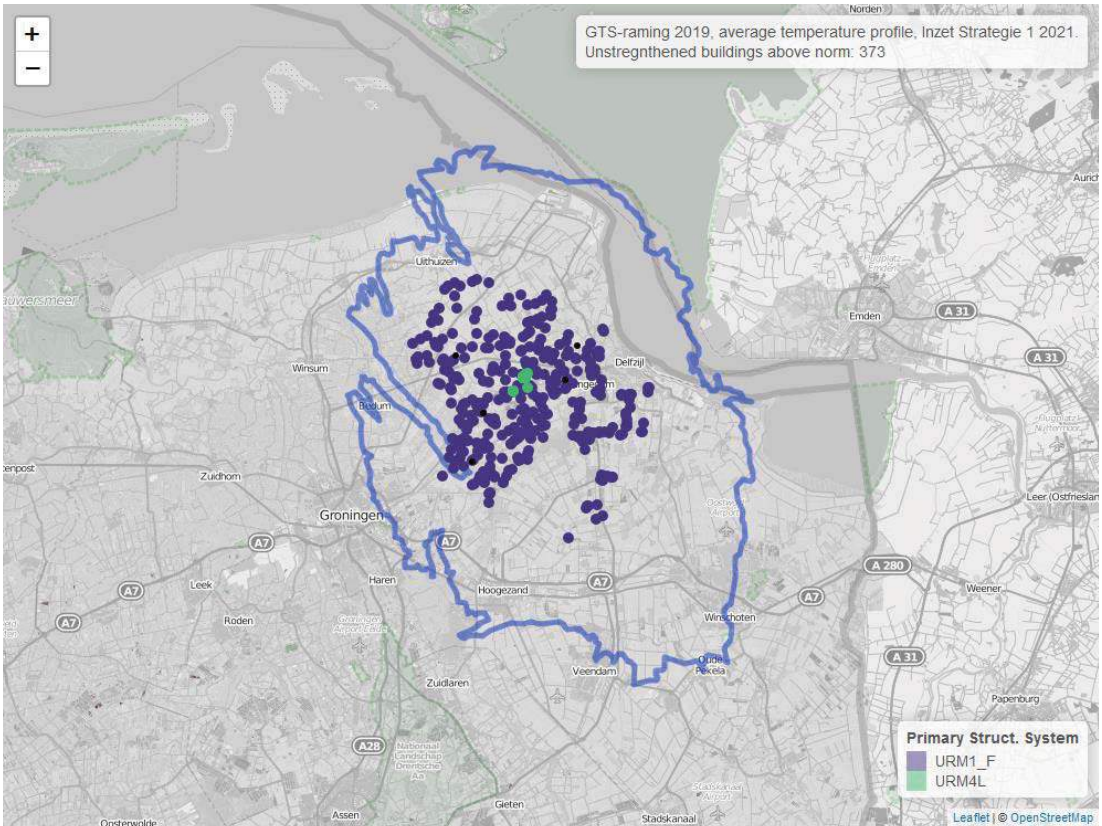

GTS-raming 2019, average temperature profile, Inzet Strategie 22019.
Unstregnthened buildings above norm: 780
Primary Struct. System
URM1_F
URM3M_U
URM4L
Leaflet | © OpenStreetMap

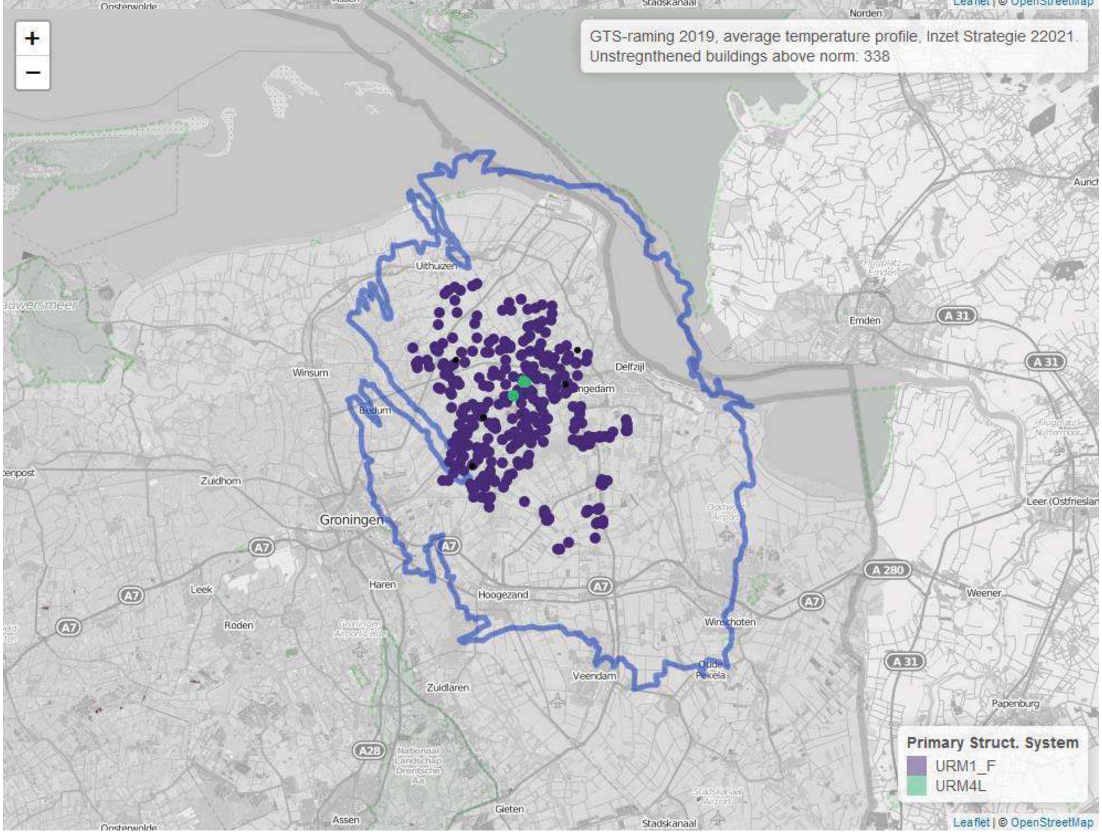
2019


GTS-raming 2019, average temperature profile, Inzet Strategie 1 2020.
Unstregnthened buildings above norm: 434
Primary Struct. System
URM1_F
URM4L
Leaflet | © OpenStreetMap

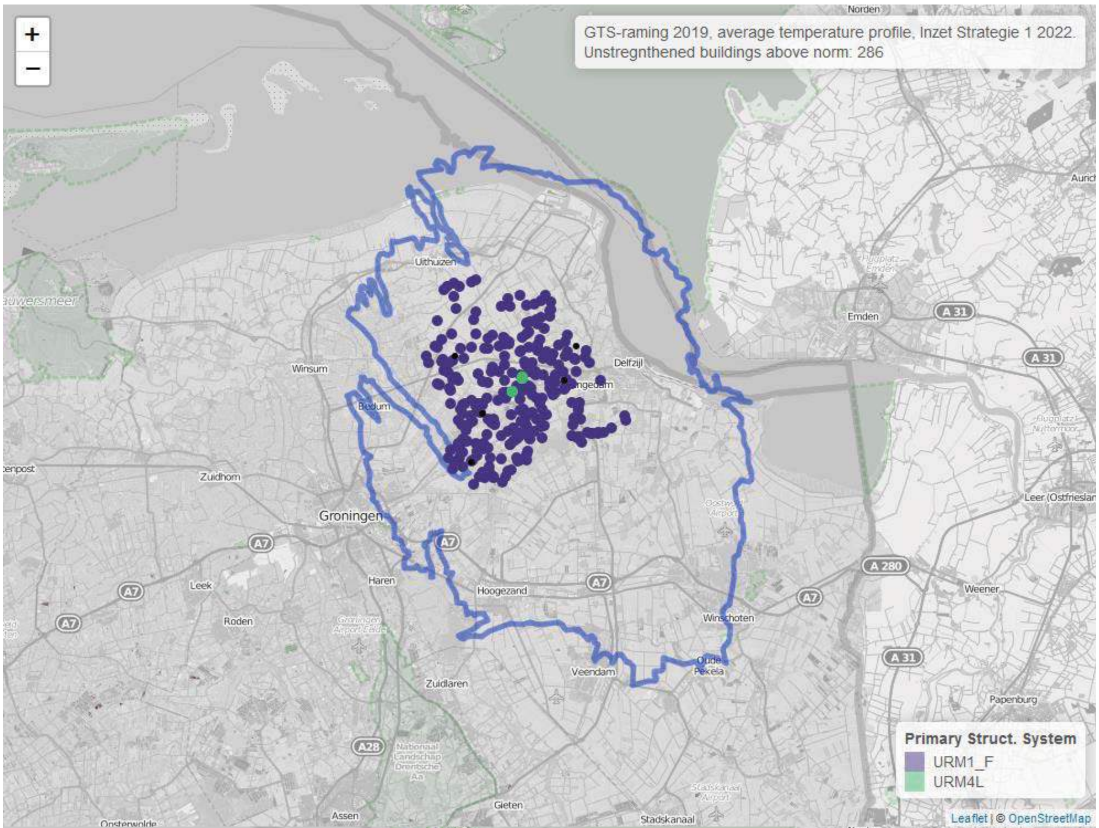

GTS-raming 2019, average temperature profile, Inzet Strategie 22020.
Unstregnthened buildings above norm: 385
Primary Struct. System
URM1_F
URM4L
Leaflet | © OpenStreetMap

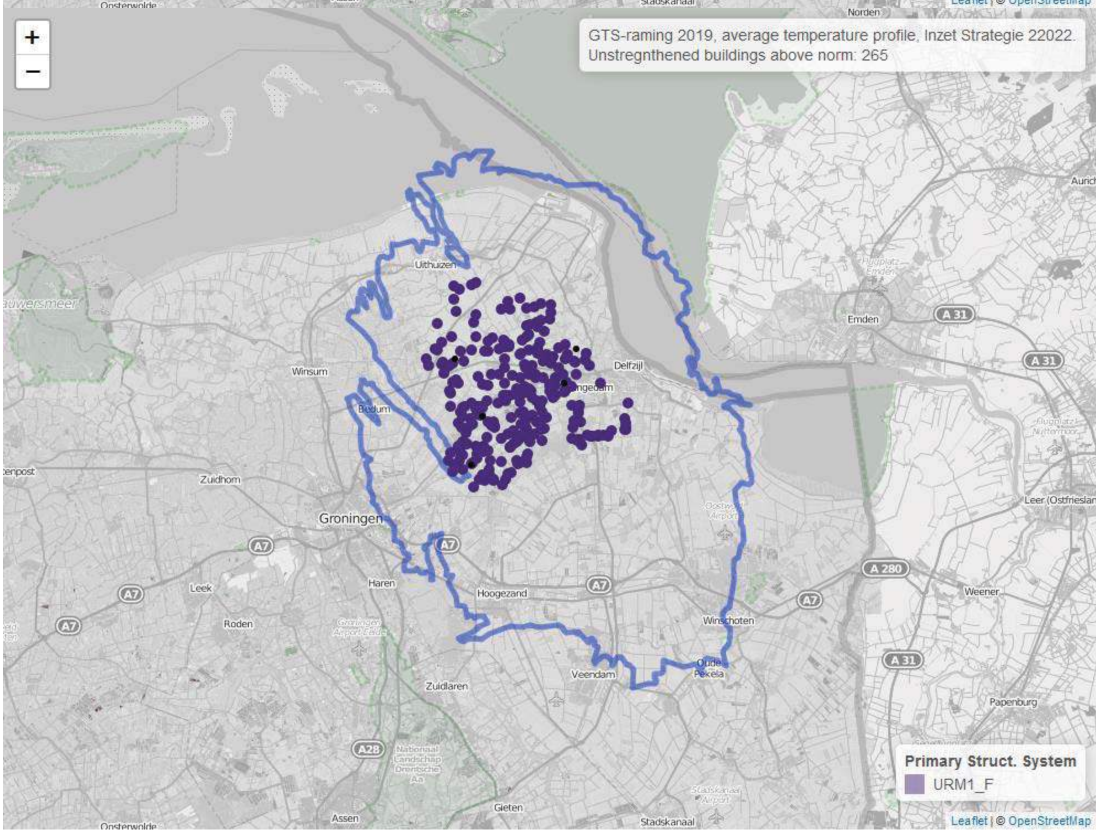
2020


GTS-raming 2019, average temperature profile, Inzet Strategie 1 2021.
Unstregnthened buildings above norm: 373
Primary Struct. System
URM1_F
URM4L
Leaflet | © OpenStreetMap

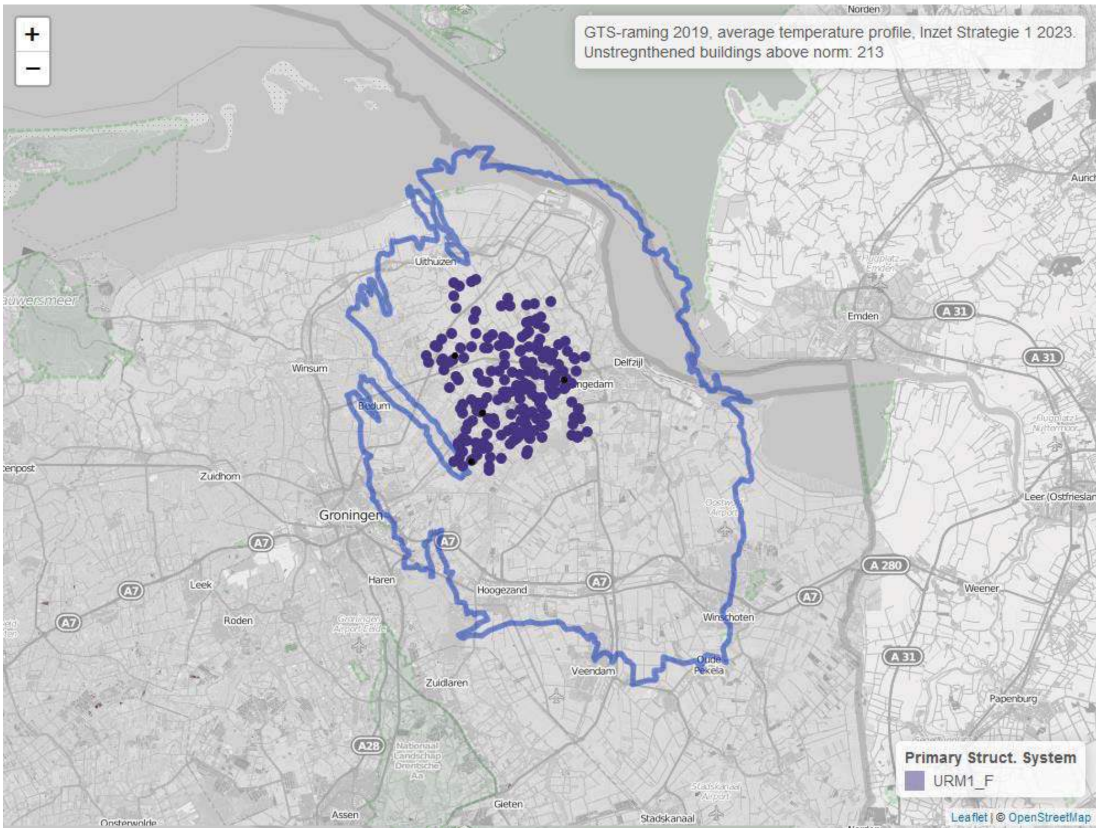

GTS-raming 2019, average temperature profile, Inzet Strategie 22021.
Unstregnthened buildings above norm: 338
Primary Struct. System
URM1_F
URM4L
Leaflet | © OpenStreetMap

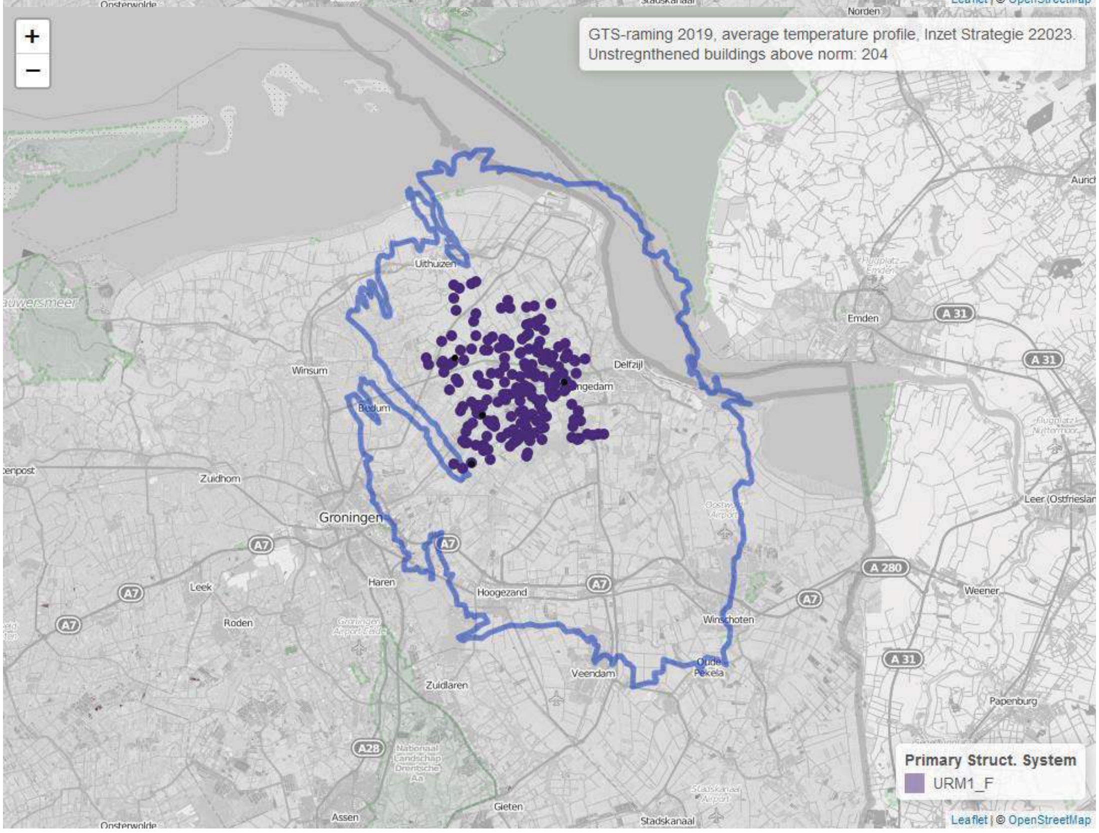
2021


GTS-raming 2019, average temperature profile, Inzet Strategie 1 2022.
Unstregnthened buildings above norm: 286
Primary Struct. System
URM1_F
URM4L
Leaflet | © OpenStreetMap

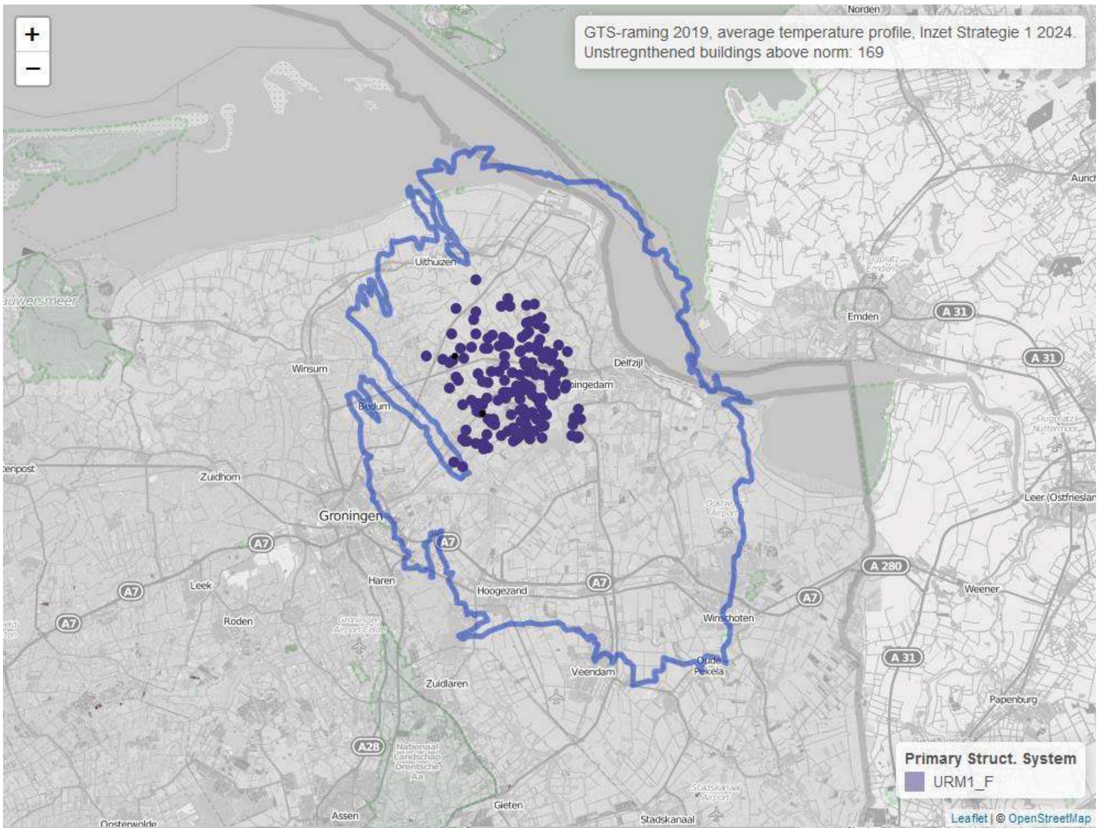

GTS-raming 2019, average temperature profile, Inzet Strategie 22022.
Unstregnthened buildings above norm: 265
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

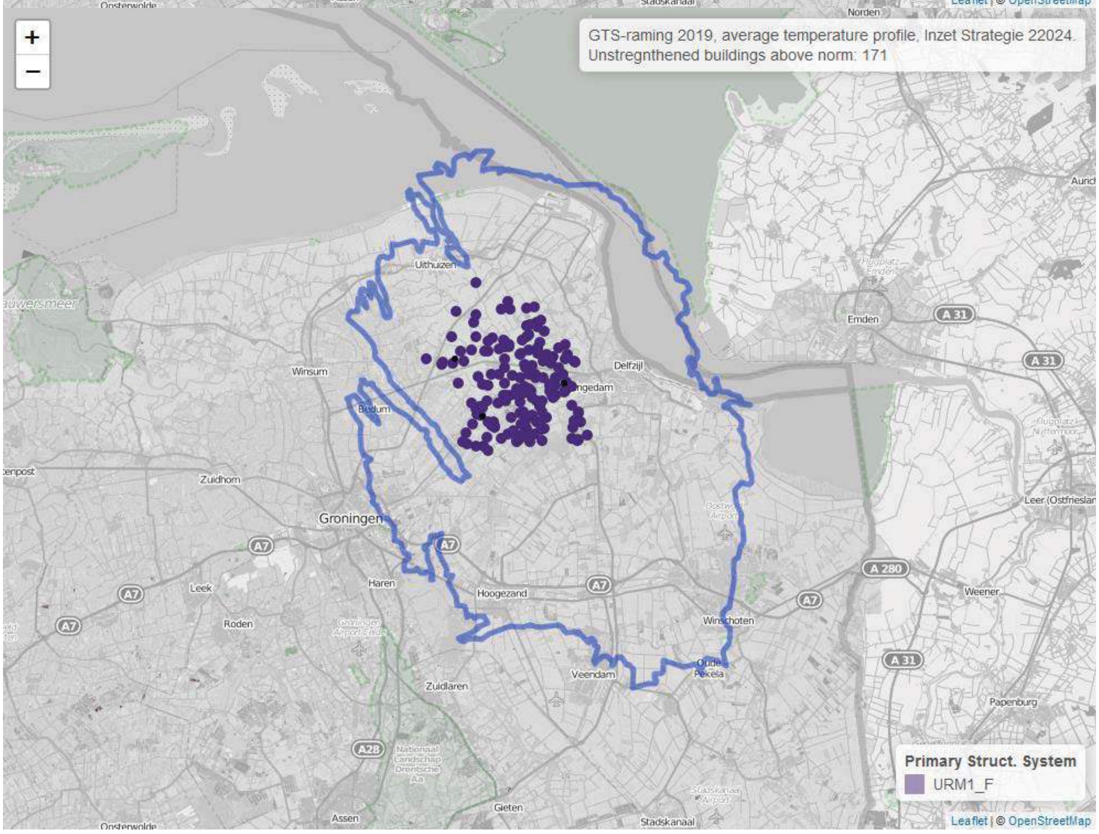
2022


GTS-raming 2019, average temperature profile, Inzet Strategie 1 2023.
Unstregnthened buildings above norm: 213
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

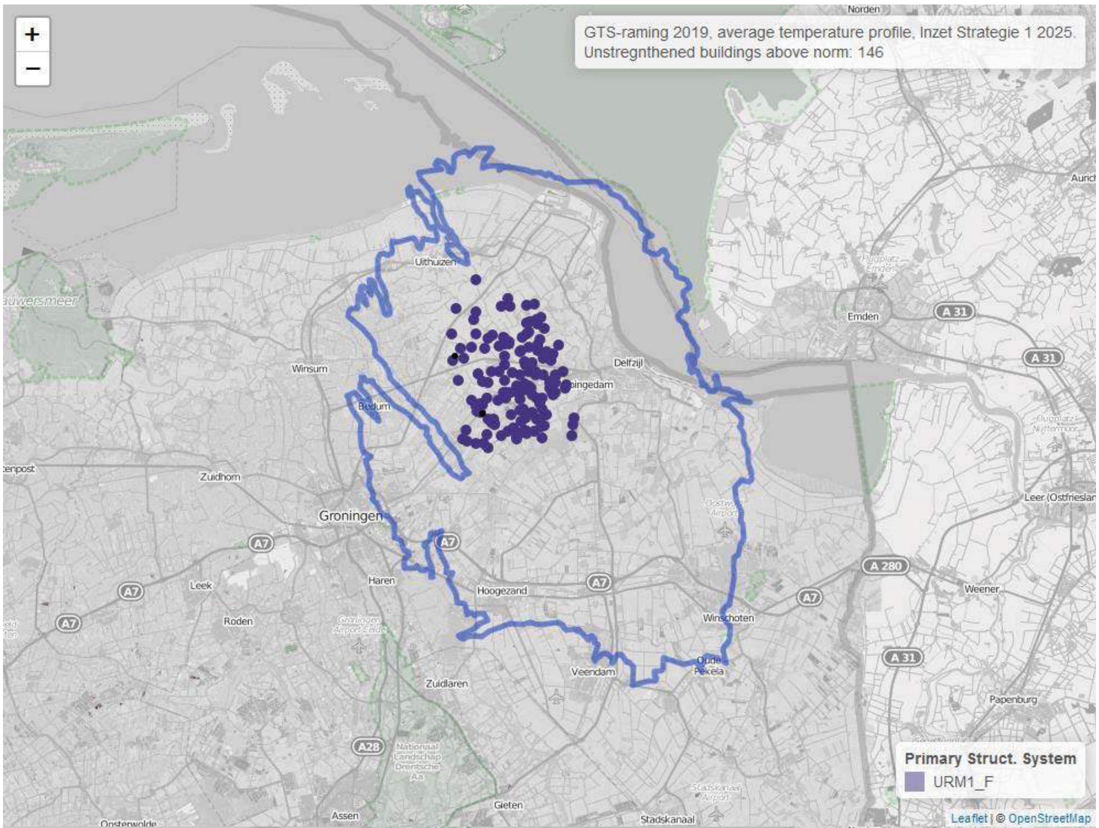

GTS-raming 2019, average temperature profile, Inzet Strategie 22023.
Unstregnthened buildings above norm: 204
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

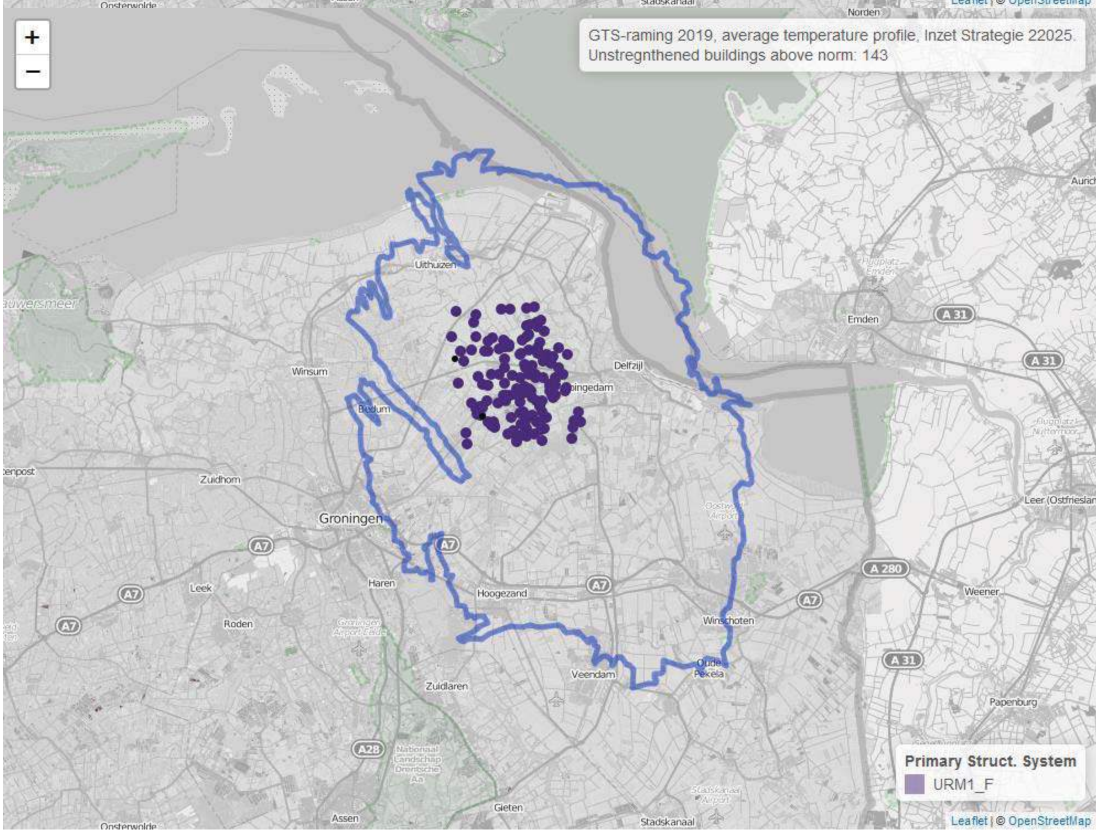
2023


GTS-raming 2019, average temperature profile, Inzet Strategie 1 2024.
Unstregnthened buildings above norm: 169
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

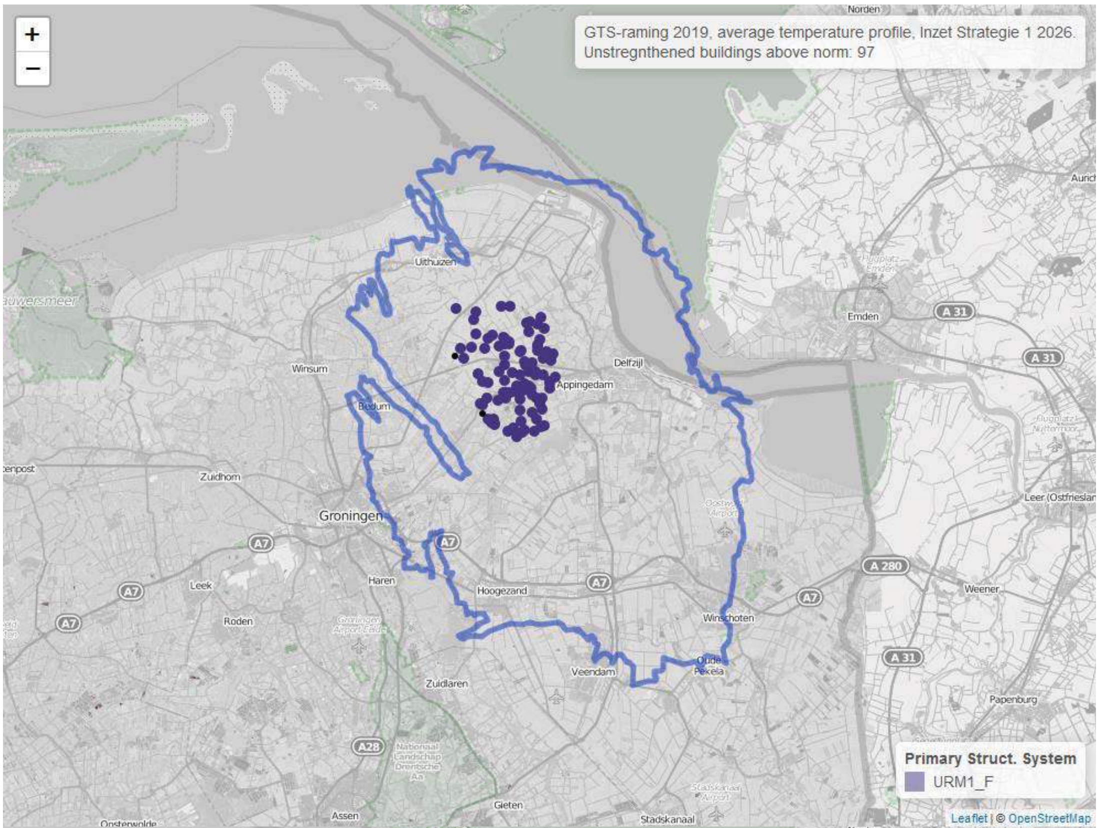

GTS-raming 2019, average temperature profile, Inzet Strategie 22024.
Unstregnthened buildings above norm: 171
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

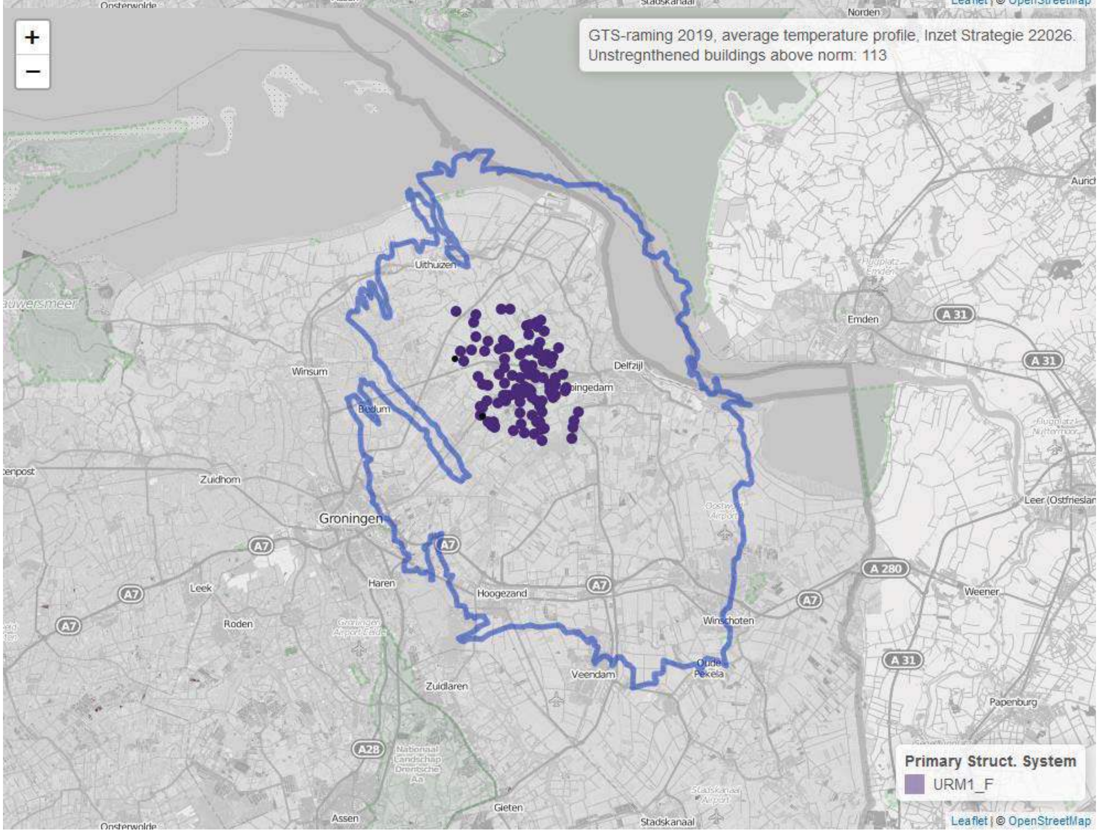
2024


GTS-raming 2019, average temperature profile, Inzet Strategie 1 2025.
Unstregnthened buildings above norm: 146
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

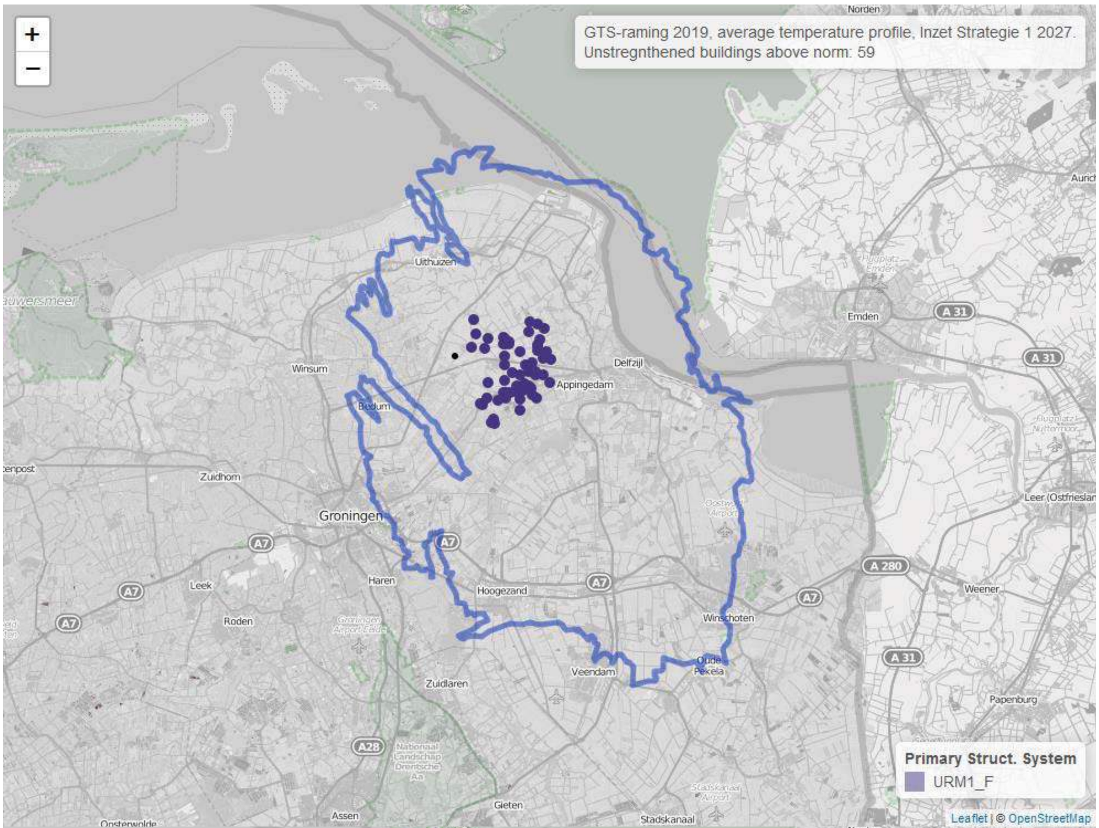

GTS-raming 2019, average temperature profile, Inzet Strategie 22025.
Unstregnthened buildings above norm: 143
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

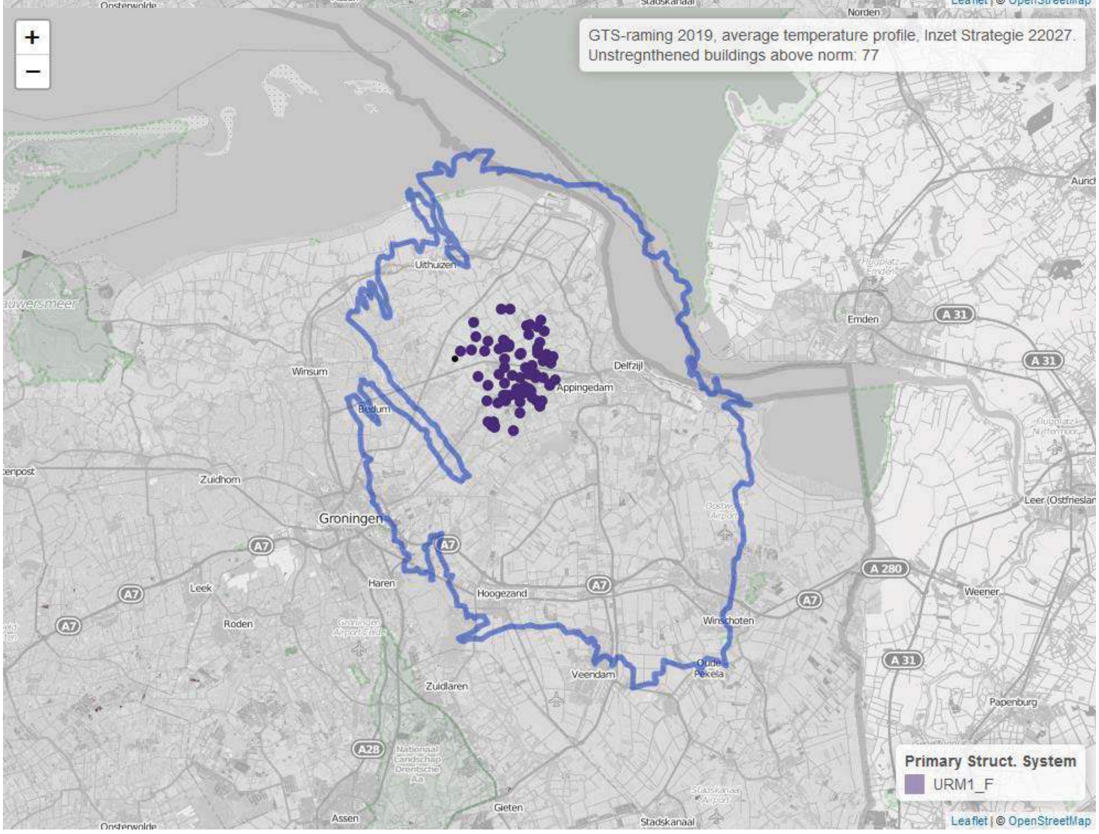
2025


GTS-raming 2019, average temperature profile, Inzet Strategie 1 2026.
Unstregnthened buildings above norm: 97
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

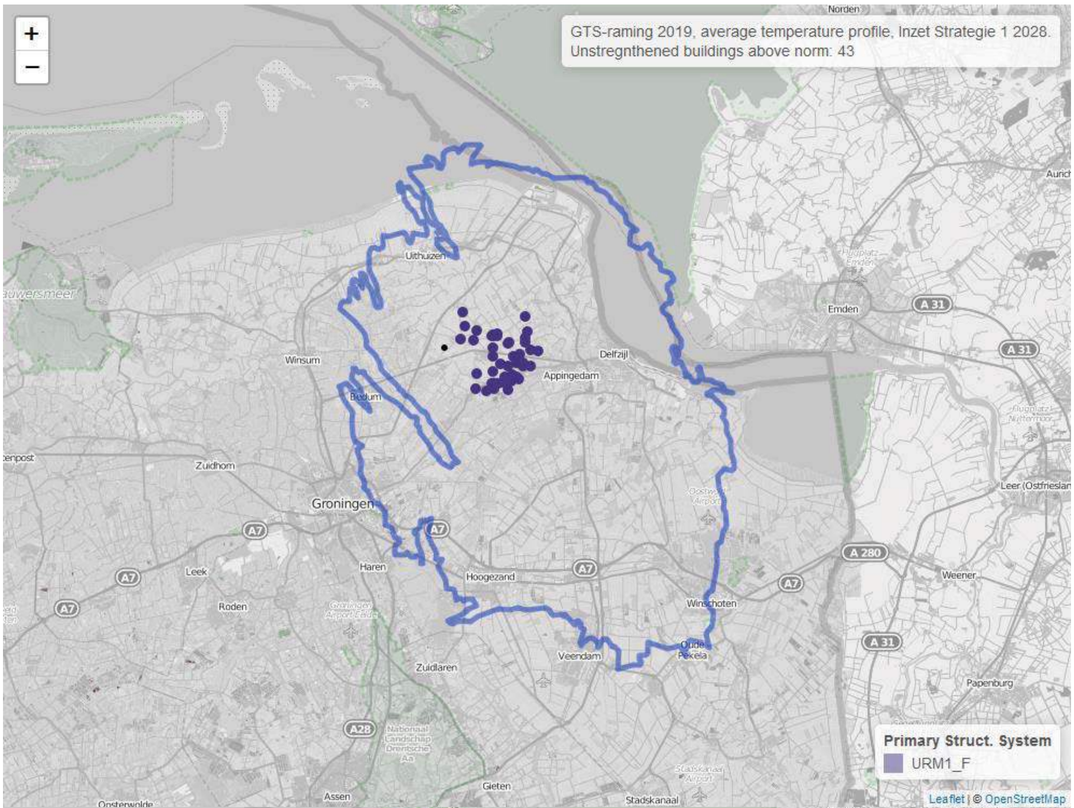

GTS-raming 2019, average temperature profile, Inzet Strategie 22026.
Unstregnthened buildings above norm: 113
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

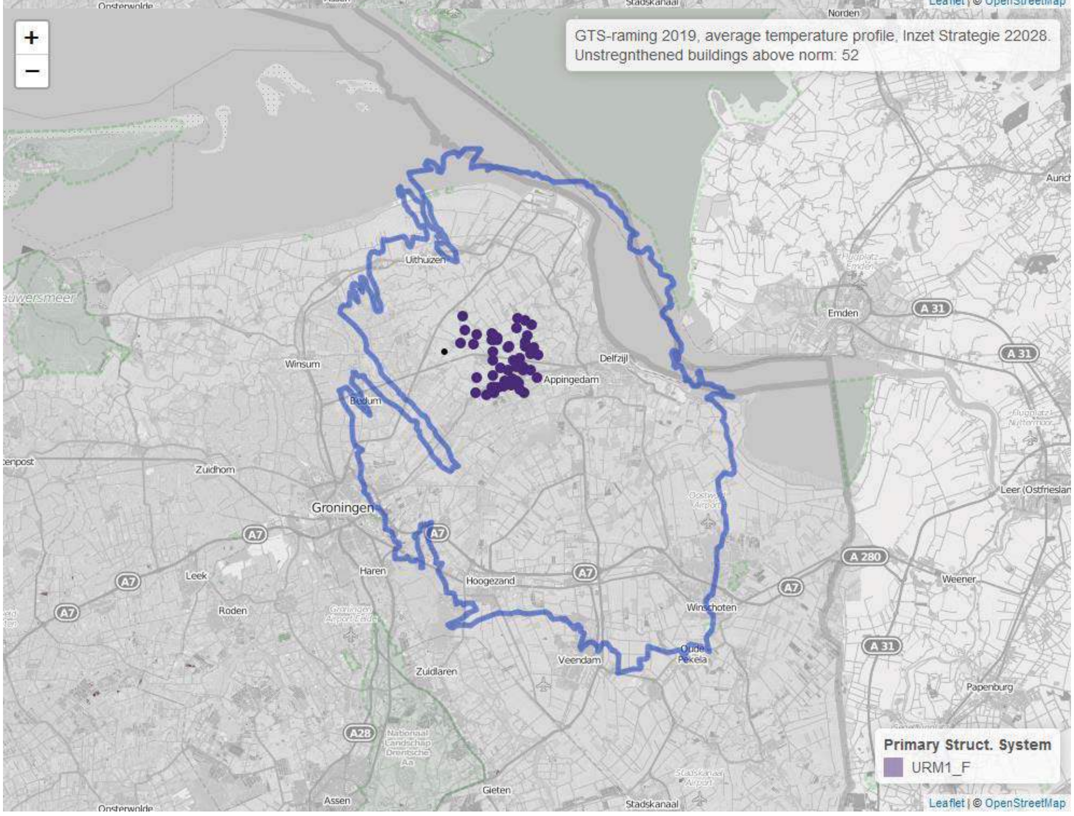
2026


GTS-raming 2019, average temperature profile, Inzet Strategie 1 2027.
Unstregnthened buildings above norm: 59
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap


GTS-raming 2019, average temperature profile, Inzet Strategie 22027.
Unstregnthened buildings above norm: 77
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

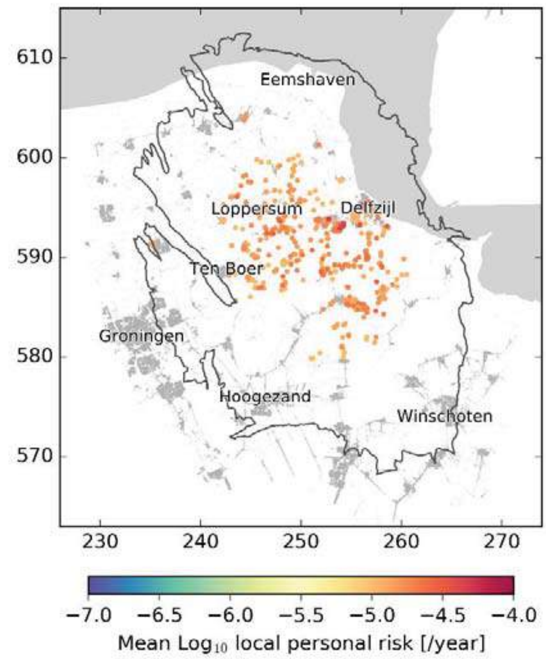
2027


GTS-raming 2019, average temperature profile, Inzet Strategie 1 2028.
Unstregnthened buildings above norm: 43
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

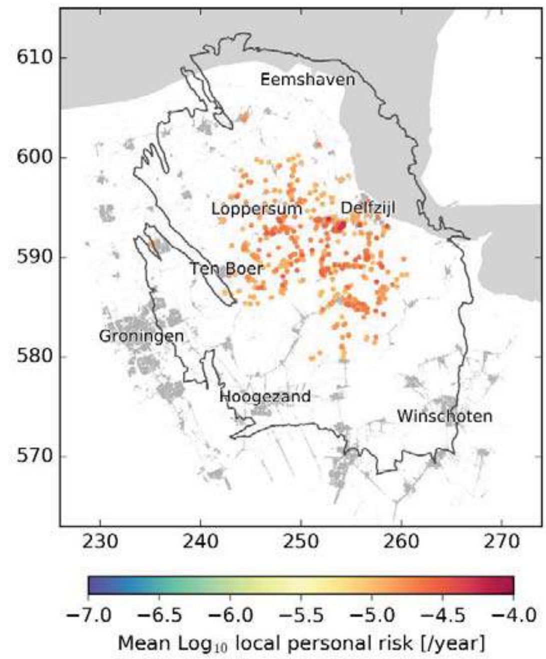

GTS-raming 2019, average temperature profile, Inzet Strategie 22028.
Unstregnthened buildings above norm: 52
Primary Struct. System
URM1_F
Leaflet | © OpenStreetMap

2028

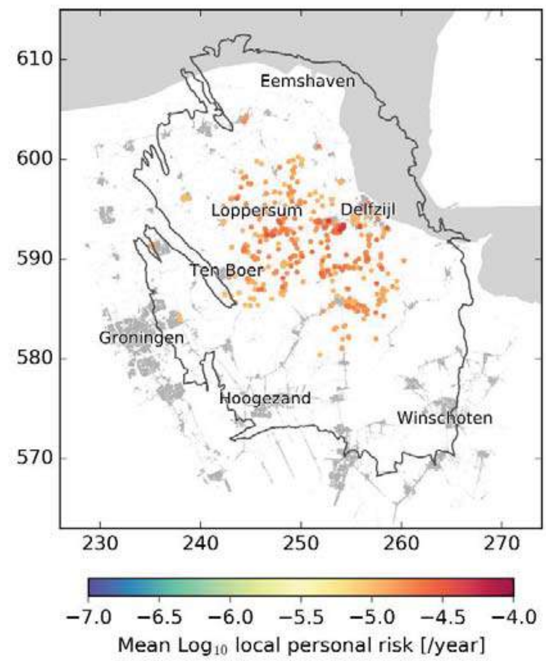
*Figure 6.7* *Maps of all buildings exceeding mean LPR>$10^{-5}$/year for the years 2019 to 2028. Different colours indicate different building typologies.*



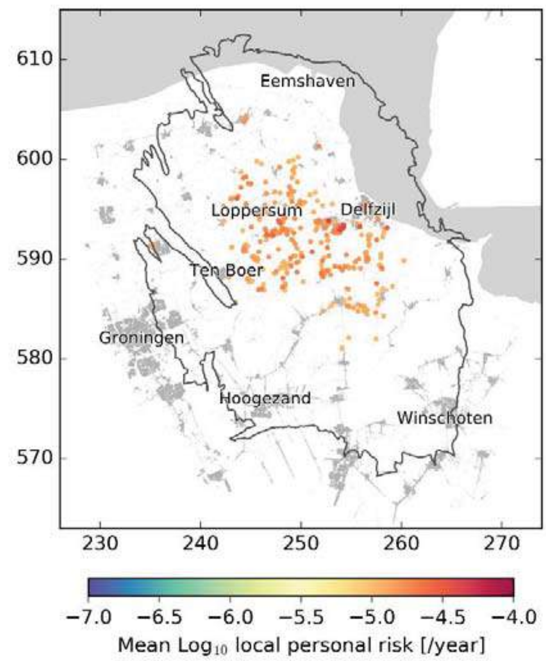

**2018**



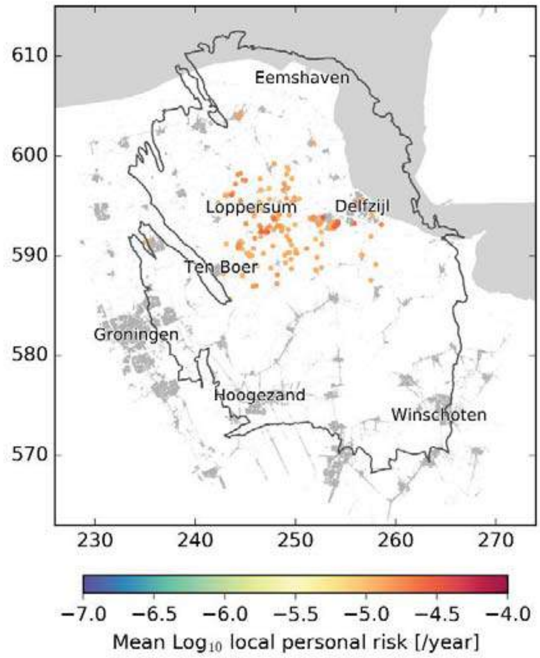

**2019**



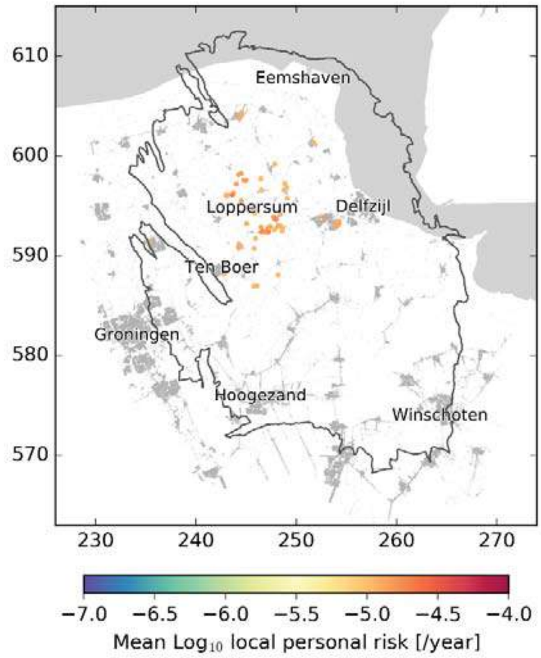

**2020**



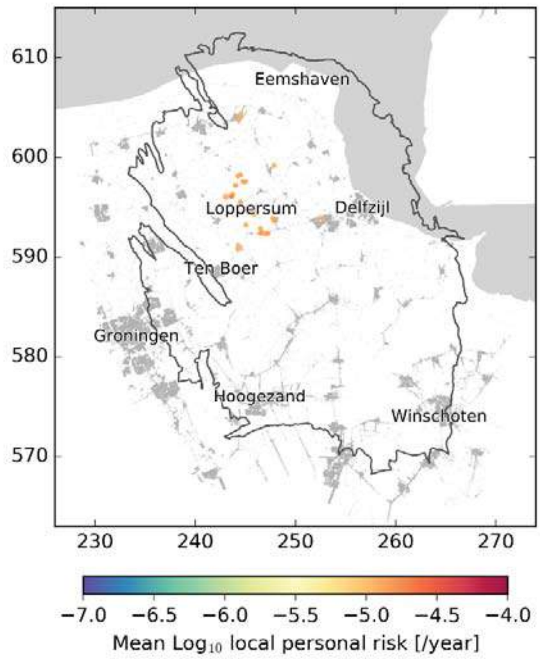

**2021**



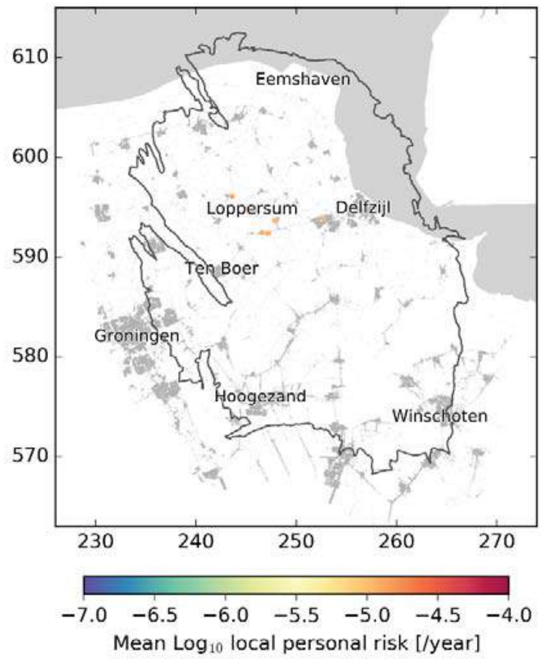

**2022**



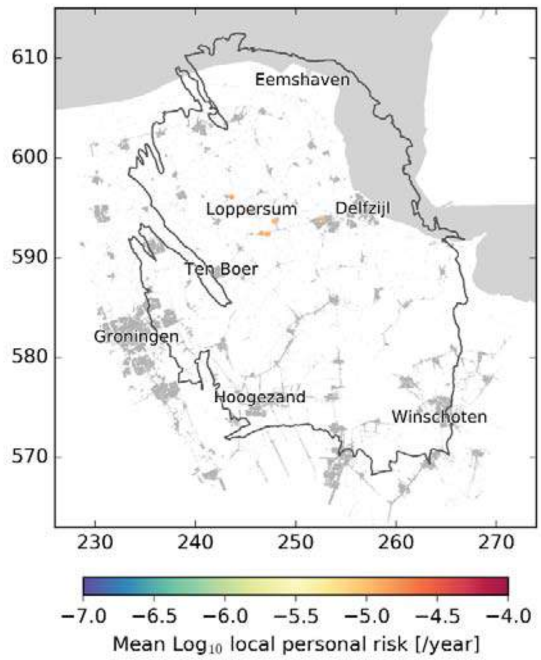

**2023**



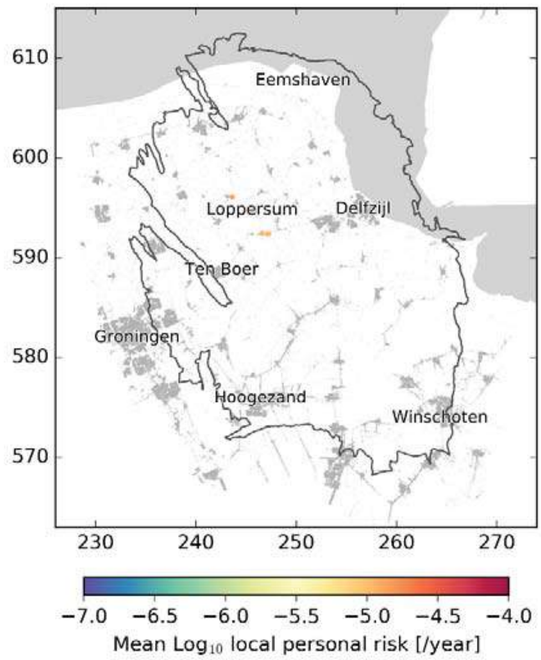

**2024**




**2025**




**2026**




**2027**

*Figure 6.8 Map indicating individual building with Local Personal Risk exceeding $10^{-5}$/year for the years 2019 to 2028 and production profile “GTS-raming 2019” (average temperature).*

# Insights into the development of the buildings above the norm

## Introduction

The Hazard and Risk assessment provides a list of buildings that are expected to meet the norm and of buildings which are not. This section describes the evolution of this estimate between this assessment and the previous one (Ref. 12).

This section will show that the continued decline of production and the targeted improvements to the exposure database (describing the building stock in Groningen) and the fragility curves (describing the response of those buildings to ground motion) have had two main effects. Firstly, the overall assessment of risk has decreased and consequently also the assessment of the number of buildings not meeting the norm has decreased. Secondly, the assessment has increased the focus on specific typologies that are most deserving of attention in the efforts to further reduce risk.

The total number of buildings not meeting the $10^{-5}$/year norm has declined from 1,478 to 780 for Operational Strategy 2 and average temperature demand. That reduction is caused by the following developments:

- The hazard has decreased because of reduced production.
- The modelled response of buildings to ground motion as captured in the so called 'fragility curves' has changed. Fragility and consequence models were updated among others in response to advice from the Assurance Panel that reviewed the previous Hazard and Risk Assessment (Ref. 19).
- Improvements in Groningen building stock knowledge resulted in updates to the Exposure database EDB V6.

Generally, these developments have had a net downward effect on risk, except for the typology representing typical farm houses with barns. This typology has been reassessed as 'more vulnerable' compared to the previous analysis and now dominates the stock of buildings not meeting the norm.

Of the 1,478 buildings that were previously assessed as not meeting the norm:

- 339 buildings are still expected not to meet the Meijdam-norm.
- 72 buildings have been strengthened and are now expected to meet this norm.
- 1,067 buildings are now expected to meet this norm. Of those, 560 still have a small probability of not meeting the norm and are now part of the so-called 'P90 group'.

Of the 780 houses that are now assessed as not meeting the norm:

- 339 were also identified in the previous assessment.
- 228 were identified in the previous assessment as having a small probability of not meeting the norm (the so-called P90 group).
- 213 are newly identified.

The following diagram illustrates the above:

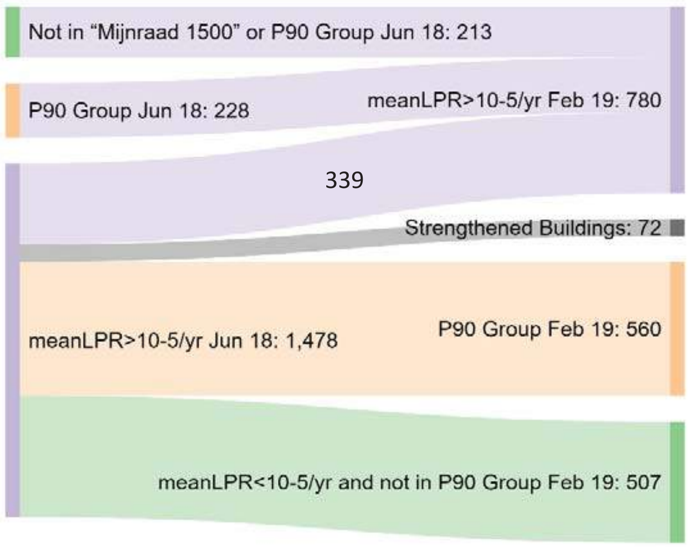



*Figure 6.9 Sankey diagram showing developments between 'Basispad Kabinet' and the current Operational Strategy 2 (average temperature demand) assessment for the buildings not meeting the 10-5/year norm.*

The assessment of whether individual houses are expected to meet or not meet the Meijdam norm is one of the inputs into the risk management policy set by the Minister (Ref. 9 to 11). How this information is used to derive inspection and/or strengthening programmes is not described in this report and is outside the remit of NAM.

## Comparing the results of risk assessments

In this section an initial comparison is presented between the Hazard and Risk Assessment for "Basispad Kabinet", and the Hazard and Risk Assessment for "GTS-raming 2019" Operational Strategy 2 with average temperature demand described in this report. To illustrate, the calendar year 2019 was chosen, also because this is the reference year used by the "Mijnraad". For the comparison we'll make use of Sankey diagrams. These are a specific type of flow diagram, in which the width of the arrows is proportional to the number of buildings.

Figure 6.10 shows a Sankey diagram summarising the overall changes (occupied buildings) per group defined by the "Mijnraad":

- Buildings with meanLPR>10-5/yr – "Mijnraad 1500" Group,
- buildings with more than 10% probability of having LPR>10-5/yr, but not part of the first bullet - the "P90 Group", and
- buildings not part of above risk priority groups.

On the left the numbers of buildings in these three groups are represented as they were in the assessment of June 2018 and on the right are the numbers in the current assessment. The connections between these illustrate the movement of the buildings in these categories between these two risk assessments.

The number of buildings above the norm decreased from 1,478 to 780. The reduction represents less than 0.5% of the total building stock. While the overall number of buildings in the P90 Group has not changed significantly, the group membership (i.e. the specific buildings in the group) has.

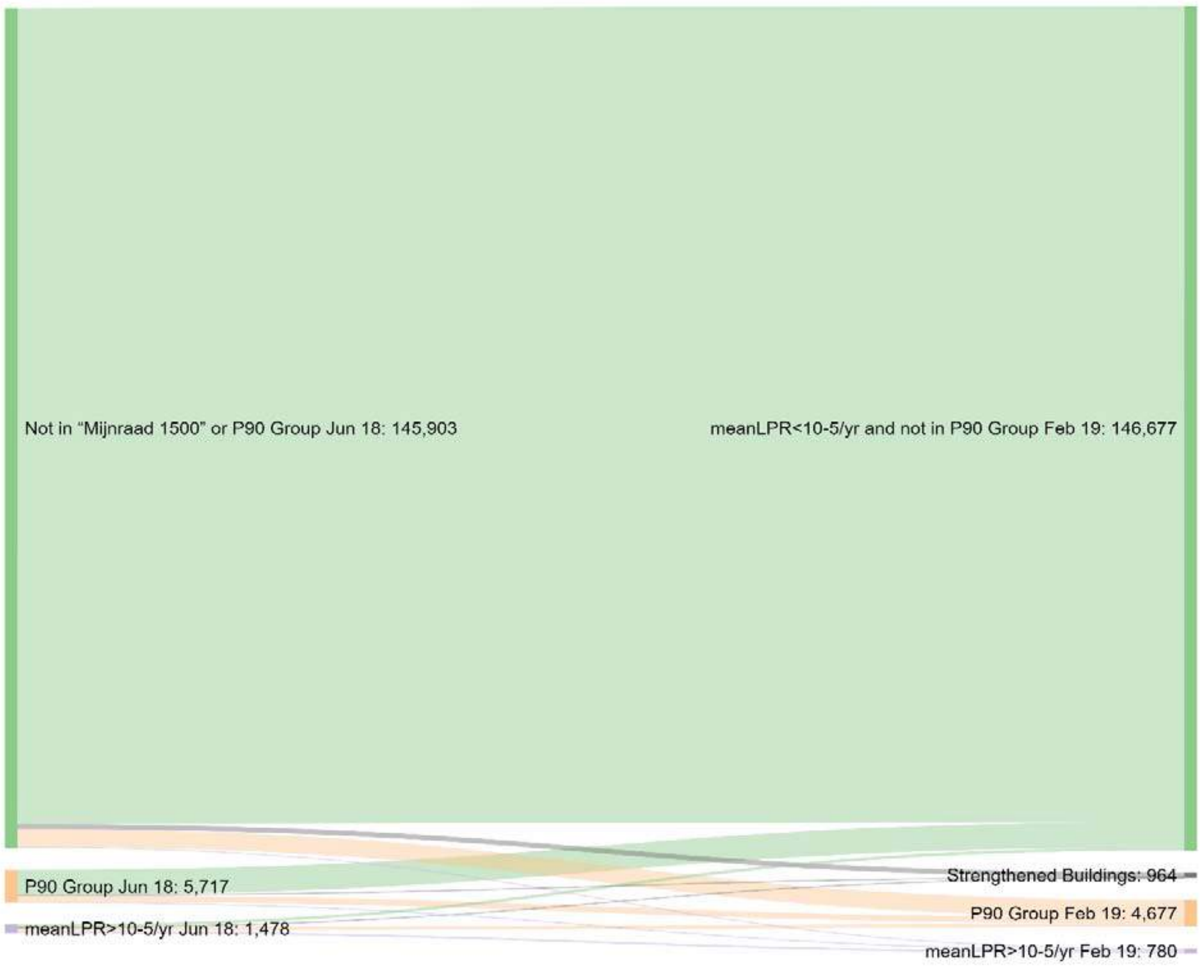



*Figure 6.10 Sankey diagram summarising the changes (occupied buildings) from "Basispad Kabinet" to "GTS-raming 2019" Operational Strategy 2 with average temperature demand.*

Anticipating that most attention will be drawn to buildings with highest risk profile, the following paragraphs focus on buildings with meanLPR>10-5/year – i.e. not meeting the Meijdam-norm.

## Update to buildings above the norm

The Sankey diagram in figure 6.11 shows how risk levels have changed for the building typologies previously above the norm (bottom left), and buildings that previously did not have meanLPR>10-5/yr, but now do (top left). The right side of the plot shows current risk levels. The flow line colours represent EDB V6 Primary System assignment. This figure is a more detailed version of figure 6.9 above and shows in more detail how the status of different typologies has evolved between risk assessments.

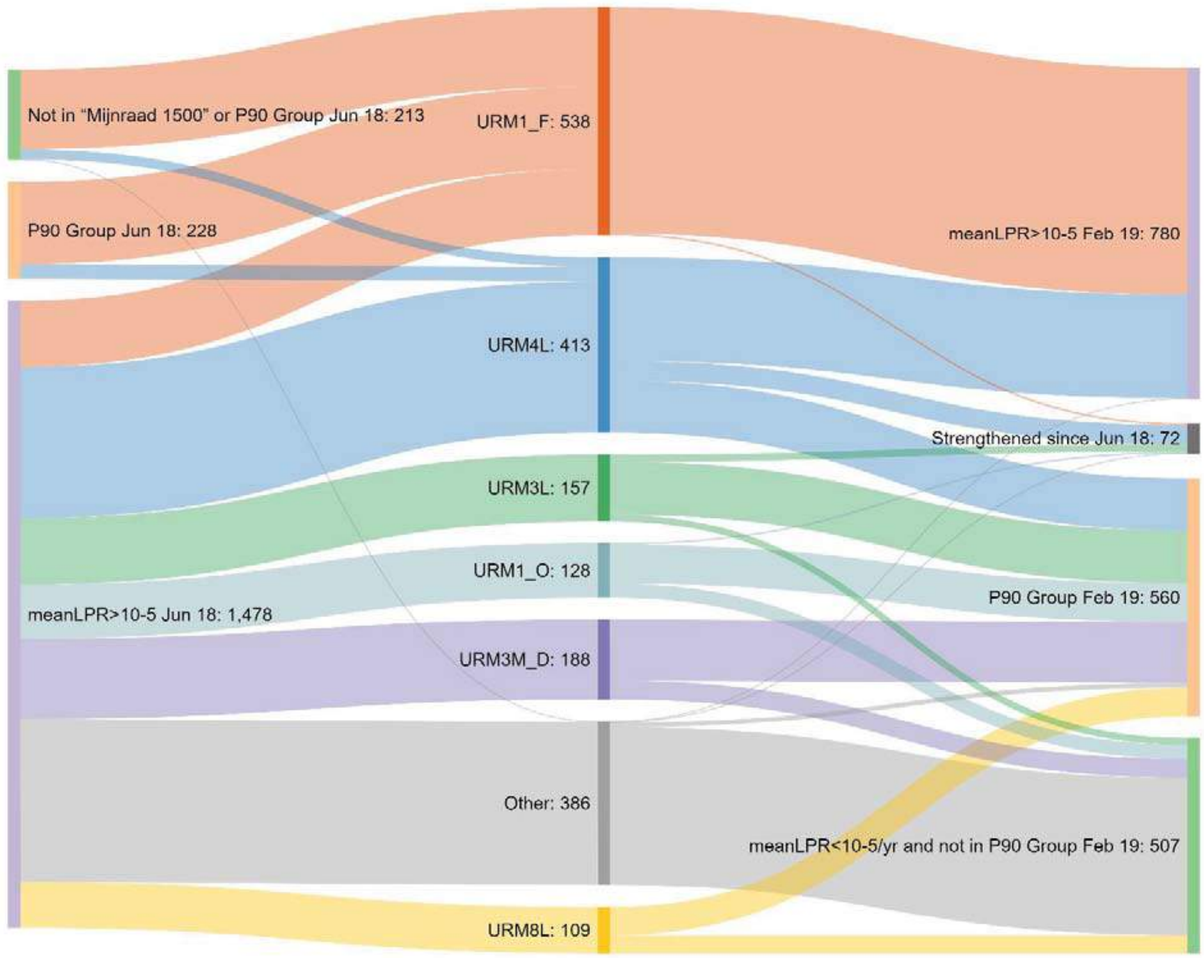



*Figure 6.11 Sankey diagram showing risk level changes for the building previously above the norm (“Basispad Kabinet”), and buildings that previously did not have meanLPR>10-5/yr, but now do (“GTS-raming 2019” Operational Strategy 2 with average temperature demand).*

As explained in Section 2, differences are the result of a combination of the following aspects:

- Reduced hazard because of reduced production from the Groningen field. It should be noted that the reduction is not equally distributed over the whole area and depends on the Operational Strategy chosen to distribute production over the field.
- Updated Fragility and Consequence models following amongst other things advice of the assurance panel (Ref. 19).
- Improvements in Groningen building stock knowledge resulting in updated Exposure database EDB V6.

In June 2018, 1,478 buildings assessed to be above norm covered 13 different Primary Systems (above summarised in 7 streams; bottom left). The “GTS-raming 2019” Operational Strategy 2 average temperature demand has 780 buildings above norm covering 3 Primary Structural systems: URM1_F, URM4L and URM3M_U (top right).

Typology URM1_F, representing a typical farm house with barn, is now assessed as more fragile and dominates the buildings above the norm – almost 70% are of this type. Of the updates to the fragility and consequence models described in section 2, an important contribution leading to a more vulnerable building type has been the use of hazard consistent records in fragility model development. This is shown in figure 6.11, where URM1_F buildings already identified above norm remain and some URM1_F in P90 Group and outside now have higher risk.

URM4L represents terraced masonry houses with cavity walls, concrete floors and large ground floor openings in the façade walls. The combination of reduced hazard and updated fragility/consequence model has resulted in a reduction of the number of these buildings above the norm. In figure 6.10 some URM4L buildings shift to the P90 Group. Note that no previously identified URM4L buildings now have risk above the norm (see also figure 6.13).

For the other typologies the combination of aspects mentioned above has resulted in risk reduction; those buildings no longer have meanLPR>10-5/yr.

## Improvements to Exposure Model (EDB V6)

Figure 6.12 shows for the 1,478 buildings above the norm the Typology updates that have taken place since June 18. It is clearly visible that typology URM1 and URM3M had been split in sub-typologies recognising that the variation with respect to seismic behaviour within these was still relatively large compared to other typologies with higher risk potential.

The other main update relates to typology URM4L, where based on new insights some buildings have been reassigned to:

- URM3L, a similar typology but with lower openings percentage in the ground floor façade walls. Because of recent shake table tests and modelling the cut-off percentage between the 2 typologies has been updated.
- URM7L, a similar typology but with lower openings percentage in the ground floor façade walls and more internal walls in both directions of the building. As part of the confirmation and validation work carried out mid last year design drawings were inspected, and these internal walls were confirmed for some buildings.

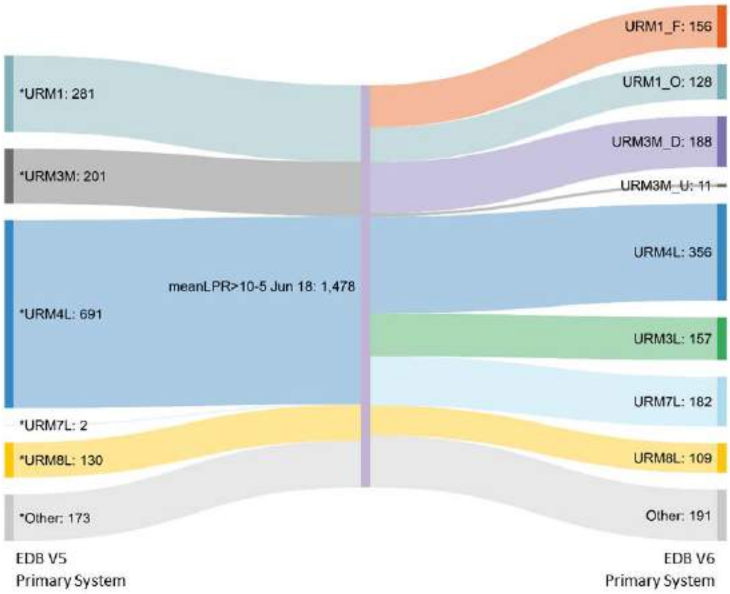



*Figure 6.12 Sankey diagram showing for the 1,478 buildings in the "Mijnraad 1500" list the Typology updates that have taken place since June 2018.*

Figure 6.13 was made after taking a closer look at the buildings that were previously not above the norm. It shows a comparison between the Structural System classification EDB V5 and V6. The differences can be clarified as follows:

- For URM1_F, partial classification and related inference rules have been improved using additional data sources, such as geometric lay-out and farm-specific information from Dataland, in combination with improved insight into the relationship between these data sources.
- In addition, the dedicated exercise to re-evaluate buildings with low probability of belonging to a vulnerable typology has led to the identification of several URM1_F buildings.
- URM3L buildings were reassigned to URM4L based on inspection information or automated image analyses by Ticinum Aerospace.

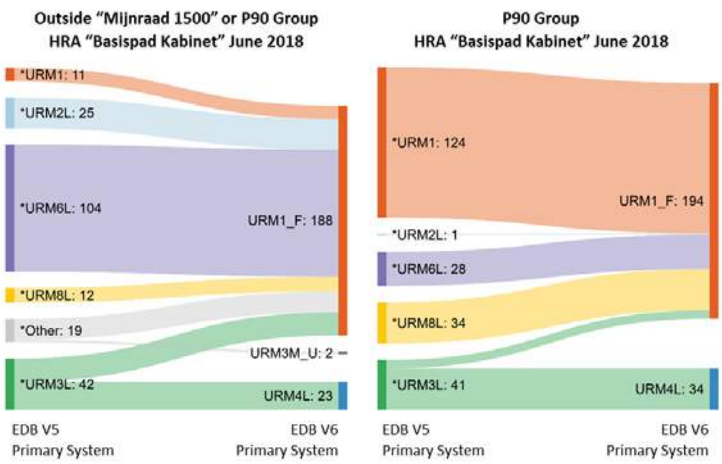



*Figure 6.13 Sankey diagram showing the Structural System classification EDB V5 and V6 compared for buildings previously not above norm*

## Risk for gas-year 2019 / 2020

The following section focuses on the upcoming 2019/2020 gas-year (i.e., consisting of the last quarter of 2019 and the first three quarters of 2020). Because of the reducing gas production, the numbers presented are lower than those relating to calendar year 2019 and given in previous section.

### Number of buildings above the norm

Table 6.6 shows the number of buildings above the Meijdam-norm in gas-year 2019/2020. These are shown for production profiles for an average, cold and warm year and Operation Strategy 1 and 2.

| Production Profile | Optimisation Strategy | Temperature | Mean OIA $10^{-5}$/year | Mean OIA $10^{-4}$/year | Mean LPR $10^{-5}$/year | Mean LPR $10^{-4}$/year |
|---|---|---|---|---|---|---|
| Reference Case (Basispad Kabinet) | - | - | 389 | 0 | 786 | 0 |
| GTS-raming 2019 | Operational Strategy 1 | Average | 290 | 0 | 429 | 0 |
| GTS-raming 2019 | Operational Strategy 2 | Average | 237 | 0 | 403 | 0 |
| GTS-raming 2019 | Operational Strategy 1 | Cold | 419 | 0 | 717 | 0 |
| GTS-raming 2019 | Operational Strategy 2 | Cold | 348 | 0 | 599 | 0 |
| GTS-raming 2019 | Operational Strategy 1 | Warm | 209 | 0 | 318 | 0 |
| GTS-raming 2019 | Operational Strategy 2 | Warm | 177 | 0 | 288 | 0 |

*Table 6.6 Number of buildings above the Meijdam-norm in gas-year 2019/2020 for production profiles for an average, cold and warm year and Operation Strategy 1 and 2 (note that the count includes buildings already strengthened, which are expected to meet the norm). As a reminder, Operational Strategy 1 minimises the pwPGV and Operational Strategy 2 minimises the event-count.*

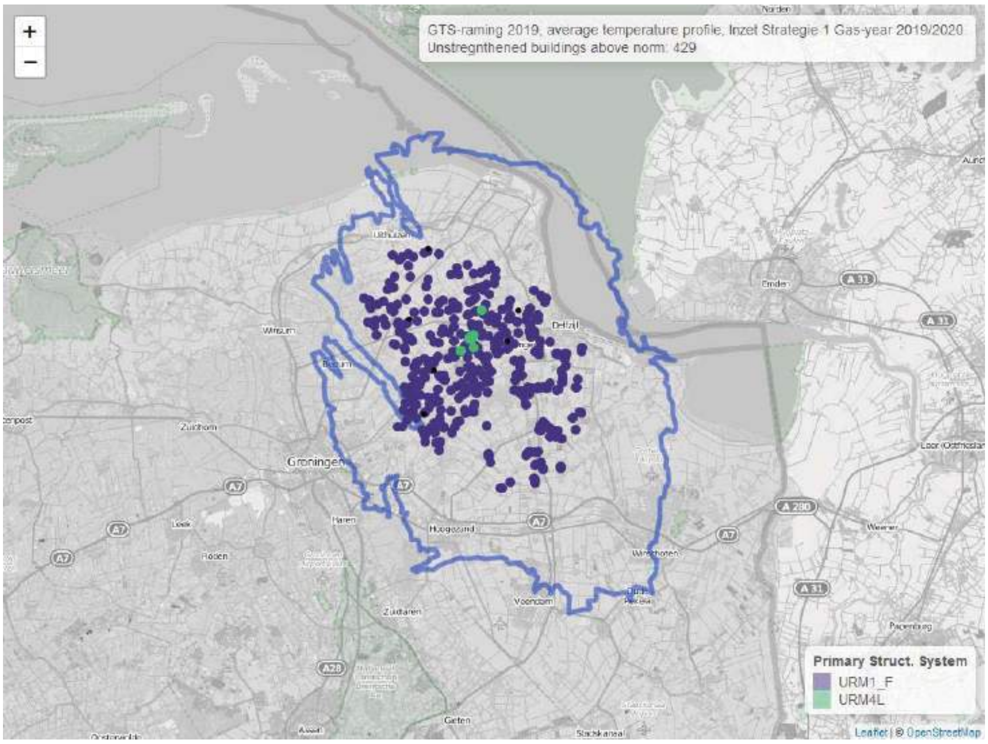
### Buildings above the norm – areal maps

The overall structural-system mix for the two profiles is the same, however in Operational Strategy 2, the buildings above the norm appear to be closer to Groningen than in Operational Strategy 1. Figure 6.14 shows the maps for the buildings above the norm in gas-year 2019/2020.

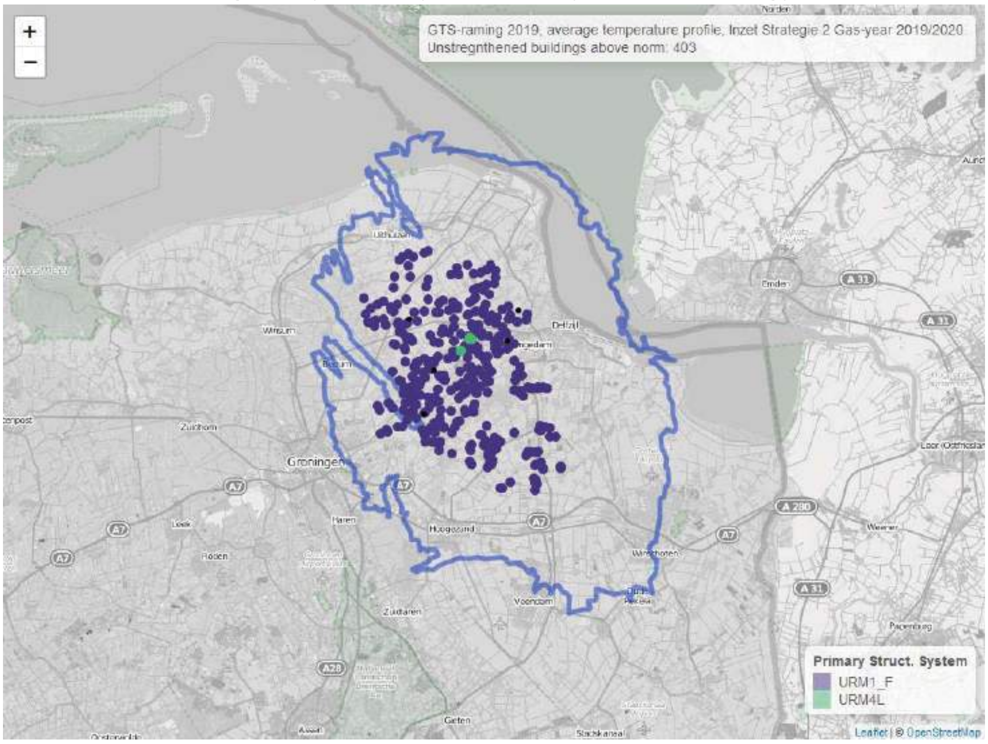
Table 6.7 shows for the average temperature profile of GTS raming 2019, the number of buildings above the Meijdam-norm (mean LPR > $10^{-5}$/year) for gas-year 2019/2020, for the different typologies.

| Operational Strategy | Primary System | Count |
|---|---|---|
| Operational Strategy 1 | URM4L | 26 |
| Operational Strategy 1 | URM1_F | 403 |
| Operational Strategy 1 | Already strengthened and expected to meet the norm | 6 |
| Operational Strategy 2 | URM4L | 19 |
| Operational Strategy 2 | URM1_F | 384 |
| Operational Strategy 2 | Already strengthened and expected to meet the norm | 5 |

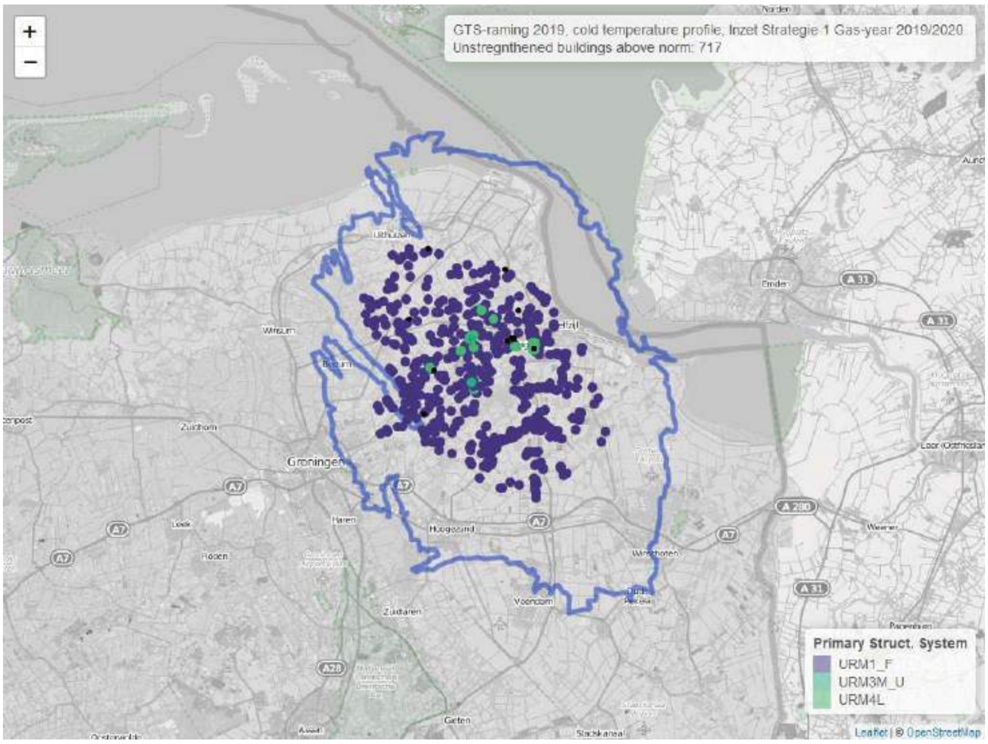
*Table 6.7 The number of buildings above the Meijdam-norm (mean LPR > $10^{-5}$/year) for gas-year 2019/2020, for both operational strategies split over the different typologies.*



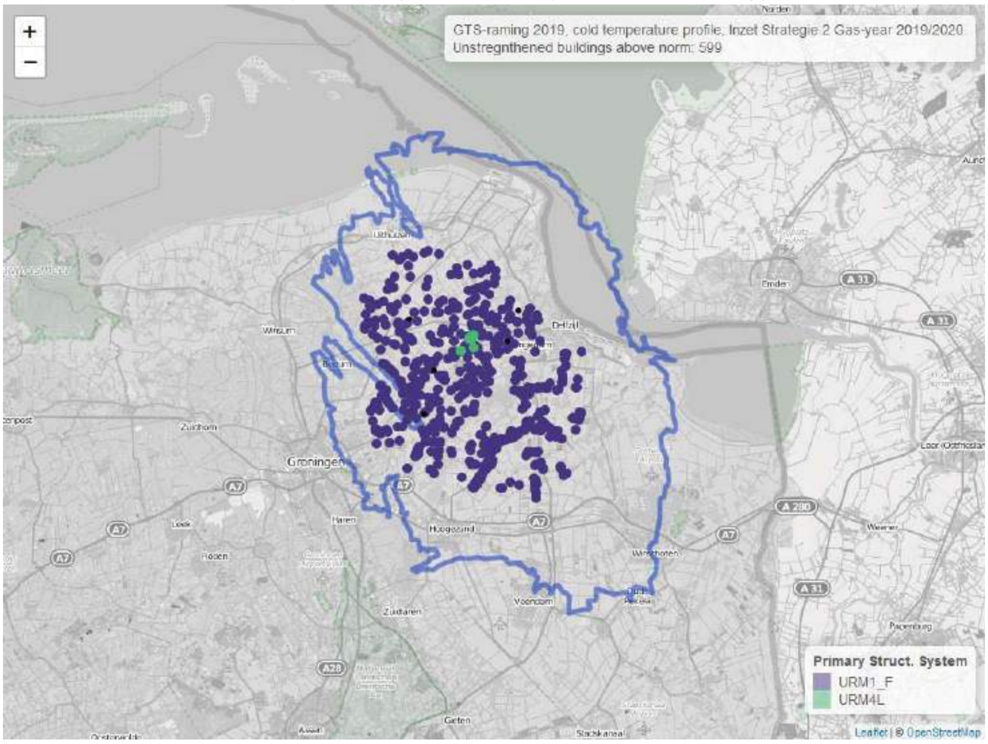

Number of buildings above the Meijdam-norm of $10^{-5}$/year for production profile GTS-raming 2019, average temperature profile and Operational Strategy 1.



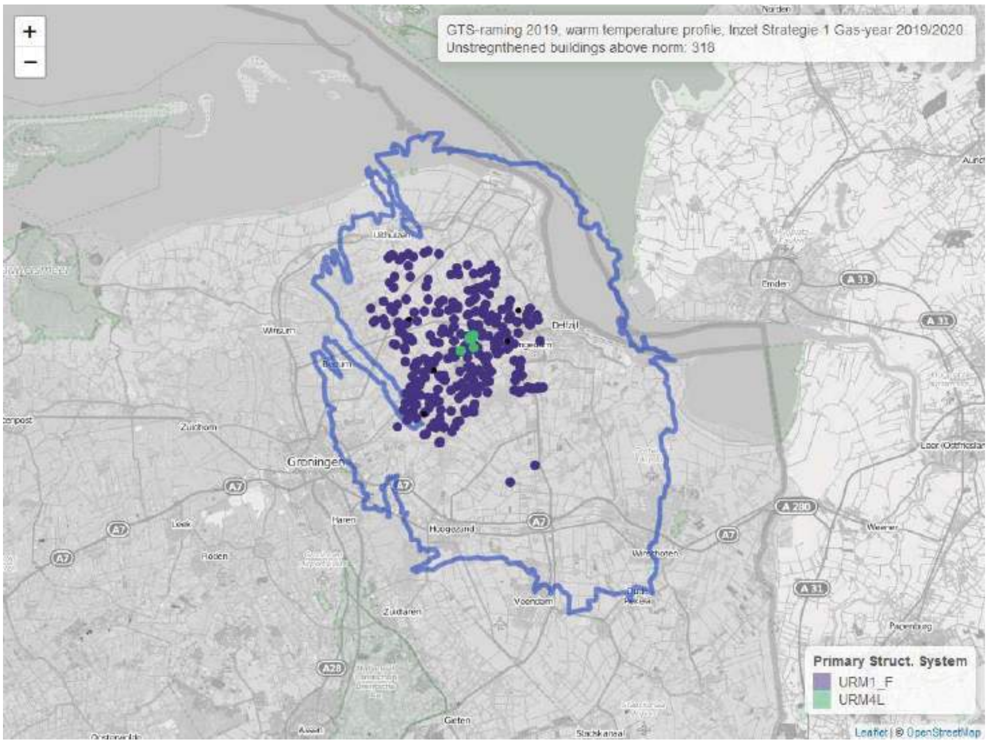

Number of buildings above the Meijdam-norm of $10^{-5}$/year for production profile GTS-raming 2019, average temperature profile and Operational Strategy 2.



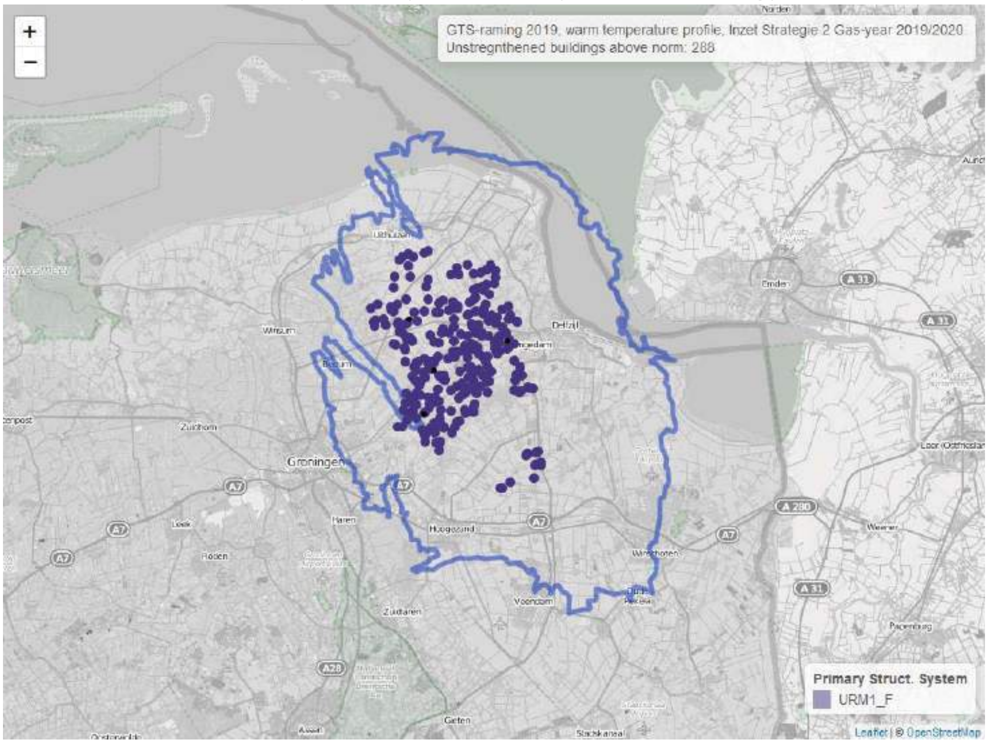

Number of buildings above the Meijdam-norm of $10^{-5}$/year for production profile GTS-raming 2019, cold temperature profile and Operational Strategy 1.




Number of buildings above the Meijdam-norm of $10^{-5}$/year for production profile GTS-raming 2019, cold temperature profile and Operational Strategy 2.




Number of buildings above the Meijdam-norm of $10^{-5}$/year for production profile GTS-raming 2019, warm temperature profile and Operational Strategy 1.




Number of buildings above the Meijdam-norm of $10^{-5}$/year for production profile GTS-raming 2019, warm temperature profile and Operational Strategy 2.

*Figure 6.14 Figures on previous pages shows the maps for the buildings above the norm in gas-year 2019/2020. The maps are provided for average, cold and warm temperature production profiles and for operational strategy 1 and 2.*

Figure 6.15 shows a reconciliation of the buildings above the Meijdam norm for the average temperature profile in gas-year 2019/2020, between the two operational strategies. Moving from operational strategy 1 (based on population-weighted PGV) to operational strategy 2 (based on event-count) adds 57 buildings closer to Groningen (middle panel in figure 6.15) and removes 84 buildings in the eastern part (right-hand panel of this figure).

Figure 6.16 shows the same for the cold temperature production profile in gas-year 2019/2020. Moving from operational strategy 1 (based on population-weighted PGV) to operational strategy 2 (based on event-count) adds 79 buildings closer to Groningen (middle panel in the figure 6.16) and removes 223 buildings in the eastern part (right-hand panel of the same figure).

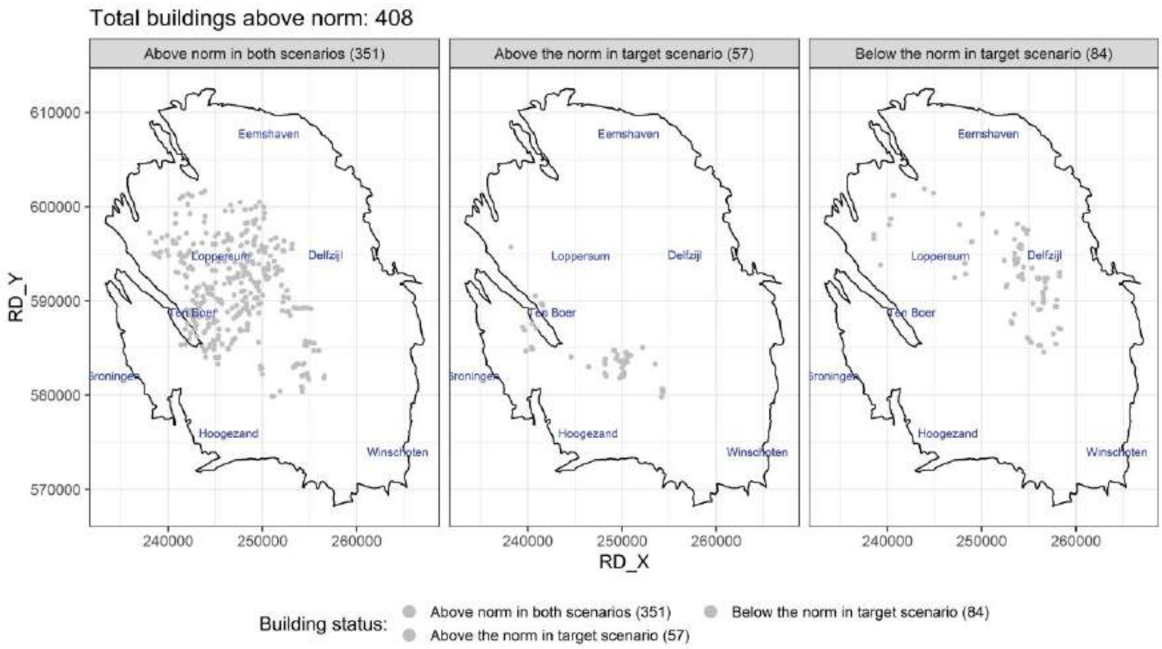



*Figure 6.15 The left figure shows the buildings above the norm in both operational strategies for the average temperature profile. Base is operational strategy 1 and the target is operational strategy 2. The middle figure shows the buildings additionally not meeting the norm for operational strategy 2, while the middle figure shows the buildings additionally not meeting the norm for operational strategy 1. This means that the buildings above the norm in operational strategy 2 are the buildings indicated in the left and middle figure together. The buildings above the norm in operational strategy 1 are the buildings indicated in the left and right figure together.*

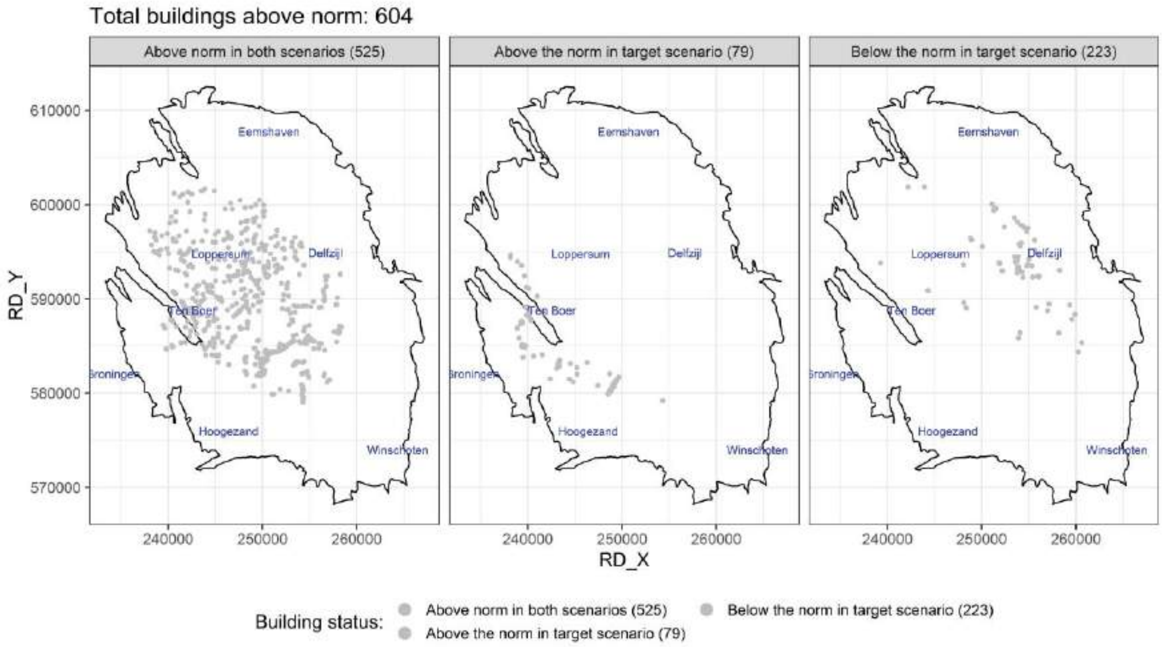



*Figure 6.16* *The left figure shows the buildings above the norm in both operational strategies for the cold temperature profile. Base is operational strategy 1 and the target is operational strategy 2. The middle figure shows the buildings additionally not meeting the norm for operational strategy 2, while the middle figure shows the buildings additionally not meeting the norm for operational strategy 1. This means that the buildings above the norm in operational strategy 2 are the buildings indicated in the left and middle figure together. The buildings above the norm in operational strategy 1 are the buildings indicated in the left and right figure together.*

## 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 >$10^{-5}$/year 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. It identifies which buildings have the highest risk of (partial) failure based on the building features in the Exposure Database. If a risk-based approach is to be followed, verification of the building features as used in the Hazard and Risk Assessment (by inspection) would be required. This means that inspection results will either confirm the building features or otherwise, which will have implications for prioritisation (for any subsequent engineering and strengthening). A risk-based inspection program will be able to identify which building may need strengthening with reasonable efficiency and help prioritising the effort.
- 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. Further studies, experiments, modelling and 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.

# 7 Damage Assessment

## Classification of Building Damage; Building Damage States

### European Seismological Commission, EMS-1998

The EMS-98, European Seismological Commission, 1998 (Ref. 43) document provides guidelines for estimation of the intensity of an earthquake based on the damage assessment of buildings.

Damage of buildings is assessed on the basis of a damage classification. This is provided for two main categories: unreinforced masonry buildings (URM) and reinforced concrete (RC) buildings. Figure 7.2 describes the 5 distinguished damage grades for both main categories. The description of the damage states in this figure are purely qualitative. For instance, “negligible to slight damage” is termed DS1, “moderate damage” DS2, “substantial to heavy damage" DS3”. The EMS scale relates DS1 to “hairline cracks in very few walls”, DS2 to “cracks in many walls” and DS3 to “large and extensive cracks in most walls”. The qualitative descriptions of the building damage states form a very useful, practical and generally accepted and applied classification system for building damage.

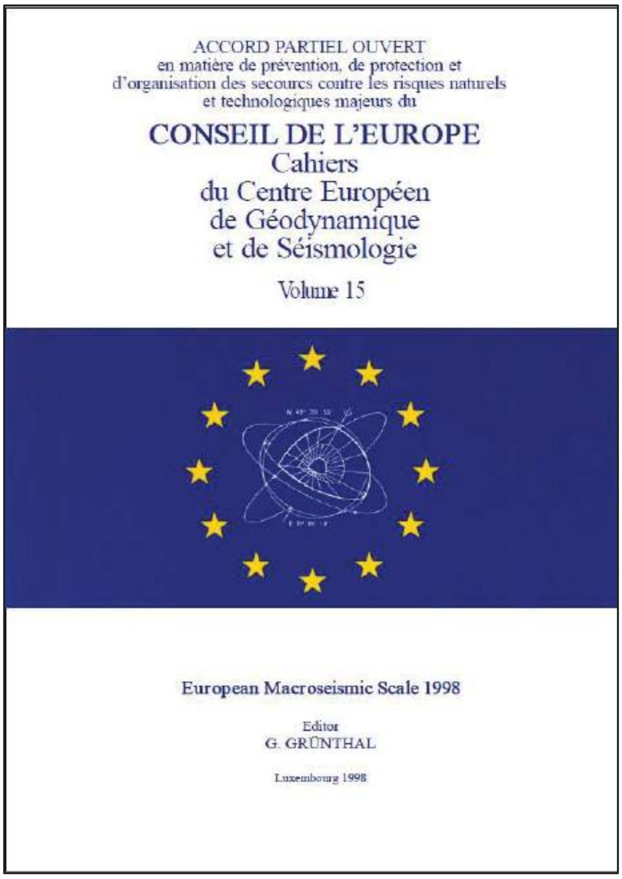
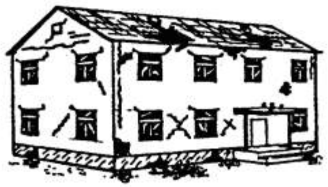



*Figure 7.1 Cover of the “European Macroseismic Scale 1998, EMS-98”by the European Seismological Commission (G. Grünthal), 1998.*

| Classification of damage to masonry buildings | |
|---|---|
|  | **Grade 1: Negligible to slight damage** **(no structural damage, slight non-structural damage)** Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases. |
|  | **Grade 2: Moderate damage** **(slight structural damage, moderate non-structural damage)** Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys. |
|  | **Grade 3: Substantial to heavy damage** **(moderate structural damage, heavy non-structural damage)** Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls). |
|  | **Grade 4: Very heavy damage** **(heavy structural damage, very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors. |
|  | **Grade 5: Destruction** **(very heavy structural damage)** Total or near total collapse. |

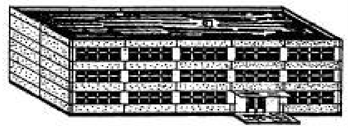
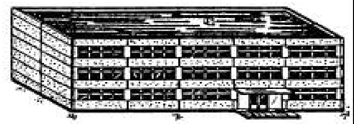
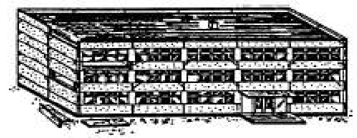
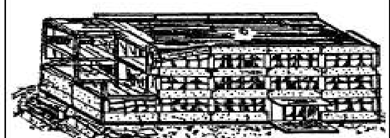
| Classification of damage to buildings of reinforced concrete | |
|---|---|
|  | **Grade 1: Negligible to slight damage** **(no structural damage, slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills. |
|  | **Grade 2: Moderate damage** **(slight structural damage, moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels. |
|  | **Grade 3: Substantial to heavy damage** **(moderate structural damage, heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels. |
|  | **Grade 4: Very heavy damage** **(heavy structural damage, very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor. |
|  | **Grade 5: Destruction** **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings. |

*Figure 7.2 Classification of damage to masonry buildings (left) and classification of damage to reinforced concrete buildings (right). Illustration taken from EMS-98, European Seismological Commission, 1998 (Ref. 43).*

## Forecast for Damage State 1 (DS1) aesthetic damage

The report "Methodology Prognosis of Building Damage and Study and Data Acquisition Plan for Building Damage" (Ref. 44), issued February 2017, describes the studies program into building damage and the methodology for forecasting building damage. The building damage assessment of November 2017 (Ref. 5) contains an introduction into the classification of damage states and into the Monte Carlo method used for forecasting building damage and fatality risk.

This section presents the forecast of building damage from DS1 on production profile "GTS-Raming 2019". The higher damage states DS4 and DS5 are relevant for risk and have been addressed in the previous sections of this report. For the assessment of DS1 building damage, empirical methods based on analysis of historical damage data are used.

The approach to forecast DS1 based on observed damage from historical earthquakes is described in section 8 of the report "Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017" (Ref. 5, pages 168-173). An update of that work has been prepared In June 2018 (Ref. 12, pages 9-11).

This section describes a further update and incorporate the latest information and knowledge available in the following areas:

- Production from the Groningen field "GTS-raming 2019"
- Exposure database V6 (EDB)

## Earthquake catalogue of events

For the forecast, a range of possible future realizations is needed that adequately represent the anticipated earthquake distribution, both in terms of magnitude and location in the field. These have been generated stochastically, using the hazard tool for the Operational Strategy 1 and Operational Strategy 2 based on the average temperature demand profile. These are the same profiles as used for the full Hazard and Risk Assessment. In the Monte Carlo simulation process, repeated random sampling of a set of input distributions is used to create a probabilistic distribution output. So-called 'synthetic earthquake catalogues' (i.e. event locations and magnitudes for the period 2019-2028) are generated from the input probability distributions of total seismic moment, number of events and event epicentres. This forecast uses events between $M_L$ = 1.8 and 4.0.

## Exposure model

The exposure database (EDB V6 Ref. 22) is an extract of a project database and consists mainly of the building typology classifications and several other building related attributes, including the population, arranged per building.

In addition to its use as input into the Hazard and Risk Modelling, the EDB deliverable also provides the necessary information to assign the TNO typologies to all 257,997 Buildings ("Basisregistratie adressen en gebouwen (BAG)" from the Kadaster) in the area considered for damage forecast.

The area of interest is the same for the Hazard and Risk Assessment and is based on the Groningen gas field outline. The extract boundary for the EDB V6 is a 5 km buffer around the gas field outline.

Table 7.1 shows how the different type of buildings present in the Groningen building stock have been assigned to the typologies used by TNO.

| TNO typologie | EDB V6 | Number of Buildings |
|---|---|---|
| “Niet gecategoriseerd”<br>(Not categorised / Secondary) | Buildings with zero population | 105,300 |
| “Boerderijen”<br>(Farms) | All buildings primary or secondary system URM1L_F | 1,983 |
| “Hoogbouw”<br>(High Rise Buildings) | Gutter height >10m | 4,613 |
| “Laagbouw voor 1940”<br>(Low Rise Buildings before 1940) | Remaining year of construction before 1940 | 40,740 |
| “Laagbouw na 1940”<br>(Low Rise Buildings after 1940) | Remaining year of construction after 1940 | 105,361 |

*Table 7.1 Assignment of EDB V6 typologies to the typologies used in the TNO Kalibratiestudie.*

Although it has been recognized that secondary buildings representing ca. 40% of all buildings mainly consisting of sheds, garages and other small normally unoccupied buildings could also incur damage, they have been excluded from the forecast because damage data/reports are unavailable for such structures. A sensitivity analysis, with assumed fragility function like Low Rise buildings after 1940, shows that secondary buildings may perhaps add up to ca. 60% additional damage cases.

Due to the absence of damage observations in the earlier TNO studies, fragility function for Low Rise buildings after 1940 have also been assigned to all High-Rise buildings. This is believed to be a conservative assumption.

## Results

Figure 7.3 shows results of the DS1 damage forecast in the form of an annual F/N curve for the Groningen field area, one per year, shown for the period 2019-2028.

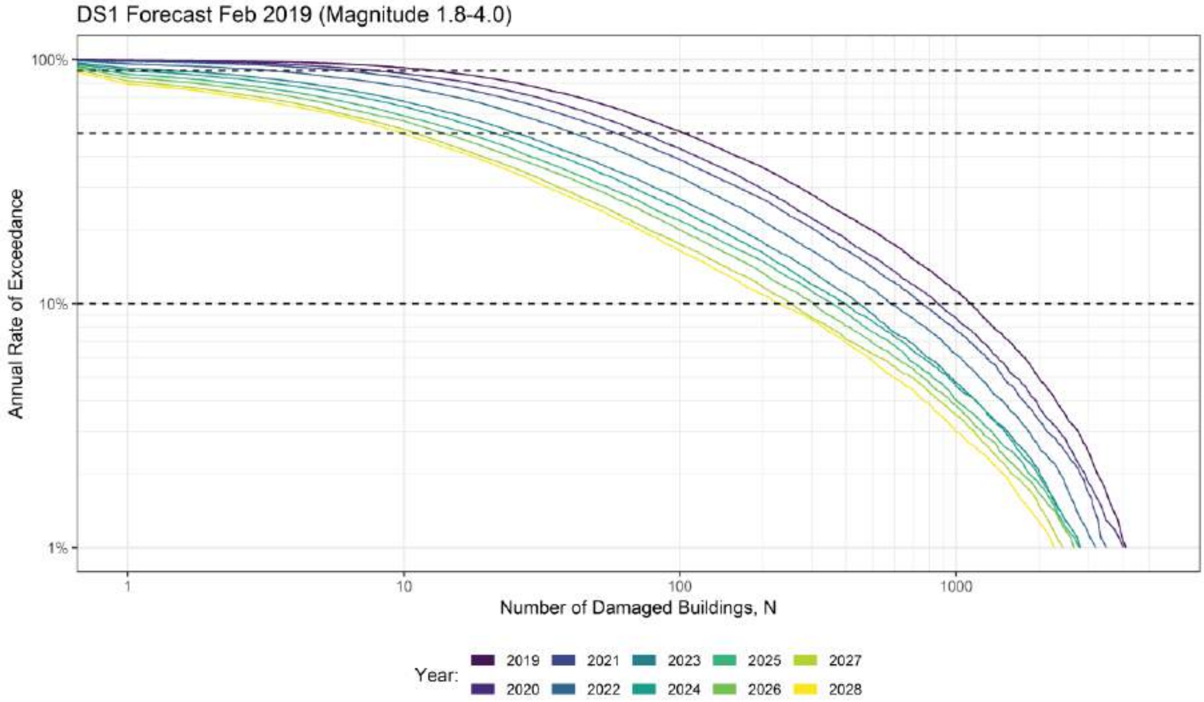
The median forecast (P50 or 50%) is indicated together with the 80% confidence interval (10% to 90%). Each building in the exposure area was assigned with a relevant typology. It was assumed that any resulting building damage is repaired after the event and before the next one (instant repair).

The figure shows that in 2019 a fifty percent chance that more than 100 buildings will be damaged with aesthetic damage (DS1) (due to all earthquakes in that year smaller than ML=4). In 2028 there is a fifty percent chance that more than 10 buildings will be damaged with aesthetic damage.

Figure 7.4 shows the Mean and P50 for the DS1 damage forecast per year for the period 2019-2028. Due to the skewed distribution of building damage the mean number of damaged buildings is considerably higher than the P50.

The DS1 damage forecasts for both operational strategies are very similar, with a maximum difference of between 10 and 20 damaged buildings per year.

# Operational Strategy 1




# Operational Strategy 2

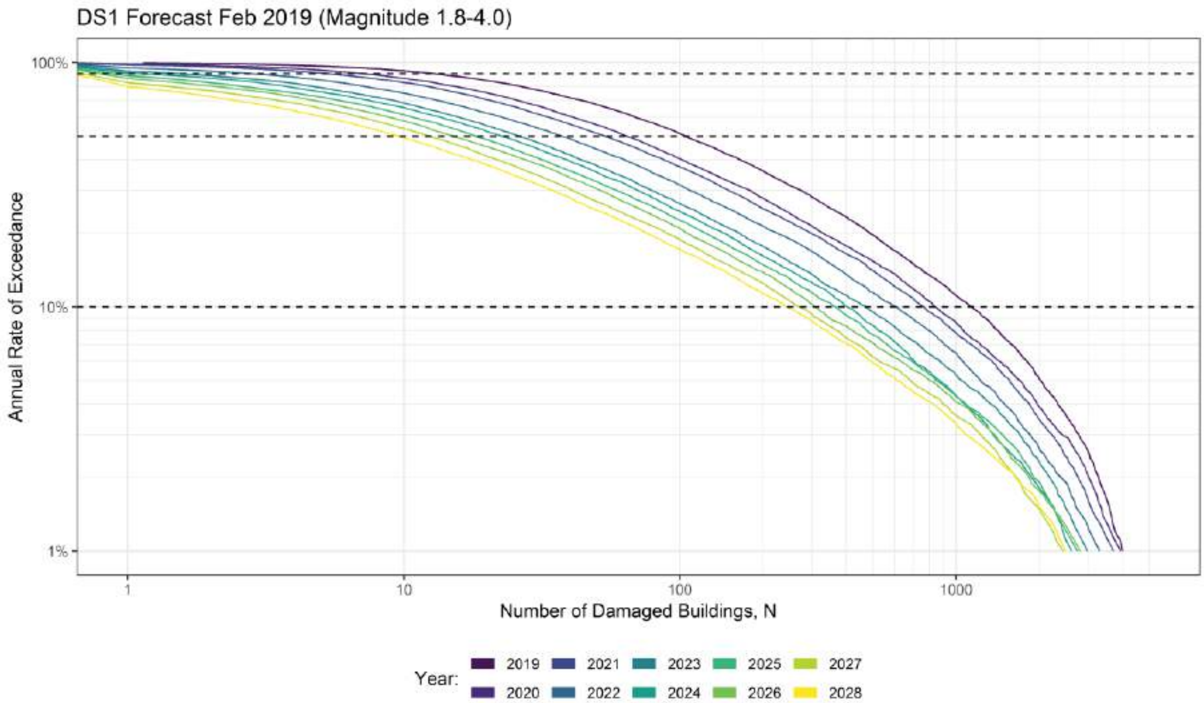
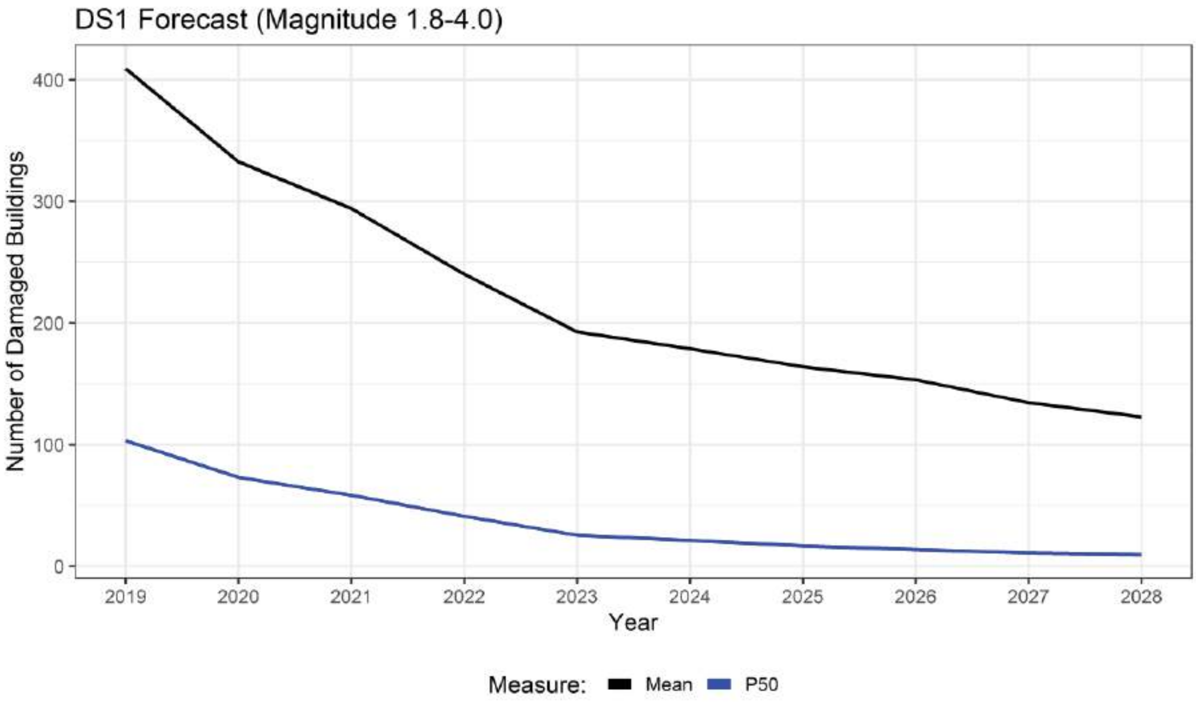



*Figure 7.3 DS1 Forecast per year for period 2019-2028 based on the middle branch of the logic tree, shown for "GTS-Raming 2019" Operational Strategy 1 and 2 average temperature demand profile.*

# Operational Strategy 1




# Operational Strategy 2

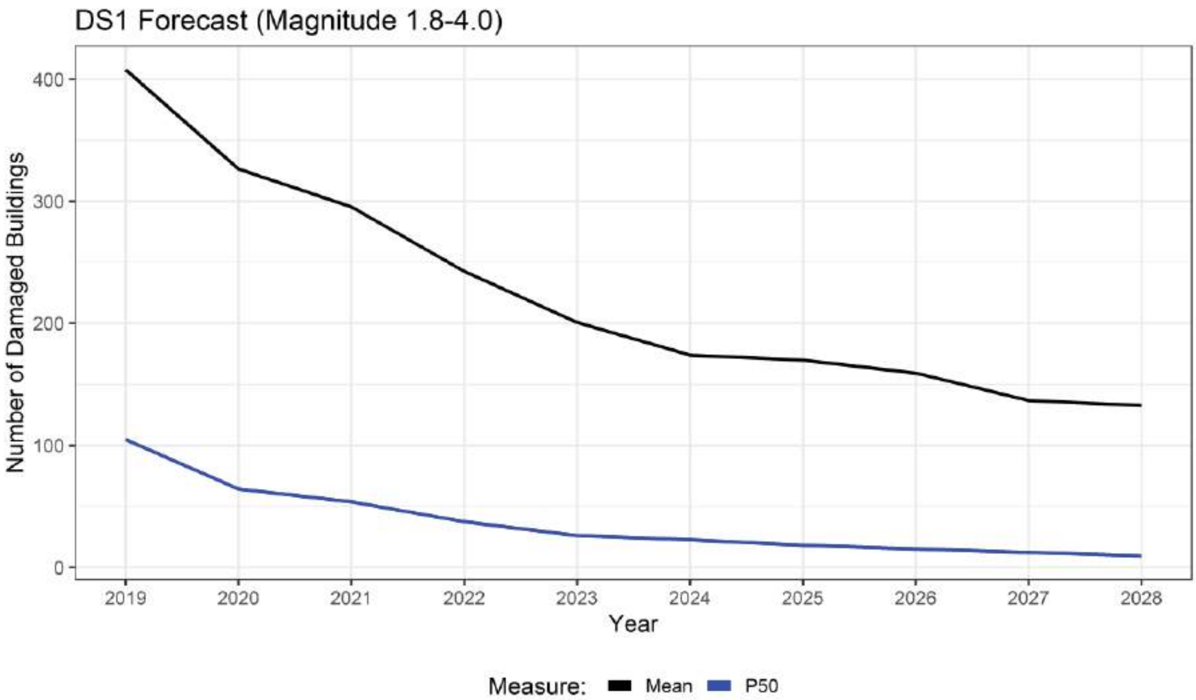



*Figure 7.4* *Mean and P50 DS1 Forecast per year for period 2018-2028 based on the middle branch of the logic tree, shown for “GTS-Raming 2019” Operational Strategy 1 and 2 average temperature demand profile.*

## Forecast for Damage State 2 (DS2) and Damage State 3 (DS3)

Fragility functions for DS2 and DS3 have been developed for each structural system identified in the exposure model using the extensive analytical modelling and experimental test campaign described in (Ref. 27). F/N curves have been calculated with the Monte Carlo risk engine which show the annual frequency of exceedance (F) of different numbers of groups of buildings (N) which simultaneously reach DS2 or DS3. Figure 7.5 shows the F/N curve for the whole field for each of the years in the period 2018 to 2027. The F/N curves for two consecutive 5-year periods (2019 to 2024 and 2025 to 2028) are shown in figure 7.6.

Figure 7.5 shows that in 2019, the annual frequency of exceedance of having anywhere 100 buildings simultaneously damaged to DS2 in a given earthquake is around 5% and the chance that 10 buildings are simultaneously damaged to DS3 in a given earthquake is a bit lower.

Figure 7.7 shows the exceedance damage count for the occurrence of the given damage state (DS). For instance, in 2019, the chance of 10 or more buildings reaching a DS2 damage state is about 11%. The chance that 100 buildings or more reach damage state DS3 is less than 2%. In Figure 7.8 DS2 and DS3 damage is compared for the two operational strategies. Differences are less than 1%.

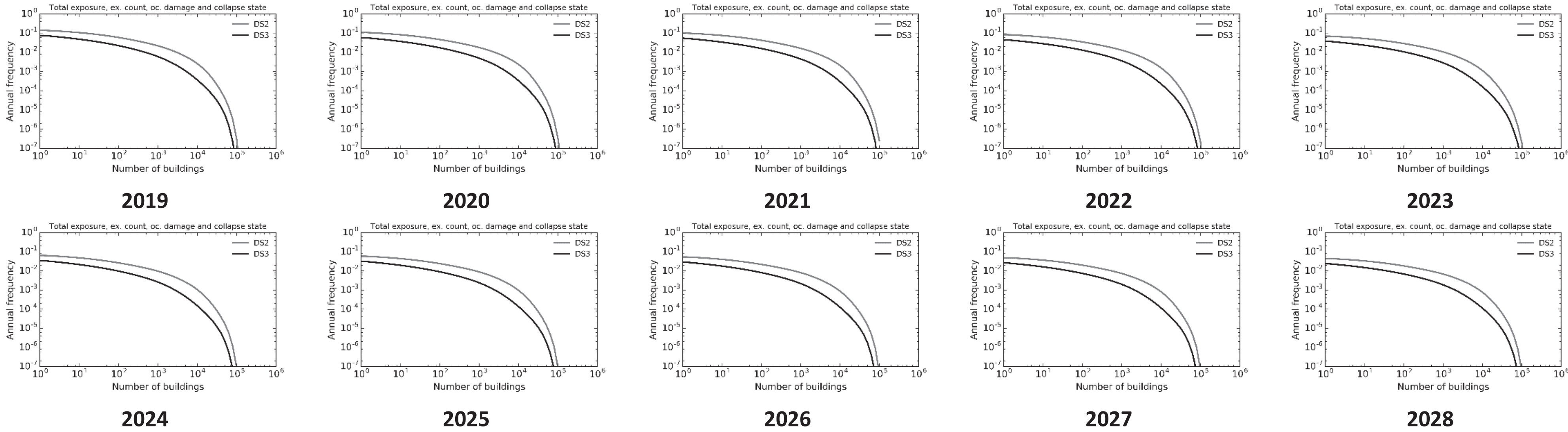
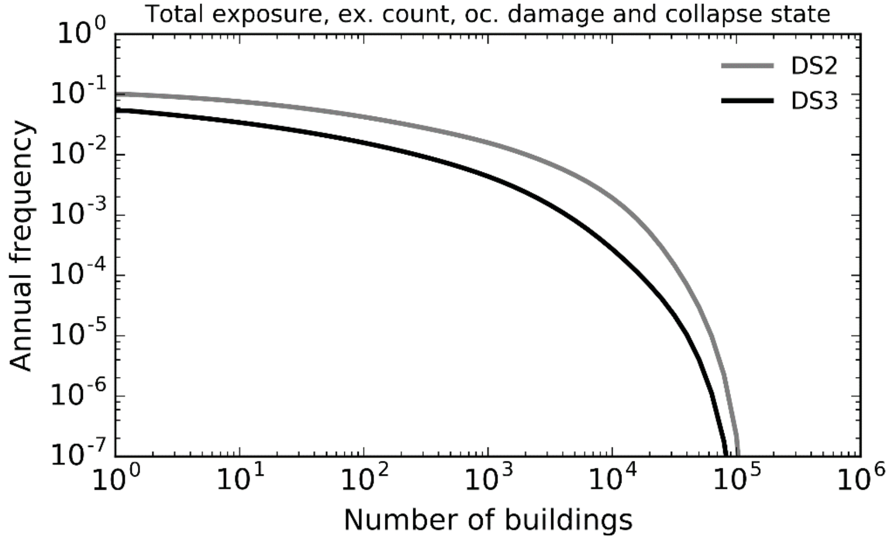
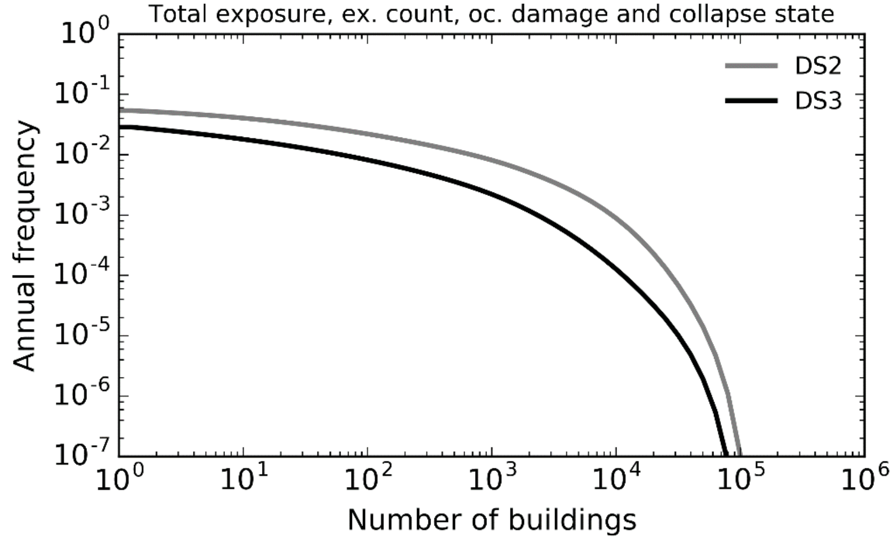



*Figure 7.5* *Maatschappelijk risico for building damage DS2 and DS3 (MR(S)) for the whole field for the years 2019 to the years 2028. The production is based on an average temperature year using the “Operational Strategy 2”.*



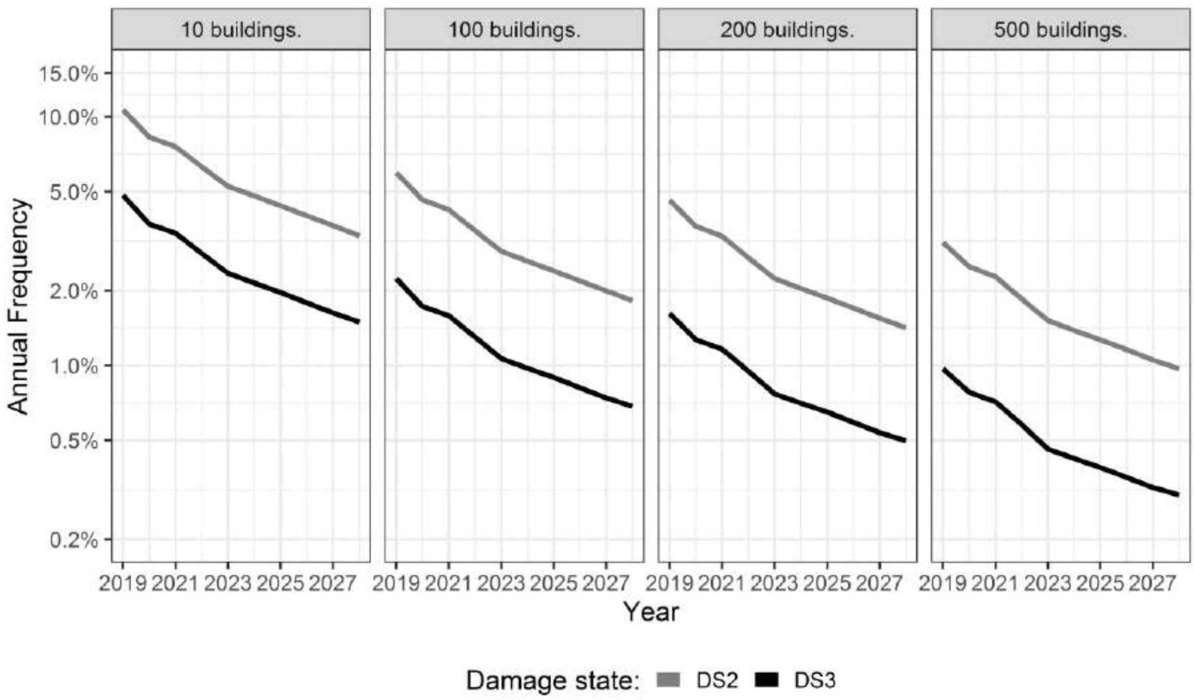

**2019 - 2024**




**2025 - 2028**

*Figure 7.6 Maatschappelijk risico for building damage DS2 and DS3 (MR(S)) for the whole field for the years 2019 to the years 2028.*

**Average Temperature Production Profile**




**Cold Temperature Production Profile**

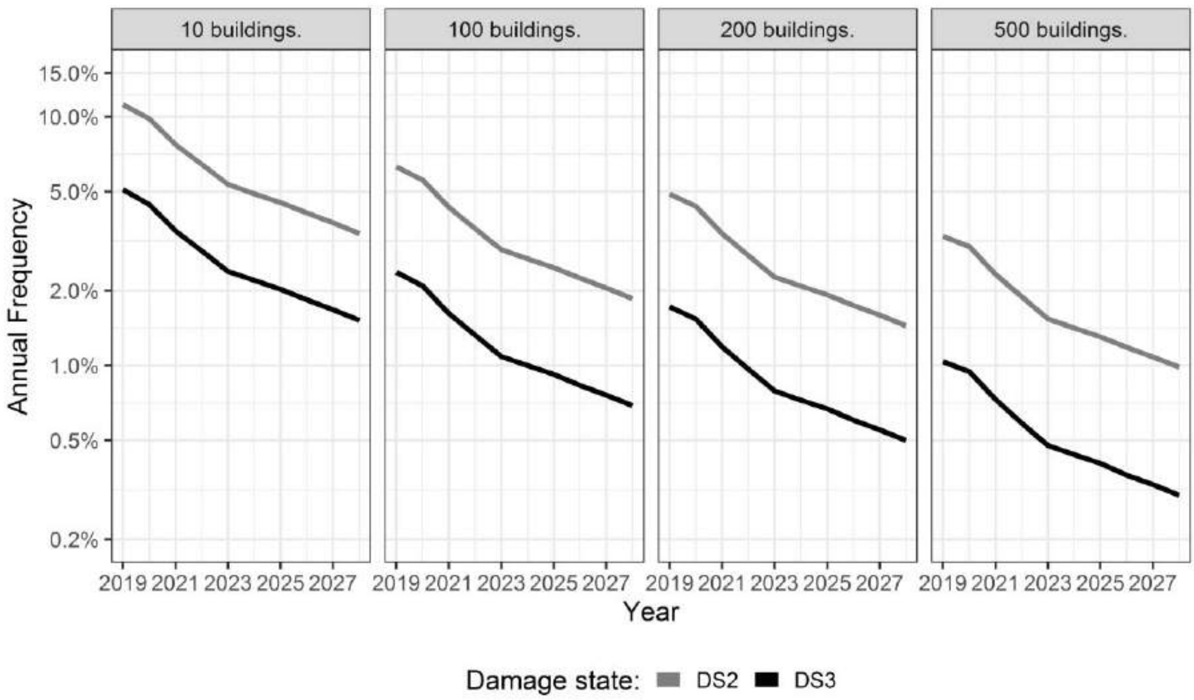
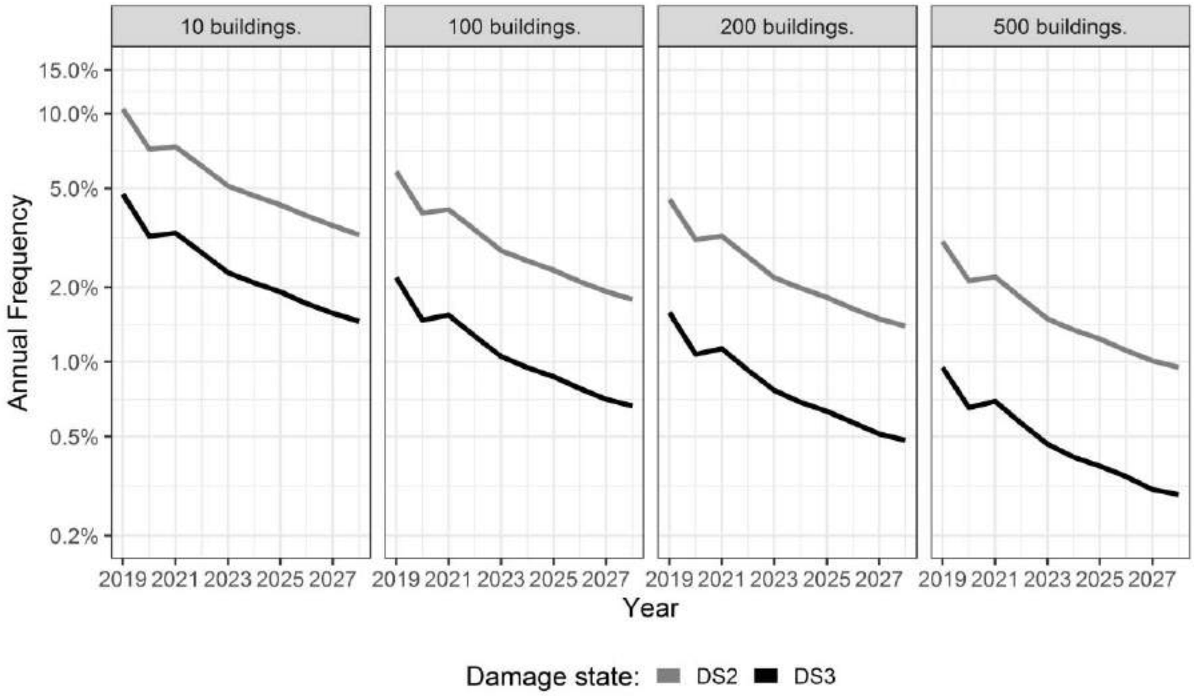



*Figure 7.7a Maatschappelijk risico for building damage DS2 and DS3 (MR(S)) for the whole field for the years 2019 to the years 2028.*

**Warm Temperature Production Profile**




**Reference Production Profile**

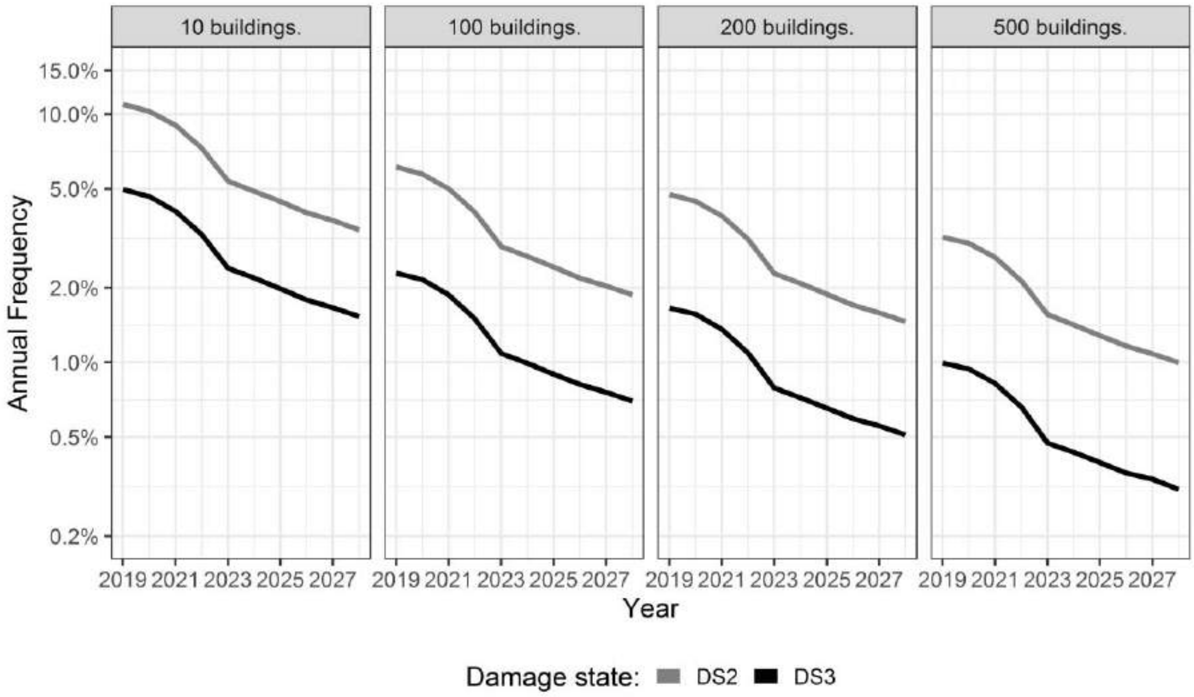



*Figure 7.7b* *Maatschappelijk risico for building damage DS2 and DS3 (MR(S)) for the whole field for the years 2019 to the years 2028.*

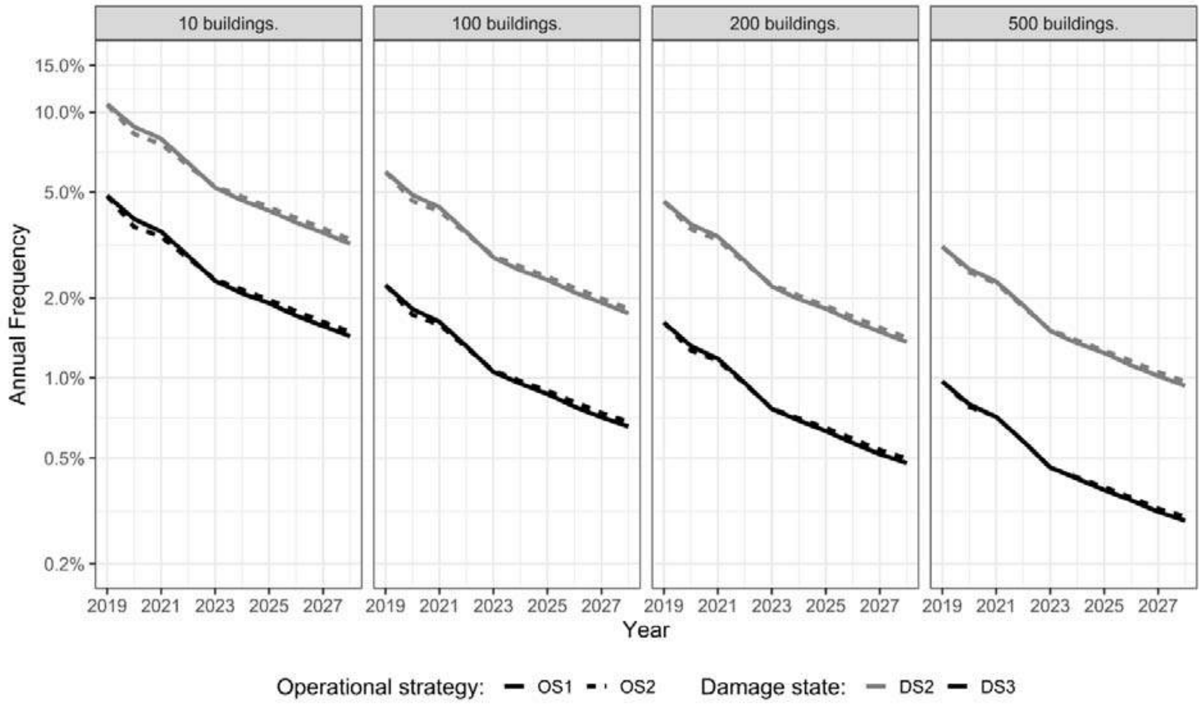



*Figure 7.8* *Maatschappelijk risico for building damage DS2 and DS3 (MR(S)) for the whole field for the years 2019 to the years 2028, based on average temperature production profile of GTS-raming 2019. The results for both operational strategy 1 and 2 are shown.*

# 8 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,

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# Appendix A – Correspondence

## Verwachtingenbrief (Expectation Letter)

Ministerie van Economische Zaken en Klimaat

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**Ons kenmerk**
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**Uw kenmerk**

**Bijlage(n)**
2

Datum - 1 3 FEB. 2019 -
Betreft Verzoek tot voorstellen van twee operationele strategieën voor het gasjaar 2019-2020

Geachte heer Atema,

Met ingang van het gasjaar 2019-2020 geldt het nieuwe stelsel voor gaswinning uit het Groningenveld, zoals vastgelegd in zowel de gewijzigde Gas- als de gewijzigde Mijnbouwwet. Hierbij verzoek ik u conform artikel 52c van de Mijnbouwwet in ieder geval twee operationele strategieën voor het gasjaar 2019/2020 voor te stellen op basis van de bijgevoegde GTS-raming voor hetzelfde gasjaar, uitgaande van scenario 2. In deze brief (inclusief bijlagen) geef ik de uitgangspunten voor beide in te dienen operationele strategieën, die uiterlijk 15 maart 2019 in mijn bezit dienen te zijn.

In de Mijnbouwregeling is in artikel 1.3a.2, eerste lid, vastgelegd dat een operationele strategie omvat:

a. een beschrijving van de volgorde van de inzet van de clusters en de verdeling van het volume over de clusters per kalendermaand uitgaande van het referentiejaar voor een gemiddeld gasjaar;
b. de wijze waarop de inzet over de clusters en de verdeling van het volume over de clusters wordt verlaagd dan wel verhoogd, afhankelijk van de ontwikkeling van de actuele temperatuur gedurende het gasjaar, waarbij in ieder geval een beschrijving wordt gegeven van de volgorde van de inzet van de clusters en de verdeling van het volume over de clusters uitgaande van het referentiejaar voor een koud en voor een warm gasjaar.

Daarnaast zijn in het tweede en derde lid van artikel 1.3a.2 van de Mijnbouwregeling, ter onderbouwing van de operationele strategie nadere eisen opgenomen, bijvoorbeeld over de rol van gasopslag Norg, de invloed van geplande onderhoudswerkzaamheden en over de dreigings- en risicoanalyse behorende bij een operationele strategie.

Bij het voorstellen van de operationele strategieën verzoek ik u de beschrijvingen te volgen zoals vastgelegd in artikel 52c van de Mijnbouwwet en artikel 1.3a.2 van de Mijnbouwregeling.

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In de bijlage geef ik meer specifiek de uitgangspunten voor de beide operationele strategieën aan.

De Minister van Economische Zaken en Klimaat,
Voor deze:

Esther Pijs
Directeur Gastransitie Groningen

Bijlagen: A: Uitgangspunten voor de operationele strategieën 2019/2020
B: GTS-raming benodigd Groningenvolume en capaciteit gasjaar 2019/2020 en verder

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Projectdirectie Gastransitie Groningen

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**Bijlage**

**Uitgangspunten voor de operationele strategieën 2019/2020**

In de studie "Production Optimisation 2018" van september 2018 werkt NAM vier mogelijke optimalisaties uit voor productie van de benodigde hoeveelheid gas uit het Groningenveld in een gasjaar, waarmee seismiciteit gereduceerd kan worden, namelijk de minimalisatie van:

- Aantal bevingen (Event Count)
- Maximale grondversnelling (Maximum Peak Ground Acceleration, maxPGA)
- Maximale grondsnelheid (Peak Ground Velocity, maxPGV)
- Grondsnelheid gewogen met bevolkingsdichtheid (Population weighted PGV, pwPGV)

Als uitgangspunt voor operationele strategie 1 dient u de optimalisatie "Grondsnelheid gewogen met bevolkingsdichtheid (Population weighted PGV)" te nemen. Uitgangspunt voor operationele strategie 2 dient de optimalisatie "Aantal bevingen (Event Count)" te zijn.[1]

Voor beide strategieën geldt:

- De strategie is gebaseerd op het productiescenario voor het gasjaar 2019-2020 conform het GTS-advies, en maakt de gevolgen inzichtelijk met betrekking tot het verwachte aantal en de grootte van de geïnduceerde aardbevingen, de seismische dreiging ('hazard') en het seismisch risico.
- De strategie wordt uitgewerkt voor een koud, gemiddeld en warm gasjaar 2019-2020.
- De strategie geeft een 10-jaarsdoorkijk voor de gasjaren na 2019-2020, conform artikel 1.3a.2 derde lid, onderdeel e.
- De strategie bevat een dreigings- en risicoanalyse waarmee een directe vergelijking mogelijk is tussen de operationele strategieën.

De benodigde productiehoeveelheid van gas uit het Groningenveld om te kunnen voldoen aan het niveau van leveringszekerheid in het gasjaar 2019-2020, evenals de graaddagenformule die voor het gasjaar 2019/2020 van toepassing zal zijn, staat beschreven in de GTS-rapportage "Raming benodigd Groningenvolume en capaciteit gasjaar 2019/2020 en verder" van 1 februari 2019, met de aanvullende bijlage "uitgangspunten volumeberekeningen". Deze GTS-rapportage is als bijlage bij deze brief gevoegd.

U dient uit te gaan van de volgende prioriteitsvolgorde:

1. lever die hoeveelheid Groningenveldgas die jaarlijks nodig is voor de leveringszekerheid binnen de graaddagenformule;
2. zorg voor voldoende underground gas storage (hierna: UGS) werkvolume gedurende de hele winter (= effectief leveringszekerheid);
3. vul UGS Norg voor het komende gasjaar;

[1] Aansluitend bij het instemmingsbesluit voor het gasjaar 2018-2019 en het advies van SodM van 16 oktober 2018: SodM, NAM productie optimalisatie studie: Beoordeling en Advies, 16 oktober 2018, kenmerk 18249842

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4. voorkom overschrijdingen van de beperkingen gesteld aan de regionale productiefluctuaties.

U dient ervoor zorg te dragen dat het verschil in maandelijkse productie niet groter is dan 20% voor het cluster Bierum en 50% voor de overige regio's, zoals bedoeld in de Mijnbouwregeling onder artikel 1.3a.1 onder 1, die voor productie in gebruik zijn, met uitzondering van Eemskanaal waarvoor geen beperking van de productiefluctuaties geldt. Deze percentages worden bepaald ten opzichte van de voorgaande maand en ten opzichte van de gemiddelde productie over de 12 voorgaande maanden. Indien er een keuze moet worden gemaakt tussen het reduceren van volume en het loslaten van de productiefluctuatiebeperking prevaleert het reduceren van volume.

Aangezien de nieuwste bodemdalingsdata pas eind maart beschikbaar komen, vraag ik u niet om een nieuwe bodemdalingsstudie uit te voeren. Wel vraag ik u aan te geven in hoeverre de conclusies uit rapport "Assessment of Subsidence based on Production Scenario "Basispad Kabinet" for the Groningen Field" uit juni 2018 nog actueel zijn.

**Uitgangpunten voor bijbehorende dreigings- en risicoanalyse bij een operationele strategie**
De dreigings- en risicoanalyse dient de elementen te bevatten die in Mijnbouwregeling artikel 1.3a.2 lid 3 zijn opgenomen. Hierbij dient te worden opgemerkt:

- Bij uitwerking van artikel 1.3a.2, lid 3 sub b, dient een schadeprognose te worden gemaakt – als gevolg van geïnduceerde bevingen – voor de schadegrenstoestanden DS1, DS2 en DS3 uit het EMS-98, European Seismological Commission, 1998. Een kwalitatieve analyse van de DS1-schades evenals een verwachting van DS2- en DS3-schades dient u 15 maart te sturen. Gegeven de omvang van de berekeningen, vraag ik u de kwantitatieve prognoses van de drie genoemde schades bij het gegeven productiescenario uiterlijk 12 april bij mij in te dienen.
- Bij uitwerking van artikel 1.3a.2, lid 3 sub e, dient voor het gasjaar 2019-2020 van een koud, gemiddeld en warm scenario uitgegaan te worden, voor de jaren hierna kan een gemiddeld temperatuurprofiel worden gehanteerd.
- Artikel 1.3a.2, lid 3 sub f en g, moeten worden bezien in het licht van Mijnbouwwet artikel 52b, geldend vanaf 1 oktober 2019.

U dient versie vijf van de modelketen, zoals gebruikt bij het opstellen van de operationele strategie voor het gasjaar 2018-2019, met de actualisaties van de gebouwendatabase en de verbeteringen in kwetsbaarheidscurves van bouwwerken, te hanteren bij het opstellen van de dreigings- en risicoanalyses. Ik verzoek u deze verbeteringen ter beschikking te stellen aan TNO zodat deze verdisconteerd kunnen worden in de modelketen die zij, i.s.m. KNMI en Deltares, op mijn verzoek ontwikkelen.

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De uitkomsten van de dreigings- en risicoanalyse, zoals berekend op basis van het basispad kabinet voor een winningsniveau van 20,6 miljard Nm³ per jaar, dienen ter vergelijking opgenomen te worden.

De uitkomsten van iedere dreigings- en risicoanalyse worden als volgt weergegeven:

a. Berekeningen van het Objectgebonden Individueel Aardbevingsrisico (OIA)[2] (hazard-kaarten en OIA-curves) voor het gasjaar 2019/2020.
b. NAM maakt aanvullende grafieken:
   i. #gebouwen verwachtingswaarde + aanvullende onzekerheidsband $>10^{-4}$/jaar tegen tijd (10-jaarsdoorkijk);
   ii. #gebouwen verwachtingswaarde + aanvullende onzekerheidsband tussen $10^{-4}$ en $10^{-5}$/jaar tegen tijd (10-jaarsdoorkijk);
c. ruimtelijke kaart met de locaties van de gebouwen waar het OIA groter is dan $10^{-5}$/jaar voor het gasjaar 2019/2020.
d. ruimtelijke kaart met de locaties van de gebouwen waar het OIA groter is dan $10^{-4}$/jaar voor het gasjaar 2019/2020.
e. NAM zal deze gegevens ook in de vorm van een tabel opnemen in haar rapportage (zie als voorbeeld: tabel 5.1a & b uit "*Seismic risk assessment for production scenario "Basispad Kabinet" for the Groningen field, June 2018*").
f. Tabel met alle gebouwtypologieën waarvan het risico $>10^{-4}$/jaar en $>10^{-5}$/jaar is voor het gasjaar 2019-2020, en voor de 10-jaarsdoorkijk.
g. In aanvulling op de ruimtelijke kaart met locaties van gebouwen, zal NAM de BAG-ID's van de betreffende gebouwen aanleveren aan de Nationaal Coördinator Groningen (NCG), conform de afspraken omtrent de uitwisseling van persoonsgegevens zodat voor de NCG gebouwen op adresniveau herleidbaar zijn.

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[2] Voor het vaststellingsbesluit 2019-2020 vraag ik u voor wat betreft de verdiscontering van de verblijfsduur in de risicoberekeningen aan te sluiten bij de eerder uitgevoerde *Hazard and Risk Assessment* van juni 2018 (in het instemmingsbesluit Groningen gasveld 2018-2019 is hier aan gerefereerd met de term (conservatief) objectgebonden individueel aardbevingsrisico (OIA)). Deze wijze, waarbij is uitgegaan een permanente aanwezigheid van personen in bouwwerken, sluit aan bij eerdere risicoberekeningen, waardoor vergelijkingen over de afgelopen jaren beter zijn in te schatten. Op 2 februari 2019 heeft het hooglerarenpanel middels het '*Briefadvies panel van hoogleraren over de berekening van de gemiddelde verblijfsduur in verschillende type bouwwerken*' mij nader geadviseerd over de berekeningswijze van het individueel aardbevingsrisico (IAR). Specifiek wordt geadviseerd om, in lijn met het advies van de Commissie Meijdam (2015), de gemiddelde verblijfsduur van personen in bepaalde typen bouwwerken te verdisconteren in het OIA om vervolgens te komen tot het IAR. Ik wil u vragen, in lijn met het advies van de commissie Meijdam en conform het advies van het hooglerarenpanel, het IAR aanvullend te rapporteren in een technische bijlage.

**Directoraat-generaal Klimaat en Energie**
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Additioneel vraag ik u een publieksvriendelijke samenvatting bij beide operationele strategieën te leveren, waarin de relatie met de bijbehorende dreigings- en risicoanalyse wordt beschreven, en beide operationele strategieën (en hun gevolgen v.w.b. de seismiciteit en het seismisch risico) worden samengevat.

## Letter Advies hooglerarenpanel over berekening aardbevingsrisico (7-3-2019)

# Tweede Kamer der Staten-Generaal

2

Vergaderjaar 2018–2019

**33 529** **Gaswinning**

**Nr. 585** **BRIEF VAN DE MINISTER VAN ECONOMISCHE ZAKEN EN KLIMAAT**

Aan de Voorzitter van de Tweede Kamer der Staten-Generaal

Den Haag, 7 maart 2019

Hierbij informeer ik u over een advies van een hooglerarenpanel dat verband houdt met het risicobeleid ten aanzien van de door de gaswinning veroorzaakte aardbevingen in Groningen. Onder begeleiding van de Mijnraad heeft een panel van hoogleraren op 31 juli 2018 geadviseerd over de interpretatie van de veiligheidsnorm van $10^{-5}$ en de berekeningswijze van het individueel aardbevingsrisico ten gevolge van de door de gaswinning veroorzaakte aardbevingen. Op mijn verzoek heeft het panel zijn advies op 3 februari 2019 van een nadere toelichting voorzien. Op 11 februari 2019 heeft Staatstoezicht op de Mijnen (SodM) geadviseerd over deze nadere toelichting[1].

**Advies hooglerarenpanel**

Het panel van hoogleraren heeft mij geadviseerd over de interpretatie van de veiligheidsnorm ($10^{-5}$). Dit advies heb ik overgenomen in het instemmingsbesluit gaswinning Groningenveld 2018–2019 en is vastgelegd in de gewijzigde Mijnbouwregeling.

Aanvullend hierop heeft het panel mij ook geadviseerd over wijze waarop het individueel aardbevingsrisico (IAR) berekend dient te worden. Het panel licht in zijn advies toe, in lijn met het advies van de Commissie Meijdam uit 2015, dat bij de berekening van het aardbevingsrisico rekening gehouden dient te worden met de gemiddelde verblijfsduur van personen in bepaalde typen bouwwerken. Bij het hanteren van een gemiddelde verblijfsduur wordt aangenomen dat een (fictief) individu maar een deel van zijn tijd doorbrengt in of rond het bouwwerk. In de dreigings- en risicoanalyse (Hazard and Risk Assessment: HRA) van juni 2018 heeft NAM geen rekening gehouden met verdiscontering van de gemiddelde verblijfsduur, en wordt aangenomen dat een individu zich permanent bevindt in een bepaald type bouwwerk. Het panel beschouwt

[1] Raadpleegbaar via www.tweedekamer.nl

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de berekeningen van NAM daarom als te conservatief. Een nadere toelichting op de definities van de verschillende soorten aardbevingsrisico's en de berekening van het IAR kunt u vinden in het bijgesloten advies van de hoogleraren[2].

SodM heeft mij geadviseerd het advies van 3 februari 2019 van de hoogleraren niet over te nemen, en bij de risicoberekening uit te blijven gaan van permanente aanwezigheid van individuen in bouwwerken. SodM stelt dat als er wordt uitgegaan van een gemiddelde verblijfsduur, er altijd bewoners zullen zijn die langer in een bouwwerk verblijven dan de aangenomen gemiddelde verblijfstijd, en hiermee dus een groter risico lopen dan het berekende risico. SodM geeft aanvullend aan dat het voorstel van de hoogleraren niet aansluit bij de Nationale Praktijk Richtlijn voor aardbevingsbestendig bouwen (de NPR 9888:2018), waarin wordt uitgegaan van een permanente verblijfsduur.

**Omgang advies**

Het advies van de hoogleraren toont dat de huidige berekeningswijze om het veiligheidsrisico te berekenen leidt tot een conservatieve, maar geen onjuiste inschatting van het veiligheidsrisico. Door rekening te houden met een gemiddelde verblijfsduur kan een meer nauwkeurige inschatting gemaakt worden van het veiligheidsrisico.

Ik ben echter van mening dat het onwenselijk is dat als bewoners in Groningen langer dan gemiddeld in hun huizen verblijven hiermee geen rekening wordt gehouden in de veiligheidsnorm, zij moeten hun woning als een plek kunnen beschouwen waar zij 24 uur per dag veilig zijn. Ik hecht er daarnaast aan dat de berekening van het aardbevingsrisico consistent is met eerdere berekeningen. Ik heb daarom aan NAM gevraagd om bij de HRA, behorende bij de operationele strategie voor het komende gasjaar, uit te blijven gaan van een permanente verblijfsduur. Het berekende aardbevingsrisico sluit hiermee aan bij de HRA van NAM uit juni 2018. De uitkomsten van deze HRA zullen betrokken worden in de jaarlijks vast te stellen prioritering van de versterkingsoperatie.

Ik vind het echter wel van belang om te onderzoeken wat het effect is op het veiligheidsrisico als de gemiddelde verblijfsduur wordt meegenomen bij bouwwerken (anders dan woningen) waarin individuen zich maar een (zeer) beperkt deel van hun tijd bevinden. Dit inzicht vind ik van belang, omdat vanuit veiligheidsoogpunt hiermee een nadere prioritering mogelijk is. Daarom heb ik NAM gevraagd om ook een inschatting te maken van het aardbevingsrisico rekening houdend met de gemiddelde verblijfsduur. Om maatwerk mogelijk te maken zal ik onderzoeken of ik deze resultaten voor bouwwerken anders dan woningen kan betrekken in de jaarlijkse prioritering van de versterkingsoperatie.

De Minister van Economische Zaken en Klimaat,
E.D. Wiebes

[2] Raadpleegbaar via www.tweedekamer.nl