# **Induced seismicity in Germany during the** last decade - an overview and update

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# Abstract

The **Federal Seismic Survey at BGR** evaluates seismic events in Germany and neighbouring countries on a daily basis. The results are supplemented by the outcomes of the seismological agencies of the federal states of Germany and German universities and stored in an event database and in the German earthquake catalogue, which is complete for earthquakes with magnitudes M<sub>L</sub> ≥ 2.

The events are classified as natural earthquakes, induced earthquakes or explosions (mostly quarry blasts). A considerable number of the events are induced earthquakes. They originate from stress changes due to human activities in the subsurface. The main causes of the induced events are coal mining, potash salt mining, natural gas extraction and geothermal energy production. We describe the characteristics of the associated seismicity for the different mining regions in Germany. In contrast to natural seismicity which originates in long-term processes, the number and strength of induced seismicity is strongly dependent on rather short-term temporal and spatial changes. The seismicity in **coal mining regions**, e.g., **decreased coinciding with the** shutdown of coal mining, whereas seismic activity in geothermal or natural gas fields show different behavior, increasing or decreasing depending on the location. Additionally, the latter both types of induced seismicity show remarkable peculiarities in their temporal behavior. Seismic events still occur with **a delay after a geothermal power plant was shut down**. Seismic activity can start several years after the start of extraction in a new natural gas field. We show the temporal course of induced seismicity over the last 10 years in dependence on the distinct extraction types and compare it with the previous decades. In addition, we also investigate the **magnitude-frequency relationship** and the energy release of the induced earthquakes and compare the parameters with those of the natural seismicity.





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Fig. 1: a) Natural earthquakes in Germany and the immediate vicinity of the border for the time period 2015 to 2024 (red circles). b) Induced earthquakes in Germany colour-coded by extraction type. Both data sets originate from the German Earthquake Catalogue of the BGR. In both maps, events in Germany not taken into account and those outside Germany are labelled in pink.





decreasing after stop of production at around 2018, energy release of gas production seems to be rather constant during the last decade.

period 1991 to 2014 and for 2015 to 2024.

## **Temporal course of seismicity**



### Energy release 1991 – 2024 - natural versus induced



**Fig. 6:** Annual energy release for induced as well as for natural earthquakes for the years 1991 to 2024. The dominating peak over the whole time span is in 1992 caused by the magnitude  $M_1 = 5.9$  Roermond earthquake.



Fig. 7: a) Percentage of energy release and total sum for 1991 to 2024. b) Percentage of energy release for three consecutive decades.

Fig. 3: Temporal course of induced earthquake activity in Germany from 2015 to 2024. For comparison purposes, the greatest magnitude of completeness among the different extraction types was selected (gas production  $M_1$ =1.7). The large number of small magnitude events in geothermal production is due to the dense temporary network of the MAGS project.

#### Summary

- The main causes for induced seismicity in Germany are coal mining, potash salt mining, natural gas extraction and deep geothermal production.
- While the majority of energy released in the years 1991 2014 was caused by coal production, it is gas that accounts for largest energy release in the years 2015 – 2024.
- During the last decade the energy released by gas production is the dominant one at a constant level, whereas shares of geothermal energy and potash are declining slightly.
- The energy release by induced earthquakes accounts for 8% of the total seismic energy release (for the time span 1991 – 2024, excluding the 1992 Roermond earthquake).
- **Outlook:** Revision of German Earthquake Catalogue with the aim of lowering the magnitude of completeness - in cooperation with earthquake services of federal states.

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