To what extent have severe accidents occurred in the energy sector over the past 30 years? [1]

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Summary

One of the measures for sustainability of energy systems is their (low) level of risk. This can be measured based on the occurrence of severe accidents in the past, or, insofar possible, through model calculations.

The Paul Scherrer Institute (PSI) in Villingen, Switzerland owns the world's most comprehensive database on severe accidents in the energy sector. Accidents are considered as 'severe' if they have one of the following consequences: at least five fatalities or at least ten injured or at least 200 evacuees or an extensive ban on consumption of food or releases of hydrocarbons exceeding 10 000 t or enforced clean-up of land and water over an area of at least 25 km^2 or economic loss of at least five million USD(2000).

The database not only includes accidents with the production of energy, but covers the entire energy supply chain, since accidents occur in each stage, during exploration, transport, processing, storage, distribution until waste treatment and disposal.

The PSI database ENSAD (Energy Related Severe Accident Database) contains currently 18 400 entries, mainly from the period 1969 – 2000. Comparisons between fossil energy carriers, hydro and nuclear power can be summarised as follows for this time span. Severe accidents are by far more frequent in emerging and developing nations compared to industrialised OECD countries with their distinct safety culture. Over the past 30 years, the OECD countries experienced for coal, gas (natural gas) and liquified gas (LPG, mineral products) a respective total of 75, 90 and 59 severe accidents with at least 5 fatalities, and with oil even 165. Hydro and nuclear power with no severe accident with direct fatalities

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are clearly less vulnerable, but the maximum possible hypothetical consequences could be very large.

Compared to the rare severe accidents, we see relatively frequent small accidents, especially with renewable energy. Systematic central data on this subject is collected only on a limited scale, which explains why data is often incomplete.

Through improvements in technology and training, as well as the optimisation of the interaction between man and machine, the number of severe accidents, as well as their impact on mankind and the environment can be significantly reduced.

Extended text

1. One of the measures for sustainability of energy systems is their (low) level of risk. Risk is measured first of all through damage to human beings in the form of immediate fatalities, shortening of life expectancy through damage to organisms, leading to premature death, or a long-term and severe reduction in health. In addition come damages to the natural and cultural (agriculture, buildings) environment. Such damages can occur during normal operation of a facility (e.g. through damaging emissions of large quantities of SO_2, nitrogen oxydes and small particles, as well as greenhouse gasses, especially CO_2), during disturbances, or sometimes only during accidents.

2. Accidents in the energy sector represent, after transport, the 2^{nd} largest group of (anthropogenous) accidents caused by man. Since they are usually not analysed separately, but as part of total anthropogenous accidents, their data collection was incomplete, and information collected often without much detail. Nevertheless, especially spectacular accidents with far-reaching consequences often lead to controverse with regulators and in debates about energy politics. This is also reflected in the reporting by media, where following catastrophes have been extensively covered:

   - Mining accidents in the Chinese coal mining industry suffered over 6 000 fatalities in 2004; in the first half of 2005, again 2 700 people died
   - In the North Sea, through the capsizing of an oil platform in 1980, and the explosion of another in 1988, each time over 100 people died
   - The loss of oil tankers such as for example the Exxon Valdez near the Alaskan and the Prestige near the Spanish Galician coast led to pollution of sea and coastal areas
   - The explosion of a liquified gas pipeline in Siberia in 1989 and of a tanker carrying liquified gas near a camping site in Spain in 1978 caused respectively

600 and 216 fatalities

- With the accident of the Chernobyl reactor (Ukraine, then Soviet Union), it's not the 31 immediate fatalities that are of concern, but rather the fear for long-term consequences, such as induced cancers, which are estimated with model calculations, under a range of assumptions.
- With the breach of 2 dams, user primarily for hydro electricity in the Chinese province Henan in 1975, 26 000 people died, while details of these accidents where made public only years later.

3. The Paul Scherrer Institute (PSI) systematically collects, documents and analyzes data on severe accidents in the energy sector since the 90's. This resulted in the world's largest database on this subject: ENSAD (Energy Related Severe Accident Database). Other man-made (anthropogenous) accidents are also considered, though to a lesser extent. ENSAD contains currently 18 400 entries, of which around 70% are anthropogenous accidents, and almost 90% in the time frame 1969 to 2000. ENSAD enables, for the first time, detailed risk comparisons based on actual incidents, i.e. not just on the basis of model calculations (Failure Mode and Effect Analysis). Frequently occurring, smaller accidents, with lower damages, that however add up, such as for example those occurring in decentralised energy systems, are investigated in much less detail. Systematic and central collection for these data is very limited, which explains why they are often fragmentary and less documented. The ENSAD database also allows interesting comparisons with damages from natural catastrophes, on which insurance companies collect substantial information.
4. In the context of ENSAD, an accident is considered severe when at least one of the following consequences could be identified:
   - at least five fatalities
   - at least ten injured
   - at least 200 evacuees
   - extensive ban on consumption of food
   - releases of hydrocarbons exceeding 10 000 t or enforced clean-up of land and water over an area of at least 25 km2
   - economic loss of at least five million USD

5. Accidents do not occur only in the actual energy production in power plants, but also in each stage of the energy supply chain. This lifecycle view includes in particular:
   - Prospection and exploration of energy and non-energy raw materials
   - Extraction of non-energy raw materials for construction and energy feedstock for operating the plant
   - Storage and processing of materials
   - Construction of the facility
   - Transport to and from the facility
   - Demolition of the facility
   - Disposal of non-utilisable materials (waste)

   For all stages, a 'cradle to grave' approach is pursued.
6. The facilities, processes or technologies in emerging and developing economies cannot be compared with those in industrialised OECD countries, either because of age and efficiency of the plant, or because of different safety standards. This shows in the accident frequency, and the resulting damages, that are significantly higher in non-OECD countries compared to OECD. Therefore, results are shown separately for both groups of countries. The lack of safety standards in the Chinese coal mines as well as the Chernobyl case demonstrate that the normal safety standards in Western countries often lack in non-OECD countries.
7. To compare, one needs to normalise the number and consequences of accidents, based on the amount of energy produced, for example a million kWh (= 1 Gagawatthour - GWh) or a Gigawatt-year – GWa – (1 GWa is 8.76 GWh). Otherwise, risk comparisons between energy carriers would have very limited meaning. The immediate fatalities of an energy supply chain, when considered in relation to their equivalent electricity production, yield a measure 'fatalities per Gigawatt-year' (GWa) that allows direct comparisons between energy supply chains and country groupings.
8. The available ENSAD data has been analysed for the time frame 1969 – 2000. This gives the following snapshot (first without normalisation).

Energy chain	OECD countries			non-OECD countries		
	Accidents	Fatalities	Fatalities max accid	Accidents	Fatalities	Fatalities max accid
Coal	75	2259	272	1146 *	22848	434
Oil	165	3789	577	232	16494	4375
Natural gas	90	1043	109	45	1000	100
Liquified gas	59	1905	498	46	2016	600
Hydro power	1	14	14	10	29924	26000 ***
Nuclear	-	-		1	31 **	31

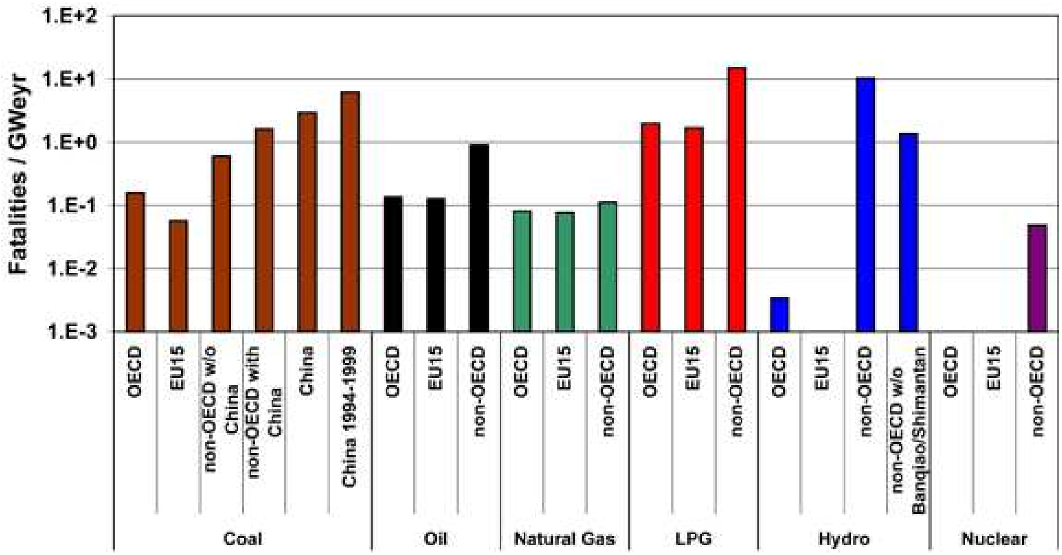
* includes 1 044 accidents with 18 017 fatalities in China

** Figure not including long-term consequences. For the case of Chernobyl, the calculations for the latent fatalities through induced cancers vary between 9 000 for Ukraine, Russia and Belarus to 33 000 for the Northern Hemisphere in the coming 70 years (Hirschberg et al, 1998). Following a study in September 2005 (Chernobyl Forum) published from a forum of various UN organisations (IAEA, WHO, UNDP, FAO, UNEP, UN-OCHA and UNSCEAR), 4 000 people could die from the consequences of radiation in the most contaminated areas. This value is much lower than the maximum value of the PSI-estimate, but the latter was not limited to the most contaminated areas.

*** 26 000 fatalities from the breach of the Banqiao/Shimandan dam in China

Around 75% of severe accidents occurred in emerging and developing countries. A large share of these where accidents with the development, processing and transport of coal and oil, as well as accidents in the use of hydro electricity. Least accident prone were Western nuclear and hydro power plants.

When normalising severe accidents per GWa, we obtain the graph in figure below.



It shows that LPG, coal, oil and natural gas represent the highest risks for severe accidents in the energy supply. Hydro and nuclear power in OECD countries are on the other extreme of the scale. In the Western industrialised countries, no accident with fatalities has occurred so far in the nuclear sector. Extrapolating the sole severe accident with damages to health in Chernobyl to OECD countries is not relevant, since in the OECD, other and more secure technologies are used. For this reason, only probabilistic security analysis, such as the German reactor studies A (1979) and B (1990) are possible. According to these, we can expect maximum 0.02 fatalities per GWa. A GWa represents around 80% of the annual electricity production of a large nuclear power station. For modern power plants with their higher security standards, this value drops another order of magnitude, i.e. around 0.002 fatalities per GWa.

9. The potential for danger alone, without consideration of the overall probability to cause a severe accident, is inappropriate as a measure for assessing an energy technology. For example, accidents in Chinese coal mines occur very frequently, but seldom claim more than 100 fatalities. In comparison, the oil and natural gas supply chains experience much less accidents, but in non-OECD countries, they cause maximal damages 1-2 orders of magnitude above these from coal. In general, a large catastrophe with many fatalities to deplore is considered more severe than many smaller accidents with the same death toll. The perception and evaluation of accidents is decisive for our willingness to accept them, or not. Therefore, several perspectives are needed.

10. Severe accidents, or at least their worst consequences can be avoided through technical measures. For example the high death toll in the Chinese coal mines can be drastically reduced through the modernisation and introduction of Western safety standards. Double-hull oil tankers will largely reduce the risk of sea and coastal pollution in case of disaster. Nuclear power plants depend on the optimisation of the interaction man-machine with mutual control, and hence compensation of the weaknesses of each, i.e. on the one side the automatic reaction of the reactor in case of deviation of its characteristics (fast shutdown, and avoiding panic reaction of operators), and measures for accident management on the other – these are interventions by the operating crew after disturbances in order to avoid consequential effects. For the newly developed French-German EPR-reactor, the first of which is being constructed in Finland, in the extremely unlikely event of a reactor meltdown, the melting core mass is contained in a base tub (core-catcher), avoiding the escape of large radioactive emissions.

    When current safety knowledge is translated into further safety measures, the number of accidents in the energy sector in the coming years and decades will go down significantly, and their consequences will be far lower. But risk can never be zero.

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