Wildfires - An emerging hazard for industrial installations in Europe?

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The wildfire seasons of 2018 and 2019 have been one of the most intense the European countries were facing during the last years. The countries often struck by wildfires in the south of the European continent were exposed to serious fire events, but furthermore also the northern Scandinavian peninsula was confronted with serious wildfires in 2018. During the last decades numerous natural events triggering technological disasters have been reported. These so called "Natech" events are a constant topic within international research activities. With respect to the ongoing climate effects these activities are becoming more and more important for adequate safety management also around European industrial sites. Whenever wildfires intersect with communities or industrial areas specific hazards arise. Regions in which wildland meets urban or suburban areas are called "Wildland Urban Interfaces (WUI)". Larger Disasters or cascading events might be triggered around critical infrastructure, industrial complexes or major accident hazard sites. Current work regarding Natech events therefore deals with so-called "Wildland Industrial Interfaces (WII)" which are areas in the near vicinity of wildfire regions where large technological disasters might be triggered by wildfires. An explorative study was carried out analysing the future trends for wildfires in Europe and the vulnerability of industrial sites and critical infrastructure against wildfires. Keeping in mind the changing nature and development of wildfires, it can already be concluded that wildfires in general are capable of causing severe effects on buildings and technical infrastructure. Especially expected future Megafires are a serious danger. If no adequate measures are taken, thermal radiation levels, ember flight or direct flame impingement might cause severe damage to industrial infrastructure or process equipment. This can lead to loss of containment events followed by toxic spills, fires or explosions. Regarding the current status, there is still limited information about detailed effects of wildfires on industrial plants.

Introduction

The wildfire seasons of 2018 and 2019 have been among the most intense the European countries were facing during the last years. The countries often struck by wildfires in the south of the European continent were exposed to serious fire events, but furthermore also the northern Scandinavian peninsula was confronted with serious wildfires in 2018 (EFFIS JRC, 2019). During this period the question arose, whether wildfires have to be considered as trigger for industrial accidents in future scenarios.

During the last decades numerous natural events triggering technological disasters have been reported (Krausmann et.al., 2017). These so called "Natech" events are an emerging topic within the research community. With respect to the ongoing effects of climate change activities in this field are becoming more and more important for adequate prevention and emergency management measures around industrial sites. Especially for regions where wildfires have been a negligible threat up until now.

Whenever wildfires intersect with communities or industrial areas specific hazards arise. Regions in which wildland meets urban or suburban areas are called "Wildland Urban Interfaces (WUI)". Disasters or cascading events might be triggered around critical infrastructure, industrial complexes or hazard sites with major accident potential. Current work regarding Natech events therefore deals with so-called "Wildland Industrial Interfaces (WII)" which are areas in the near vicinity of wildfire regions where technological disasters might be triggered by wildfires (Johnston and Flannigan, 2018). In the past emphasis was placed on protecting sensible wildland and forest areas from environmental damage by the means of land use planning which is a necessary and important step in many policies like the Seveso III directive (Directive 2012/18/EU). Unmanaged wildland has never been seen as a danger itself, although the threat of wildfires is not new on the European continent. Climate change and the change of the surrounding conditions also for industrial installations raises concerns about plant safety. A number of incidents have been recorded, where wildfires opposed a serious threat to industrial installations. The following short cases should indicate the nature and effects of such events.

During the last years also the production of tar sands in the region of Alberta, Canada has increased significantly. The upstream processing of the crude is carried out in one of the several refineries in the area. During the wildfire season of 2016 the area around Fort McMurray was significantly affected by the ongoing wildfires. Around 88.000 people had to be evacuated and around 2.600 houses burned down. Additional to the combustion products from burning wood, also large amounts of toxic smoke were generated by burning homes, cars, shops, etc. Fort McMurray is the heart of the Canadian tar or oil sands production. For the production processes large amounts of solvents are necessary to be able to get hold of the final products. These solvents are brought to the refineries and production sites by large pipelines. Due to the remote location of the production sites, the pipelines cross large wildland areas. In the course of the 2016 fires which had a size of over 500.000 ha, these solvent pipelines had to be shut down partially which led to a significant reduction of the production rates also at the refineries. The total financial loss was around CAD $3.6-billion.

During the wildfires of 2019 a biogas plant in Flegentreu, Brandenburg, Germany was endangered by an extensive wildfire. The fire involved a former military training ground that was used for this purpose for over a century. Large areas are suspected to contain leftover or unexploded ammunition so for emergency responders it was not possible to enter the hazardous area. Emergency response had to rely on different strategies while the fire itself gained intensity. Local fire services and emergency response activities got overstretched and called for help from other regions in Germany. The event was declared a disaster event by following German jurisdiction. Besides regular emergency response capacities also the German army (Bundeswehr) was called for help due to its capacities for aerial firefighting and the capability of protected movement in areas containing ammunition leftovers. The wildfire developed towards several towns in the area. As a precautionary measure they were evacuated for several days.

In the course of the events the biogas plant was endangered by the growing fire. The park consists of 10 single biogas plants with an overall thermal power of 7,2 MW. The plant processes renewable raw materials. The plant was erected in 2007/2008 and has an overall size of around 15 hectares. Bundeswehr tried to protect the biogas park using CH 53 helicopters with 5000 L exterior water containers. Water was taken from a nearby lake. Bundeswehr helicopters were flying 480 missions with 120 flight hours in the course of this wildfire. Bundeswehr stated that the increased need for aerial firefighting also stretched their capacities to a certain limit. The fire was extinguished in the end by extensive response efforts including multiple stakeholders. Emergency response measures were also supported by rain. The biogas park was not harmed in the end.

In October 2018 a wildfire (grassland) causes the explosion of an underground storage tank in South Korea. The fire was caught on CCTV cameras and was caused by a carelessly used sky lantern in the near vicinity of the plant. The fire entered the tankfarm and reached the storage tank within several minutes. The fire of burning gasoline raged over 17 hours and was releasing toxic smoke towards the city of Seoul. Close by communities have been given advice to keep windows and doors closed to reduce exposure to toxic fumes.

These short case studies show that there is an immanent threat for industrial installations in the wildfire prone areas. Although now major accident caused by wildfires had been reported up until now, there is a strong indication for the hazard potential wildfires oppose to industrial installations. In the following section, the nature and behaviour of wildfires will be explained briefly.

The wildfire hazard

Fires in complex industrial environments pose severe risks inside and around these facilities. The effects and triggers of fire hazards are well known around the industry, although accidents still happen. Nevertheless, various aspects of wildfires are special compared to common accidental fires occurring in an industrial surrounding. The strong influence of atmospheric conditions and the possible size of wildfires are only some of the specialities. In comparison to many other natural hazards, wildfires are natural events that can be influenced prior to their occurrence. That is a distinctive attribute compared to other natural hazards. Proper wildland and vegetation management in potential wildfire areas for example can limit the development of wildfires. Three main factors govern fire behaviour and help to classify different types of wildfires:

- Fuel (amount, arrangement, moisture)
- Weather (wind, temperature, humidity, precipitation)
- Topography (slope or aspect of the land)

Fires governed by fuel (convective fires), fires influenced by wind (wind driven fires) and topography driven fires. In general it can be said that the intensity of wildfires increases with higher wind speeds and upward slopes. Regional effects like narrow canyons or valleys might also lead to more intensive fires or extreme fire behaviour.
According to European wildfire statistics up to nearly 90% of the wildfires are triggered by human activities either by accident but also on purpose (San-Miguel-Ayanz et. al., 2019). Once ignited the fire can spread in different types of vegetation like grassland, forest, shrub, etc. In large forest areas the fire shows different behaviour than in pure grassland. Different types of vegetation do therefore lead to different combustion behaviour and fire intensity. High amounts of combustible material can dramatically intensify the fire.

Wildfires in general are a natural phenomenon playing a distinct role in the earths ecological system. Although society mostly recognizes wildfire as a major problem it is scientifically understood that wildfires are a necessary and natural factor in some ecosystems. In a long term perspective the wildfire situation can be seen embedded in a series of different controlling factors described as triangles by Moritz et al. 2005. Wildfires are mainly influenced by two feedback loops between fire behaviour and the local wildfire situation, as well as between the local wildfire situation and the overall fire regime.

Fire behaviour can change in seconds, the overall wildfire situation in several days and the fire regime in a long term perspective over decades. Climate change influences the overall fire regime which leads to a change in the wildfire situation in terms of size and behaviour. When fires themselves grow larger they are able to influence weather and consequently also climate in a long-term perspective. But this is just one aspect. If the situation in terms of fuel or vegetation changes the fire regime can also be influenced. Any event or activity influencing vegetation and therefore fuel can also influence the overall wildfire regime.

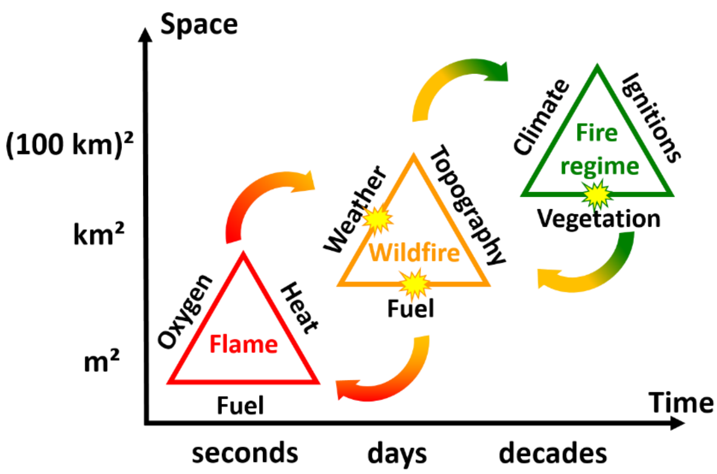

Figure 1: Controlling factors of wildfires at different scales (Moritz et al. 2005)

From an industry perspective, wildfires can have two main types of effects: direct effects and indirect effects. Both can lead to critical situations in a chain of events. Case studies within this report show that there are also a lot of indirect effects, occurring in the context of large wildfire events. They are connected to direct effects of the fire but do not directly involve plant infrastructure. Such events might be linked to business activities, supply chains, emergency measures or other types of plant related activities. Examples are power blackouts, shutdown of product supply or an unavailable workforce due to emergency evacuation. Direct effects of wildfires can be smoke, flames, thermal radiation and spot-fire ignition by firebrands. These effects are linked to the physical behaviour of an ongoing fire and will be discussed in the following paragraphs.

Most process installations are designed to withstand a certain level of thermal radiation. This to prevent rapid escalation or domino effects during fire events. Wildfires oppose a specific threat in terms of thermal radiation due to their nature of forming large and intensive fire fronts. These fire fronts can reach extents of several kilometres. Large areas might be enclosed by the fire front and thermal radiation can reach process units from several sides at a time. Compared to fires in an industrial surrounding this is a quite unique threat. To be able to assess the possible thermal loads of wildfires for single plants, further studies will be necessary.

Throughout the scientific community there are different ways for the classification of wildfires. Leaving aside all categories and classifications, wildfires in general seem to grow bigger and burn faster than in the past (Roman, 2018). A serious factor in this development are local climate effects triggered by global climate change but there is also a significant human influence. Poor vegetation and land use management and more effective firefighting measures change the natural fire periods. The decrease in the use of biomass on the industrial level and an increase of overall available biomass, managed as well as unmanaged, leads to more available fuel in the wildland areas (Moritz et al. 2005). So-called megafires are therefore a future threat in Europe. These fires have severe environmental, social and economic impact mainly due to their size. They cannot be controlled by current means of response and easily reach a size of thousand hectares. Megafires show some effects that are currently only seen to a limited extent in the European context but are occurring quite frequently in areas in the U.S. or in Canada. According to Alexander et al. (1982) extreme wildfires show a higher rate of spread and intensity as average wildfires.

Explorative analysis of the European situation

In the following section the effect of wildfires on the European industry and critical infrastructure in terms of possible Natech events will be assessed in form of an explorative approach. The assessment will be based on data from forecasts, the structure of European industrial facilities and learnings from already ongoing initiatives. Having described the nature of the wildfire hazard in the previous section, the next steps focussed on exposure to wildfire prone areas and the vulnerability of European industrial sites in general.

Base for a possible exposure to forest or wildfires is the presence of a certain grade of vegetation in the vicinity of the sites under concern. The grade of forestation differs throughout the European continent and so does the composition of the forest itself. European forests are used commercially to a high extent although the ratio between fellings and growth has only been at around 65 % during the last decades. This means that the amount of biomass and therefore fuel on the European continent is constantly increasing. Around 60 % of the European forests are privately owned. The increase in European forest areas leads also to a growth of Wildland Urban Interfaces and therefore also Wildland Industrial Interfaces (WII). Modugno et al. (2016) analysed wildland urban interface regions in Europe. In some areas between 30 and 50 % of the surface region can be defined as wildland urban interface area. Analysing these areas in context with the present wildfire situation it can be seen, that up until now, most of the regions suffering from wildfires in Europe are areas with a low to medium grade of wildland urban interface. Over the last decades forests show an increased vulnerability against external disturbing factors like storms, fires, droughts, invasive species or diseases. Forecasts from the EEA (European Environment Agency) show a significant increase in the number of heat waves that will reach Europe in the future decades (EEA, 2019). Statistics expect up to over 30 heat waves in a 30 year period by the end of the century. The regions most suffering from those approaching heat waves will be the Mediterranean South East Europe but also the northern parts of the continent (Figure 2).

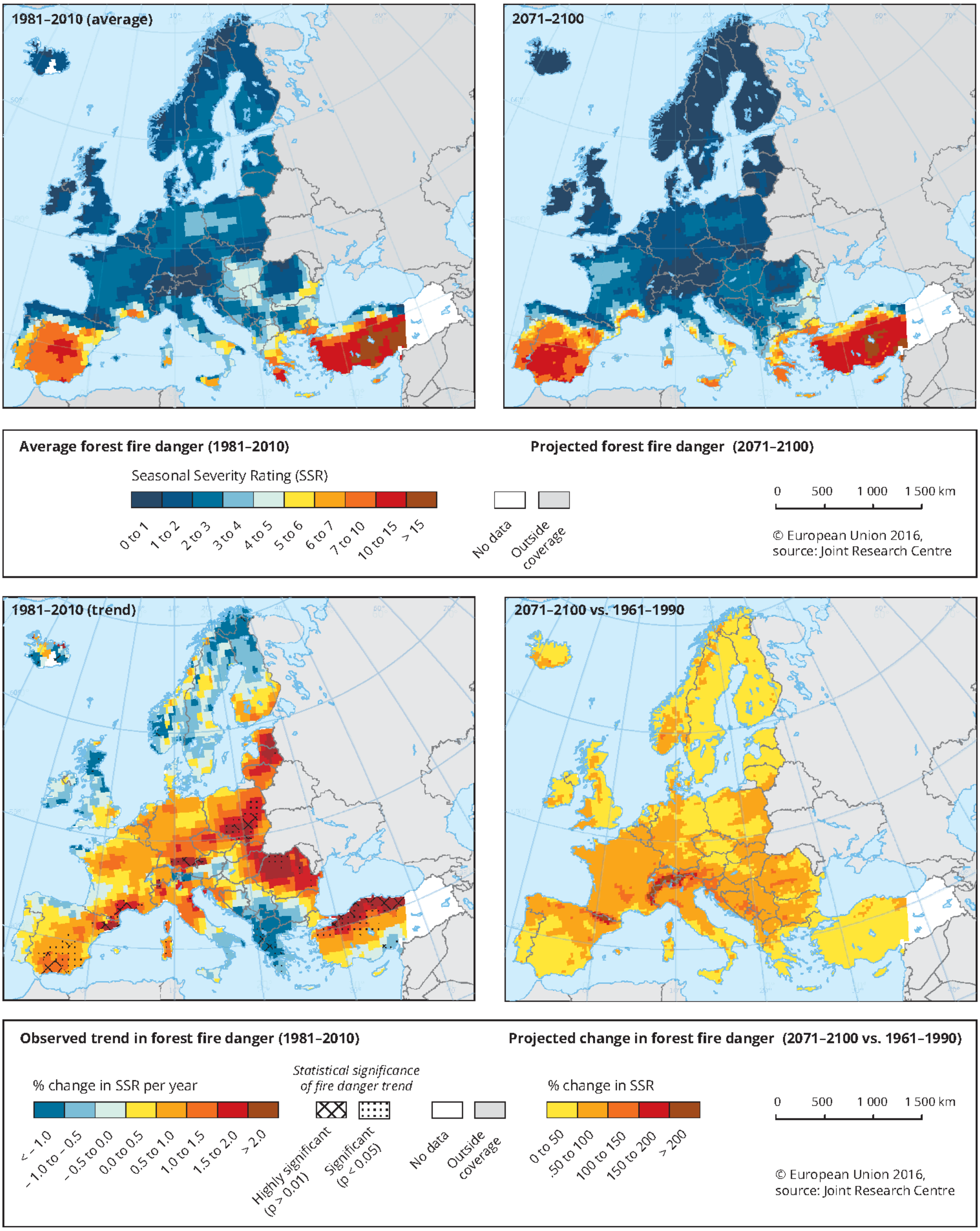

Figure 2: Fire danger forecast (JRC, 2019)

Ongoing dry periods and the increased vulnerability of forest areas driven by climate change do strongly influence the fuel situation according to the wildfire triangle. Although fire danger depends on the type of vegetation it can be generalized that large areas with high amounts of dry or dead vegetation increases fire danger in general. Other effects of climate change for example the change in the precipitation patterns might also lead to an increased wildfire danger. Local extreme weather events like storms can destroy forest areas and can lead to large fuel accumulations due to dead or fallen trees. If not properly cleaned these fuel accumulations lead also to more intense wildfires.

Bringing together information regarding wildland with climate forecasts and wildland interface areas, it can be seen that fires in the Wildland Urban Interface areas and therefore also in the Wildland Industrial Interface, are an emerging risk. The regions with large areas of WUI will also face an increase in the wildfire danger in the next decades. This will also increase the likelihood for industrial accidents triggered by wildfires in these areas.

Certain businesses activities or industry sectors are more likely triggering events then others depending on the type of operation and the facilities in use. Accident reports from the EU Major Accident Reporting System eMARS (https://emars.jrc.ec.europa.eu) show that in the last decade (2008 – 2018) the number of major accidents and near misses was significantly higher in the oil and gas sector as well as in chemical production compared to other industry sectors. About one third of all chemical companies in Europe are situated in south and southeast Europe as well as around 50- 60% of Europe's refinery capacities (European Commission, 2010). This brings together emerging wildfire danger and large numbers of facilities susceptible to such events.

Besides production also distribution and supply networks are endangered by the wildfire situation. Pipelines for example are connecting oil and gas fields with refineries and industrial production facilities. Compared to the rest of Europe there is a quite dense network of local and European pipelines in East and Southeast Europe. A lot of these pipelines are laid underground, but there are also pipelines running through vegetated areas on the surface.
The European chemical industry is wide spread over the continent. According to data from the European Chemical Industry Council (CEFIC, 2018), the number of chemical companies per 1000 km² varies significantly over Europe. While there are only 5 chemical companies per 1000 km² in Germany, there are around 35 per 1000 km² in Poland.
Studies on the average number of personnel at a single company show, that the chemical industry in East Europe is small structured. Although Poland has around 11.000 chemical companies overall, a lot of companies have less than 50 personnel, while the average chemical company in Germany has around 230 personnel. Smaller industrial complexes do have less extensive emergency response capacities like on-site fire brigades and are therefore also depend on external response capacities. They are therefore more prone to the external fire hazard opposed by wildfires.

The constant need for risk reduction in populated areas drives production facilities and hazardous industrial operations towards rural areas with lower population density. Keeping in mind future wildfire scenarios this might lead to an increase of Natech risks. Besides that some industries show an inherent need to operate in remote areas. Especially mining operations or oil and gas production have to follow the geological circumstances and are therefore often situated in less dense populated remote areas.
Plant operators focus on risk reduction within their areas of operation. In terms of wildfire safety this covers only one of the necessary aspects. Unmanaged or uncontrolled wildland outside facilities can cause a severe threat and has to be seen as a hazard as such. This also includes agriculturally used areas not managed in terms of wildfire safety.

Wildland is mostly seen as a part of nature that needs to be protected and preserved. Also the Seveso III Directive aims at environmental protection at first. This is fundamentally right but does neglect the fact that unmanaged and uncontrolled wildland can also be a hazard for industrial installations. This situation might create a feedback loop culminating in possible Natech disasters. All relevant standards regarding wildfire safety see adequate zoning and wildland management as one of the key factors. An analysis of plants throughout different industrial branches in the European industry shows that unmanaged wildland is in some occasion closer than 10 m to plant installations. Some plants even show wildland inside their area of operation. Figure 3 shows a natural gas compressor station that is situated in a forest area. The station is surrounded by vegetation. A safety belt with very limited vegetation was created approx. 20m around the station. Outside the safety perimeter the forest is very dense and fuel rich. Under certain wind conditions the plant might be endangered even by direct flames impingement. Vegetated surfaces inside the plant might act as receivers for ember flight and spot fires.

Figure 3: Natural gas compressor station in a forest area (Google maps ©2009, GeoBasis DE/BKG)

In principle vegetation around industrial facilities does not necessarily have to be problematic. The hazards of wildfires are largely manageable, as long as the wildfire situation is constantly monitored and adequate measures are taken. Unmanaged wildland can create a serious threat to industrial facilities. This is also true for vegetation inside plants.
Industrial complexes are often spread over large areas. In terms of oil storage tank farms for example they are result of the required safety distances to prevent incident escalation. Analysing various European industrial complexes it can be seen, that in some parts of the industry up to 75 % of the total area of the production facilities are covered by vegetation. This is especially true for facilities in the oil and gas sector, chemical storage facilities and power stations. Vegetation inside the plant mostly consists of grassland but some facilities do even show larger, forest like areas inside the installations. Compared to plants in wildfire regions in Canada or Australia this is quite unique.

In Europe there is a tendency that vegetation inside a plant follows vegetation outside the plant, which means that less vegetation can be found inside a plant, when the amount of vegetation outside the plant is also lower. This seems logical at first, but might also be an indication for, why especially in the wildfire regions in the south of Europe (Greece, Spain, Italy, etc.) no major events have been reported due to wildfires until now. With an increase of the wildfire danger in the heavily vegetated areas, also the hazard of fire spread inside plants increases. Large vegetated areas inside the plants act as entry points for external fires or as receiver surfaces for firebrands or spot fires. As the case studies at the beginning of this report show, grassland fires can easily spread into storage or production units and act as escalation vectors.
Findings from residential fire protection show that not only vegetated areas can act as receivers for spark ignition, but also vents, air intakes, large openings or storage of combustible material around buildings or process facilities. Storage of combustible material can act as a bridge for approaching wildfires. In some European industries it is common to store combustible materials in large piles or bulk storage areas. These areas might act as receivers for external ignition sources like firebrands.

Other types of storage facilities might also be endangered by approaching wildfires. Storage of intermediate bulk containers close to heavily vegetated areas or on dry grassland might in case of a fire lead to loss of containment and rapid fire spread into production facilities (Atkinson, 2007).

Sparks are quite well studied as an ignition hazard inside hazardous areas or process equipment (Mannan et.al., 2012). There is only limited data available about firebrands or flying embers that attack a production plant from outside. During wildfire events thousands of firebrands are carried with the wind ahead of the fire front. Although there is no specific data on the ignition hazard due to embers entering industrial facilities, some practical considerations that can be developed. In embers or firebrands are capable of entering facilities and equipment and are creating a possible fire or even explosion hazard inside plants. Combustible roofs, open doors or windows as well as air intakes, can act as entry points for the burning or glowing particles. Large vegetated areas within the sites are also acting as "receiver surfaces" for embers.

A brief calculation following the findings from Gould et al. 2008, for a floating roof tank with a diameter of 70 m (ca. 3800 m² surface area) will illustrate the problem of firebrands for industrial installations. Using the sample calculation from Bushfire Verification Method Handbook (Australian Building Codes Board) around 5 firebrands per m² have to be expected at a separation distance of 30 m to neighbouring wildland. These values are referring to an eucalypt forest, with 5 years of no wildfire (5 year old forest). Regarding the input parameters around 20.000 embers have to be expected on the storage Tank surface, which increases the likelihood for ignition drastically.

In terms of thermal radiation a lot of process units and installations are designed to withstand a certain thresholds of thermal radiation to prevent rapid escalation or domino effects (Mannan et al., 2012). These threshold levels are mostly referring to maximum permissible heat loads but do most often not include thermal dose effects. Although wildfires can be very intensive and show also large extents, flame fronts are loosing intensity very quickly, while for example a burning storage tank might be alight for several hours. An ongoing technical study assesses the possible thermal effects of wildfires on storage facilities.
Besides smoke effects, firebrands and thermal radiation, direct flame impingement has to be considered a hazard especially in future fires. Big flame lengths and thermal loads able to endanger critical infrastructure or production and storage facilities have to be expected. Analysing EFFIS (European Forest Fire Information System) data on the size of wildfires it can be concluded that the largest wildfires in Europe are currently found in the Mediterranean area. Currently only a limited number of mega fires has been seen in Europe up until now. There are strong indicators that the number of mega fires will increase in future decades, which will also increase the hazard of direct flame impingement to hazardous industry and critical infrastructure.

Conclusions

The wildfire threat is an uprising concern on European level but the topic itself is of course not new. Keeping in mind the changing nature and development of wildfires, it can be concluded that wildfires in general are capable of causing severe effects on buildings and technical infrastructure. Especially expected future Megafires are a serious hazard. If no adequate measures are taken, thermal radiation levels, ember flight or direct flame impingement might cause severe damage to industrial infrastructure or process equipment. This can lead to loss of containment events followed by toxic spills, fires or explosions. Regarding the current status, there is still limited information about detailed effects of wildfires on industrial plants. Several countries around the world have brought initiatives and guidelines in place that do address the wildfire problem at several levels. It has proven necessary by countries like Canada or Australia, that policy makers support communities and industry

during the adaption to the growing danger of wildfires. Due to the change in the nature of wildfires (Megafires) in Europe, wildfires have definitely to be considered as emerging risk for European industries.
Wildfire safety of industrial facilities cannot be achieved only by on-site prevention and mitigation measures. Since the threat is external to the facilities, there is a demand for coordinated activities with communities and other stakeholders. An adequate level of wildfire safety can only be achieved if all stakeholders know their role and act according to a comprehensive strategic approach of wildfire safety. Currently there is no common European policy in place to deal with the hazard of wildfires on multiple levels and across sectors. Since the threat is external to the facilities, there is a demand for coordinated activities with communities and other stakeholders, similar to land use planning activities within the Seveso III directive.

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