

## Sources of Emissions in Refinery – Legal Regulations and Costs

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### ABSTRACT

Crude oil processing associated with the impact on the environment. Refinery production processes are a source of emissions in virtually all environmental components. The article characterizes the sources of emissions by dividing them taking into account various criteria and describes the regulatory and legal environment, addressing the problems of industrial emissions, taking into account current and forecast guidance at European and national level. Highlighted the various aspects related to the effects of legislation and its implementation, among which, indicated as the most important implementation costs in relation to the underlying operating costs.

**Keywords:** environmental protection, emissions, emission sources, refinery, regulations, costs.

### INTRODUCTION

The state of the natural environment depends on many factors, including pollution caused by the introduction of a substances into the air, water or soil /ground that cause risk, adversely affect human health and the state of the environment. The accumulation of solid, liquid, gaseous or energy substances in large amounts on the earth's surface may adversely affect human health, the animate nature, climate, soil, water or cause other unfavorable changes in the environment. Due to the fact that the level of environmental pollution is not the same everywhere, and various pollutants are released into the atmosphere from many sources, which spread in the atmosphere and, additionally, may be transformed into new compounds, regulations are being developed to reduce this process. Since the implementation of regulations and new strategies and measures for reducing emissions from various sources in the world and in Poland, its volume has significantly decreased. Pollution emission levels have now been regulated [1, 2, 3, 4, 5, 6, 7, 8, 9] and are falling with new information from research, awareness

and development of environmentally friendly technologies. In addition to developing limit values for specific pollutants and setting emission levels at European and national level, the legislation provides the tools to take action in relation to the specific sectors consisting the source of pollution. Pollution can be caused by natural or anthropogenic sources. The anthropogenic sources include mainly industry [10]. Industry is a huge consumer of natural resources that are used in energy processes and transformed into products in technological processes. Both the main and the supporting processes are the source of emissions to the environment. The refining industry in particular, which processes crude oil, is a source of emissions to air, water, and soil / ground, and is also a source of waste, noise, lighting, smoke and odour nuisance. Therefore, integrated environmental protection management in the refinery is one of the most important elements of the environmental policy, which introduces many programs and activities aimed at reducing emissions. As a consequence, there is a downward trend in pollution generated by refineries per Mg of processed crude oil [11, 12].

## DIVISION OF EMISSION SOURCES AT THE REFINERY

The division of emission sources in a refinery is difficult since it depends on many factors, including source categories, the so-called SNAP (Selected Nomenclature for Sources of Air Pollution), the method of including in the calculations (modelling), determining what, where, how, in what amount and when it is emitted, and a precise inventory depending on the needs of forecasting concentrations or reporting to many public administration bodies [1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13]. A thorough analysis of the characteristics of processes and operations, including manufacturing

as well as preparation and process streams, allows to identify places where emissions of substances may occur into the environment, which makes the identification of emission sources and their classification correct. Table 1 presents the distribution of emission sources in the refining industry with the identification of their sources.

In addition, the obligation to report emissions to reporting systems is related to different rules to various institutions, such as KOBiZE (The National Centre for Emissions Management), GUS (Central Statistical Office), or PRTR (Pollutant Release and Transfer Register). Moreover, in the greenhouse gas emission monitoring and reporting system, which is the basis of the EU ETS

**Table 1.** Division of emission sources in the refining industry

Identification of sources	Distribution of emission sources	
Origin of the emission source	natural	biological processes soil / ground degradation
	anthropogenic (energy, industrial, communication sources)	combustion of fuels technological processes transport
Component of the environment into which the substance is introduced	sources of emissions to air, water, soil / ground, sources of waste generation	
The way of introducing pollutants into the environment	organized issue sources	emission of pollutants from all kinds of technological processes and combustion processes introduced through technical means for introducing an organized substance into a given component of the environment
	sources of fugitive emissions	flare emissions, leakage emissions and diffusion emissions
Method of spreading pollutants in modelling	point sources	emissions from individual stacks
	surface sources	open tanks in sewage treatment plants, aeration chambers, lagoons, heaps
	line sources	belt conveyors
	spatial sources	undeveloped installations
Depending on the SNAP emission source category	SNAP emission sources	combustion processes in the energy production and transformation sector
		combustion processes in industry
		production processes
		extraction and distribution of fossil fuels
		use of solvents and other products
		other vehicles and devices
		waste management
other sources of emission and absorption of pollutants		
Due to the type of emission sources	sources of energy, process and technological emissions	
Due to the type of pollution from a given source	physical, chemical and biological sources	
Due to primary and secondary impacts	primary emission sources	occurring as they were released
	secondary emission sources	products of physical changes and chemical reactions
Due to the conditions of pollution formation	emission sources under normal and abnormal conditions	
Due to the size of installations and plants	low emission sources	emission at heights up to 40 m
	high emission sources	emissions above 70 m

(Emission Trading Scheme), we can distinguish major, minor and de minimis emission streams.

Refining processes can also emit odorous substances, including organic compounds (oxygen, sulfur, hydrogen sulfide, mercaptans) with a characteristic odour. The refinery itself, as a facility, may be a source of GHG (greenhouse gas) emissions or carbon footprint in the life cycle of engine fuels [14, 15]. In many studies [11, 12, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26], the authors agree that refining processes in crude oil processing plants are the primary sources of emissions pollution to the environment, both to the air, can also be related to soil / ground and groundwater pollution as well as the generation of waste. The largest amounts are gaseous pollutants. Particulate pollutants are small amounts in the combustion of fuel oil, from waste incineration, fluid catalytic cracking and in the treatment of petroleum coke. Table 2 presents an example of air pollutants from refinery processes [12].

## LEGAL CONDITIONS

For the operators of refining installations, whose activities are related to the use of natural resources, it becomes a practice to constantly commit to intensive activities aimed at adapting to changing legislative requirements. Refineries operate in a legal environment, both international, European and national, as well as local (Figure 1).

From the point of view of a refinery, the industrial emissions directive, the so-called IED Directive [9] plays the most important role. It introduced, inter alia, significant reduction of SO<sub>2</sub>, NO<sub>x</sub> and dust emission limits from power plants and sanctioned the BAT conclusions, which are part of the BREF reference documents, as legally binding [27].

The most important current or future BAT conclusions for refineries and / or self-powered refinery / petrochemical complexes are [16]:

- BAT conclusions for the refining of oil and gas (REF),
- BAT conclusions for large-volume chemicals production (LVOC),
- BAT conclusions for large combustion plants (LCP),
- BAT conclusions for gas and waste water treatment systems in the chemical industry (CWW).

The changing legislation is of great importance for the refining industry and may cause it to incur additional costs in terms of adjustment to the applicable law, but also in anticipation and development activities. Figure 2 shows selected regulations that have a significant impact on the refining industry.

Over the years, in the perspective to 2050, the industry will face challenges not only related to the BAT conclusions. The European Union is introducing more and more strict environmental requirements (Figures 1 and 2). In addition,

**Table 2.** Type and source of the emission in the refining industry [12]

Type of emission	Source of pollutant emission	Type of pollutants emitted
Energy emission	combustion of fuels in a heat and power plant (combustion of oils and process gases for the production of steam, electricity)	dust, SO <sub>2</sub> , NO <sub>x</sub> , CO; hydrocarbons
	technological furnaces (combustion of oils and process gases)	dust, SO <sub>2</sub> , NO <sub>x</sub> , CO; hydrocarbons
Emissions from production processes	distillation installations (group of equipment for the separation of crude oil)	hydrocarbons, organic sulfur compounds, H <sub>2</sub> S
	catalytic conversion installations (processes of catalytic cracking, fluid coking, reforming)	hydrocarbons, organic sulfur compounds, H <sub>2</sub> S, SO <sub>2</sub> , CO, dust
	refining and purification installations (desulphurization, mercaptan extraction, alkaline washing, amine washing installations)	hydrocarbons, sulfur compounds, odours
Emissions from storage, transport, handling and cooling circuits, wastewater treatment plants, flares and blows	storage	hydrocarbons
	reloading	hydrocarbons, gasoline and low-boiling products
	cooling towers; wastewater treatment plants	hydrocarbons
	pipeline transport (pump, valve, compressor seals)	hydrocarbons
	sampling	hydrocarbons
Emission from reduction devices	in flue gas treatment installations (desulphurization, denitrification)	SO <sub>3</sub> aerosols

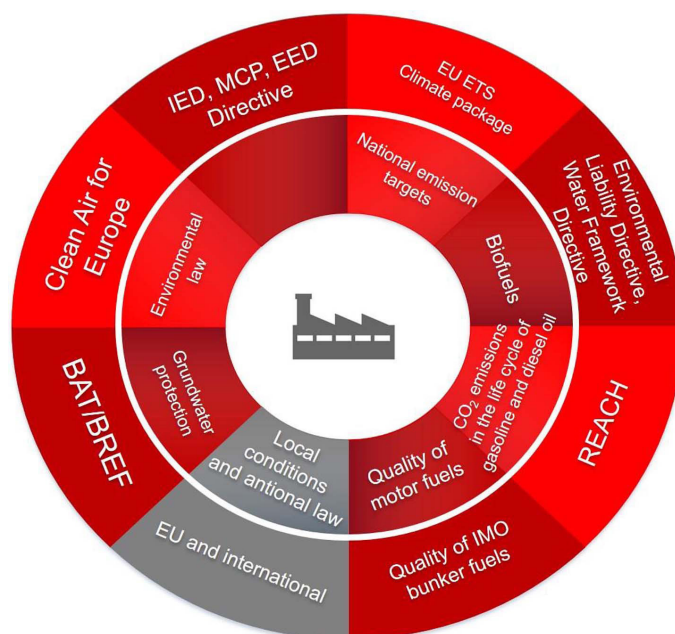


Fig. 1. The regulatory environment in which the refinery operates

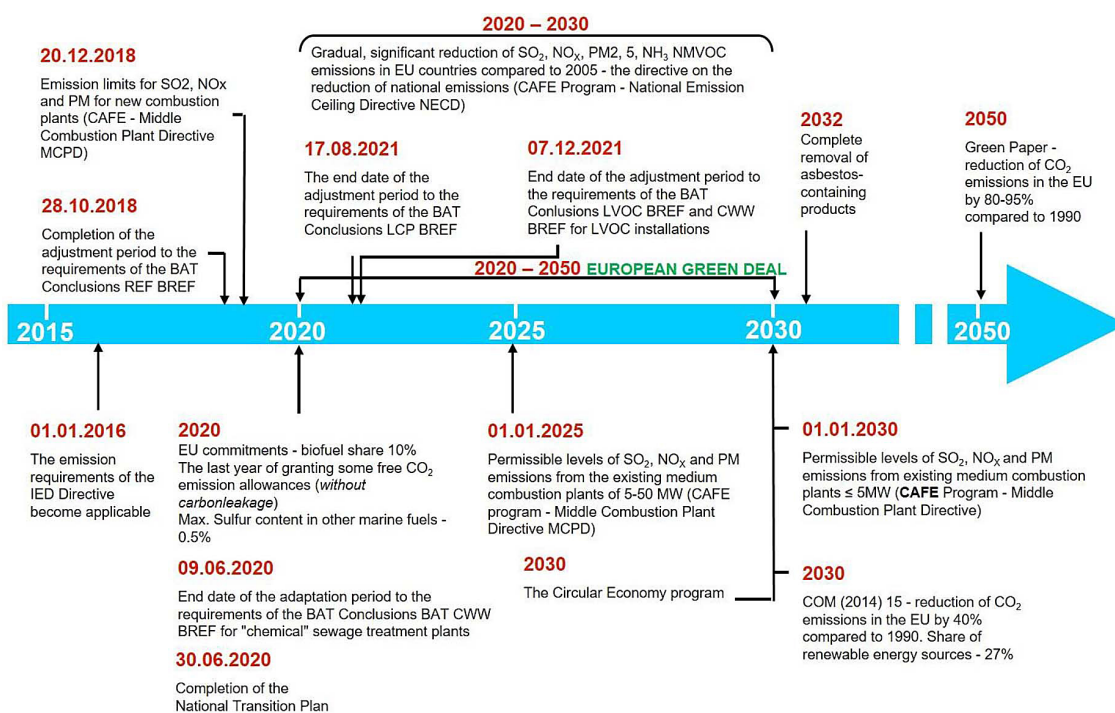


Fig. 2. The legal regulations regarding the refinery industry

there are regulations, such as the climate and energy package, which focuses mainly on reducing CO<sub>2</sub> emissions. It is a set of binding acts aimed at ensuring the implementation of the European Union's assumptions regarding counteracting climate change, including EU ETS Directive, Non-ETS Decision, CCS (Carbon Capture and Storage) Directive, RES Directive, Regulation (EC) No. 443/2009 of the European Parliament

and of the Council of April 23, 2009, setting out emission standards for new passenger cars in as part of the Community's integrated approach to reduce CO<sub>2</sub> emissions from light commercial vehicles, Directive 2009/30/EC of the European Parliament and of the Council of April 23, 2009 amending Directive 98/70/EC relating to petrol and diesel fuel specifications and introducing a monitoring mechanism and reducing greenhouse

gas emissions and amending Council Directive 1999/32 / EC relating to the specification of fuels to be used by inland navigation vessels and repealing Directive 93/12/EEC as well as Directive 2006/32/ EC of the European Parliament and of the Council of April 5, 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC [28, 29, 30, 31].

The principles of the circular economy aimed at minimizing the consumption of raw materials and utilities from primary sources, or the National Emission Ceilings Directive (NEC) introducing restrictions on annual mass emissions in individual Member States of the European Union [27] are also important.

The Water Framework Directive [32], organizing and coordinating existing European water legislation to protect water from pollution at its source, with the requirement that Member States gradually reduce water pollution from the group of substances referred to as *priority substances* is becoming important. In accordance with the above-mentioned the Directive requires Member States to cease or phase out emissions, discharges and losses of more hazardous pollutants known as *priority hazardous substances*.

Public access to information on industrial pollution has improved significantly over the past few decades. The European Pollutant Release and Transfer Register (E-PRTR), which provides comprehensive records of emissions and transfers of pollutants from major industrial activities, provides annual information on over 30,000 pollutants. industrial plants in 33 European countries, on the amount of pollutants released into air, water, soil / ground and on off-site waste transfers, as well as pollutants in waste water.

Sustainable development criteria have also been introduced to reduce the impact of industry on the natural environment. Examples of industry initiatives include the widespread adoption of environmental management practices under the European Eco-Management and Audit Scheme (EMAS) and the ISO14001 standard. Voluntary corporate social responsibility initiatives have been implemented to achieve social and environmental goals that go beyond the legal requirements, such as the Chemical Industry Initiative “Responsibility and Care”. At EU policy level, the Commission has adopted a CSR strategy, while at international level, the ISO 26000 CSR standard provides guidance on how companies and organizations can act in a socially responsible manner.

The work of the European Environment Agency (EEA), which supports the implementation and evaluation of EU policies to reduce industrial pollution is noteworthy. The EEA helps the EU develop long-term strategies to reduce the negative environmental impact of industry by providing assessments and informing policy makers. Its main tasks include the release of data reported by European countries under the reporting obligations under European legislation.

European oil refineries work closely with regulatory standards setting bodies, but also with various sectors and industries, including the automotive sector, making the EU a world leader in fuel specifications and many clean fuel and engine technologies, helping to improve air quality. This partnership phased out leaded petrol in Europe thanks to technological advances in European refineries. Refineries reduced the share of aromatic compounds, olefins, benzene and PAHs (polycyclic aromatic hydrocarbons) in the produced motor fuels, which contributed to the reduction of pollution in exhaust gases. Sulfur from fuels has also been practically eliminated, which is a necessary condition for the effective operation of the catalysts.

## COSTS OF THE IMPLEMENTATION OF THE LAW

The negative environmental impact of the European refining industry has improved over the past several decades. Several factors contributed to the changes: stricter environmental regulations, improved energy efficiency, a general trend in European industry to change production technology, and the participation of companies in voluntary programs to reduce their negative impact on the environment. Figures 3 and 4 show trends in the emissions to air of sulfur oxides and nitrogen oxides from European refineries in the years 2007–2017 [33].

The emission reductions contribute significantly to the improvement of air quality in Europe. These are expensive investments in the refining industry and should therefore be achieved in the most cost-effective way to avoid that compliance investments displace investments in other improvement projects such as technological upgrades or energy efficiency.

For example, the costs incurred by the Dutch refining industry are quantified at EUR 42 million

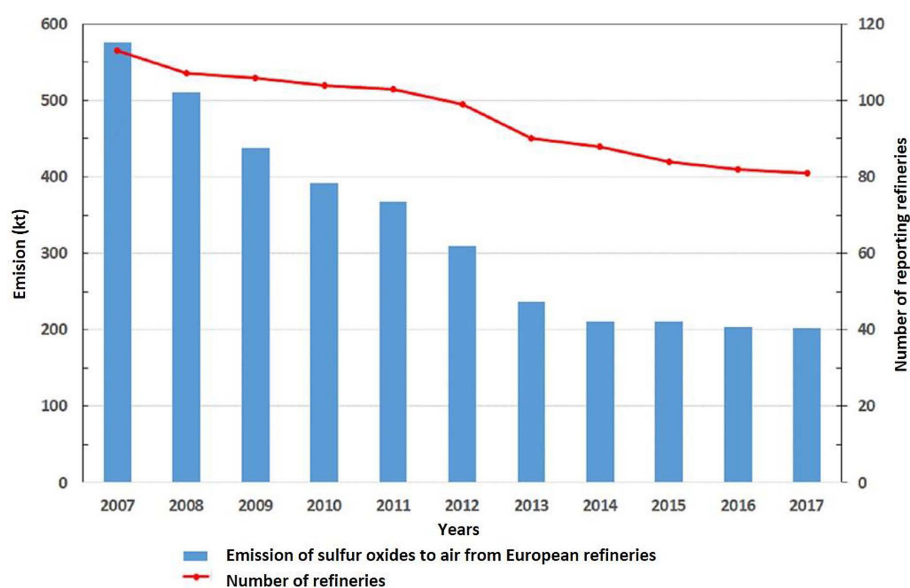


Fig. 3. Trend of emissions of sulfur oxides into the air from European refineries in the years 2007–2017 [33]

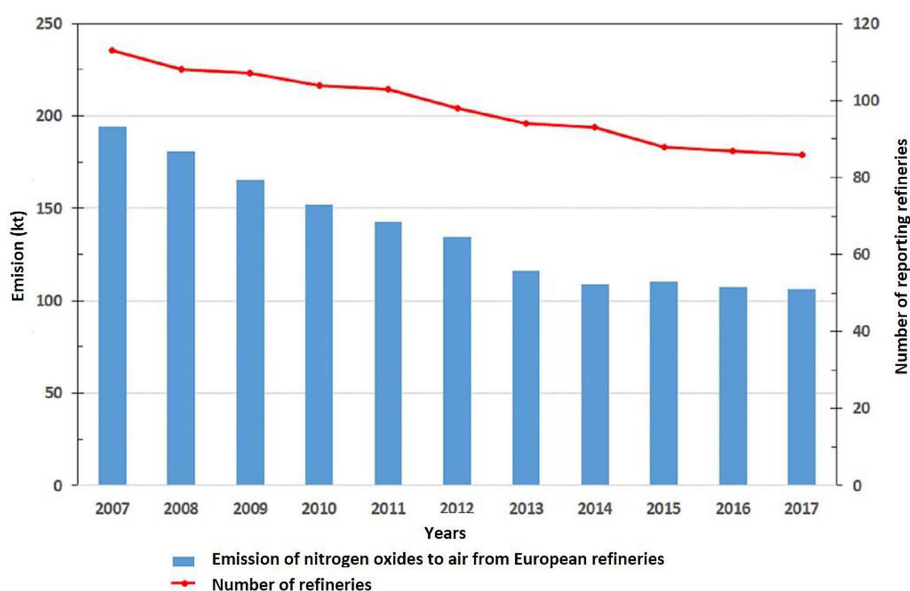


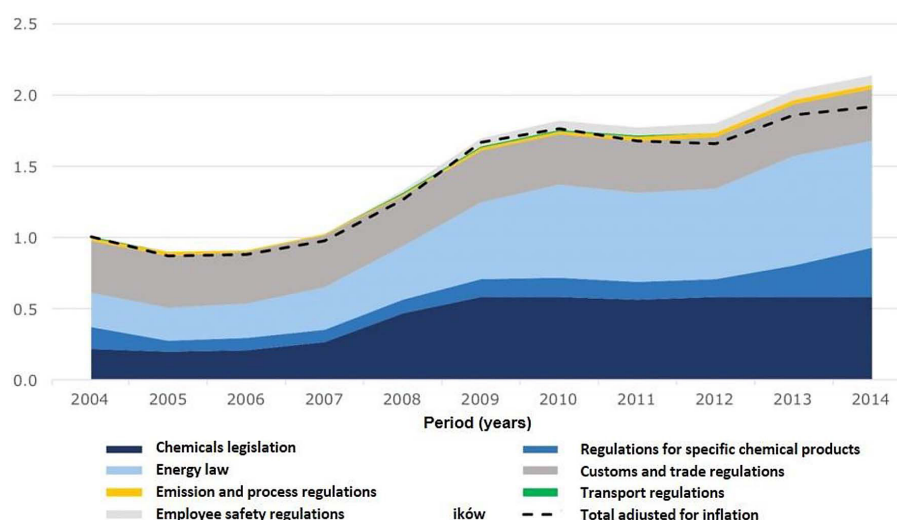
Fig. 4. Trend of emissions of nitrogen oxides into the air from European refineries in the years 2007–2017 [33]

/ year for  $\text{SO}_2$  activities, EUR 5 million/year for  $\text{NO}_x$  activities and EUR 14 million/year for NMVOC activities. This adds up to a total cost of EUR 61 million per year for the Netherlands to achieve the emission reductions observed between 2005 and 2012 [34].

Based on the report on *Cumulative cost assessment for the EU chemical industry* commissioned by the European Commission [35], Figure 5 shows an example of the increase in costs related to the introduction of new regulations in the chemical industry in 2004–2014. It was found that the tightening legislation resulted in more than twofold increase in costs related to the adjustment to the regulations over 10 years.

The CONCAWE reports [36, 37] and the report prepared by ECN Wood Mackenzie [23] provide an estimate of the costs to be incurred by the refining industry due to the change in EU regulations. The total cost assessment is presented in Table 3, and per barrel of oil in Figure 6.

According to the estimates contained in the Fuels Europe report on *Vision 2050 a pathway for the evolution of the refining industry and liquid fuels 2018* [38], the costs of adjusting the refining industry in the years 2030–2050 (depending on the scenario of the global energy policy) may amount to as much as EUR 50 billion for the entire EU refining system (CONCAWE calculations). This estimated cost relates only to the



**Fig. 5.** The accumulated cost increase related to changes in the legislative package per subsector and their composition in the legislative package – annual share in the added value 2004–2014 [24]

overall cost of introducing various technologies, the so-called CAPEX (*capital expenditures*) in terms of identified technological possibilities. It does not take into account investment costs outside the refining site, as well as corresponding changes in operating costs, the so-called OPEX (*operating expenditures*) [38].

## CONCLUSIONS

The European refining industry offers many important economic and social benefits, including producing goods and products as well as generating employment and tax revenues. The burden of costs related to tightening legislation will have a significant impact on the competitiveness of the refining sector, reducing aggregate gross and net margins as well as lowering the value added of this sector's industry for domestic economies.

This could ultimately lower the attractiveness of operating or investing in the sector and increase the risk of refineries closing. The new restrictive legislation and social expectations also require a technological change towards biofuels, synthetic and artificial fuels, which is associated with additional costs.

While the refining sector is now at the forefront of environmental performance, new stringent measures have been established to further reduction of emissions. The challenge will be to reduce fugitive emissions of VOCs (Volatile Organic Compounds) and aromatic substances. However, it should be borne in mind that the technical and thermodynamic possibility of further emission reductions from refining sources may soon be exhausted, not without consequences for an increase in energy consumption or a reduction in production, and thus an increase in environmental impact.

**Table 3.** The estimated costs resulting from the EU legislation which the refining industry will have to bear in order to adapt to the changes in legislation depending on scenarios [39]

Costs	Amount	Legislation				
		UE-ETS	IED	IMO	RED	REACH
Estimated investment expenses	24.3–47.2	–	6.6–22	17.5–25	–	0.2
Annual capital expenditure	3.6–7.1	–	1–3.3	2.6–3.8	–	0.0
Estimated operating cost	3.2–5.2	1–1.8	0.4–1.2	1.8–2.2	–	0.1
Estimated total annual cost	7.8–13.3	1–1.8	1.4–4.5	4.4–5.9	0.9	0.1

**Note:**

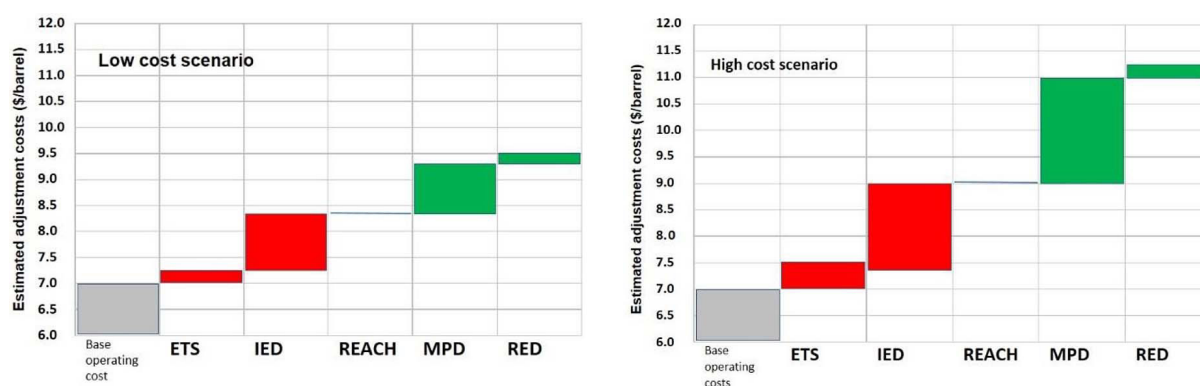
EU-ETS – regulations related to the European Trading System for Greenhouse Gas Emission Allowances.

IED – regulations related to the adaptation to the requirements of the Directive on industrial emissions.

IMO – regulations related to the adaptation to the requirements for sulfur content in marine fuels.

RED – regulations related to the requirements for biocomponents and biofuels.

REACH – regulations related to registration, evaluation, authorization and restriction of chemicals.



**Fig. 6.** Estimated costs resulting from the EU legislation which the refining industry will have to meet to adapt to the changes in legislation depending on the scenario [39]

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