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Abstract

Climate change and high level of atmospheric pollution is a global problem that has taken on particular significance in recent years and will continue to grow in the near future. To deal with this problem, it is very important to adopt sustainable development practices in organizations day to day activities. The goal of sustainable development is to meet the needs of present generations without compromising the ability of future generations to meet their own needs.

There are three main pillars of achieving sustainable development: environment, economic and social, in this study the focus is on the environmental pillar. To achieve environmental sustainability, there is a large number of voluntary and mandatory environmental standards. These standards provide guidelines for making the environmental pillar strong.

In this study, mandatory environmental standards affecting heavy industries in the US and the EU were studied and compared. Additionally, linkage of these standards with global and continental environmental treaties were studied. The study suggests that, the EU is somewhat ahead of the US when it comes to climate change regulations. For regulations concerning air pollution, the US is still the environmental leader and the policies in the EU are not always leading to the best outcomes when it comes to industrial environmental performance due to weak enforcement system in the EU.

To understand the application of environmental regulations, the aluminum industry was selected in the EU. Main regulations studied were EU-ETS for reducing GHG emissions (climate change) and IED for reducing harmful pollutants entering the atmosphere (air pollution). For EU-ETS, methods for quantification of GHG emissions were studied. For IED, monitoring methodology and emission limit values of different pollutants based on the use of best available technology was studied. The study suggests that there exists a good framework within these regulations for reducing GHG emissions and other harmful pollutants from entering into the atmosphere in the EU from aluminum industry.

Finally, it has been demonstrated that reporting of organizations performance on environmental sustainability is important for both internal and external stakeholders. Therefore, effort is made to understand internal reporting mechanisms and processes in the organizations. Also, a detailed analysis was done for the monitoring and reporting process under the IED. The result from this analysis can be used to constitute a system design for implementing monitoring and reporting process of IED on software systems.

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Nomenclature

µg-ng	Micro gram-Nano Gram	CFR	Code of Federal Regulations
A(AQD)	Ambient Air Quality Directive	CH_4	Methane
AEL	Associated Emission Limit	Cl_2	Chlorine
Al	Aluminum	CLRTAP	Convention on Long Range Transboundary Air Pollution
Al_2O_3	Aluminum Oxide	CO	Carbon monoxide
AQLV	Air Quality Limit Values	CO_2	Carbon dioxide
ARP	Acid Rain Program	CO_2e	Carbon dioxide equivalent
As	Arsenic	COP-21	Conference of the Parties-21st session
AVR	Accreditation and Verification Regulation	CSAPR	Cross State Air Pollution Rule
BAT	Best Available Technology	CSR	Corporate Social Responsibility
BREF Documents	Best Available Technology Reference Documents	DFE	Diffuse and Fugitive Emissions
C_2F_6	Hexafluoroethane	EAA	European Aluminum Association
C_6H_6	Benzene	EEA	European Environment Agency
$Ca(OH)_2$	Calcium hydroxide	EEA	European Economic Area
CAA	Clean Air Act	EEX	European Energy Exchange
CAP	Criteria Air Pollutants	e-GGRT	Electronic Greenhouse Gas Reporting tool
CAS	Chemical Abstract Service	ELV	Emission Limit Values
Cd	Cadmium	EN	European Standards
CDP	Carbon Disclosure Project	EPA	Environmental Protection Agency
CEIP	Center on Emission Inventory and Projection	EPER	European Pollutant Emission Register
CEN	European Committee for Standardization (French: Comité Européen de Normalisation)	EPI	Environmental Performance Index
CEPS	Center for European Policy Studies	E-PRTR	European Pollutant Release and Transfer Register
CF_4	Tetrafluoromethane	EU (C)	European Union (Commission)
CFC	Chlorofluorocarbon	EU-ETS	European Union-Emission Trading System

F-gas	Fluorine Gas	Kg	Kilogram
GDP	Gross Domestic Product	LCP	Large Combustion Powerplant
GHG	Greenhouse Gases	m^3	Meter cube
GHGRP	Greenhouse Gas Reporting Program	MACT	Maximum Achievable Control Technology
GRI	Global Reporting Initiative	MCP	Medium Combustion Powerplant
GWP	Global Warming Potential	mg	milligram
H_2S	Hydrogensulphide	MRR	Monitoring & Reporting Regulations
H_2SO_4	Sulphuric acid	MRV	Monitoring Reporting & Verification
HAP	Hazardous Air Pollutants	MS	Member States
HCFC	Hydrochlorofluorocarbon	Mw	Megawatt
HCl	Hydrogen Chloride	N_2O	Nitrous Oxide
HDI	Human Development Index	Na_3AlF_6	Cryolite
HF	Hydrogen Fluoride	NAAQS	National Ambient Air Quality Standards
HFC	Hydrofluorocarbon	NECD	National Emission Ceiling Directive
Hg	Mercury	NESHAP	National Emission Standard for Hazardous Air Pollutant
Hr	Hour	NF_3	Nitrogen Trifluoride
Id	Identification	NGO	Non-Governmental Organization
IEA	International Energy Agency	NH_3	Ammonia
IED	Industrial Emissions Directive	Ni	Nickel
IPCC	Intergovernmental Panel on Climate Change	Nm^3	Normal Meter cube
IPPC	Integrated Pollution Prevention and Control Bureau	nmVOC	Non-methane Volatile Organic Compound
ISO	International Organization for Standardization	NO_x	Oxides of Nitrogen
IUPAC	International Union of Pure & Applied Chemistry	NSPS	New Source Performance Standards
IWI	Inclusive Wealth Index	NSR	New Source Review

O_2	Oxygen	TRI	Toxic Release Inventory
O_3	Ozone	UK	United Kingdom
ODS	Ozone Depleting Substance	UN	United Nations
PAH	Polyaromatic Hydrocarbon	UNECE	United Nation Economic Commission for Europe
Pb	Lead	UNEP	United Nations Environment Program
PCDD/F	Polychlorinated Dibenzo Dioxins/Furans	UNFCCC	United Nation Framework Convention on Climate Change
PFC	Perfluoro Carbon	USA	United States of America
PH_3	Phosphine gas	US-EPA	United States-Environment Protection Agency
$PM_{2.5/10}$	Particulate Matter (2.5 micrometers to 10 micrometers in diameter)	VOC	Volatile Organic Compound
POP	Persistent Organic Pollutants	WHO	World Health Organization
PRTR	Pollutant Release and Transfer Register	WID	Waste Incineration Directive
SF_6	Sulphur hexafluoride	Wt	Weight
SIP	State Implementation Plan	Yr	Year
SO_2	Sulphur dioxide		

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Note for reading references

The references in the thesis are written according to the Vancouver style (description available from https://www.ntnu.edu/viko/vancouver-examples). If the reference number is at the end of paragraph after full stop, it signifies that the information in whole paragraph is taken from that reference. References for most of the environmental regulations in Europe and few other reports from government authorities were electronically available. Therefore, in the reference list, the link for corresponding regulation/report is included along with regulation/report name, number and year. For most of the other references, effort is made to include ISBN, ISSN, DOI number where it was possible.

Some of the references were reports from governmental organizations which didn't carry standard identification code. In case the link to some of the reference is broken in the future, all the references which didn't have any standard identification code along with different European regulations are included as an electronic copy (pdf copies in USB drive along with thesis file) with file name corresponding to the reference number in the reference list.

The appendix has a separate reference list with numbering [A], [B] etc

1 Introduction

1.1 Background

The world is changing. Rising world population, declining resources and changing climate are reshaping where we live and how we live. The damage done to the current environmental condition of our planet is quite noticeable. There is limited availability of freshwater, amount of food which can be produced and other natural resources. There is convincing evidence that the current rate at which the resources are depleting is unsustainable. Major fisheries have been depleted by around 70% or are at their biological limit. Forest cover has been reduced by around 50% worldwide; 50% of the wetlands and more than 90% of the grassland have been lost. Around 40% of world population is experiencing water shortages. [6]

Currently, the four major environmental concerns in the world are

- Water quality & quantity.
- Depletion of fossil fuel.
- Climate change resulting from the use of fossil fuel.
- Population growth eventually exceeding earths holding capacity. [6]

The Inclusive Wealth Index (IWI) is an index which looks beyond the traditional index for development of the nations such as Gross Domestic Product (GDP) and Human Development Index (HDI). IWI evaluates countries development by considering use of natural and capital resources over a period. IWI takes a more holistic approach and shows the true state of the nation’s wealth and sustainability of its growth. The assessment shows that despite having robust growth in countries like Brazil, China, South Africa and United States in terms of GDP, they have significantly depleted their natural resources. Over the period of 19 years from 1990-2008, the natural resources per capita declined by 33% in South Africa, by 25% in Brazil, by 20% in United States and by 17% in China. The sharp decline in natural resources can cause major concerns in maintaining long term stability in any country. One of the important challenges which needs immediate concern is climate change and air pollution. Therefore, it is important for any country to establish a development model which is long term sustainable. [35]

1.1.1 Climate change & Air Pollution

Climate change & air pollution due to different pollutants in the air is one of the major concerns all around the world. The air pollution is also known to cause adverse effect on crops, trees, lakes, animals, natural environment, building, monuments and statues. It has been estimated that large amount of premature deaths and adverse health effects are linked to air pollution. Over 350 manmade contaminants such as dioxins, volatile organic compounds, persistent organic pollutants are responsible for decreased hand-eye coordination, memory, physical stamina etc. [4]

The report from the United Nations Intergovernmental Panel on Climate Change (IPCC) stated that earth cannot tolerate any more increase in temperature. In order, not to have further temperature rise the CO_2 emissions must be reduced by 60-80% of the 1990 levels by the year 2050. Increase in populations by 2050 and corresponding increase in energy demand will make it difficult to achieve this reduction targets. [6] The climate change causes 300,000 deaths annually and affects more than 300 million people due to severe heat waves, floods, storms & forest fires [4].

The bottom-line is that, there is urgent need for non-governmental organizations (NGO), government agencies and individuals to find ways to be more sustainable.

1.2 Sustainable development and its three pillars

The term sustainable development is often misunderstood and misinterpreted. Sustainable development is usually defined as the development that meets the needs of present generations without compromising the ability of future generations to meet their own needs. Sustainable development has been adopted by the United Nations (UN) as a combination of economic, social & environmental development commonly known as three pillars of sustainability as shown in Figure 1-1. [34]

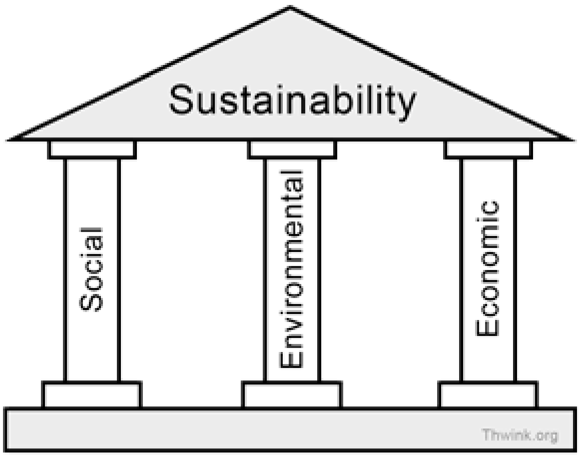

Figure 1-1: Three pillars of sustainability

1. **The Social Pillar**: The social pillar of sustainability in an organization seeks cohesion of society it operates in. The organization makes the social pillar strong by taking care of health, safety, nutrition, shelter of the employees. All these parameter's fall under the umbrella of corporate social responsibility (CSR). The vital parameters in achieving this success are to treat employees fairly, being responsible neighbor & community member locally and globally. [28]

2. **The Environment pillar**: The environmental sustainability is achieved when there is zero or minimum adverse impact of an organizations facilities, products and operation on the environment. Herman Daly, one of the pioneers in environmental sustainability proposed that, for renewable resources, the rate of harvest should not exceed the rate of regeneration. For pollution, the rates of waste generation from projects should not exceed the assimilative capacity of the environment. For nonrenewable resources, the depletion of the non-renewable resources should require comparable development of renewable substitute for that source. [33]
3. **The Economic pillar**: Economic pillar of sustainability is where the most organizations feel that they are on the firm ground. The economic pillar is strong and sustainable when organizations make developments without disturbing environmental and social pillar. The innovation in manufacturing processes by reducing environmental footprint of the product helps in increasing financial benefits without disturbing social & environmental pillar and creates sustainable organization. [28]

One of the key challenges for any organization is to measure and report their data on three pillars to different stakeholders. In this study, the focus is on the environmental pillar. The analysis of the data about different environmental factors on whole organization helps in understanding hotspots of organizations impact on different areas such as climate change, air & water pollution, effects on biodiversity etc. This analysis can be then transposed into different initiatives aimed at reducing environmental footprint of organization. It is becoming increasingly common for large corporations to report on their sustainability performance. Therefore, it is important to understand current state of sustainability reporting standards available worldwide. [28]

1.3 Sustainability standards

Sustainability standards provide guidelines to improve organizations performance on environmental, economic or social aspects. The sustainability report is a report summarizing organizations performance on environmental, economic and social aspects. Following the guidelines of sustainability standards by organization around the world is a key step in progressing towards achieving a sustainable global economy. Following sustainability standards helps organization to drive innovation in the business process by analyzing organization level data. The sustainability reporting for an organization helps to add value in various areas such as building trust, improved process & systems, reducing compliance costs and creating long term success environment. [6]

As the awareness of sustainability around the world is increasing, there is also an increase in the standards for sustainability reporting worldwide. This reporting standards include mandatory and voluntary standards, that requires or motivates organization to report on their sustainability performance on three pillars of sustainability discussed above.

A study was conducted to find out the number of sustainability reporting standards available in 64 countries around the world. The study suggests that, in many countries early voluntary efforts by an organization to report on their sustainability performance, have been followed by an increase in mandatory regulations put forward by the government. Figure 1-2 below shows the distribution of voluntary vs mandatory sustainability standards in 2016 compared to 2013 around the world. The height of the bar in the figure represents number of sustainability standards. [1]

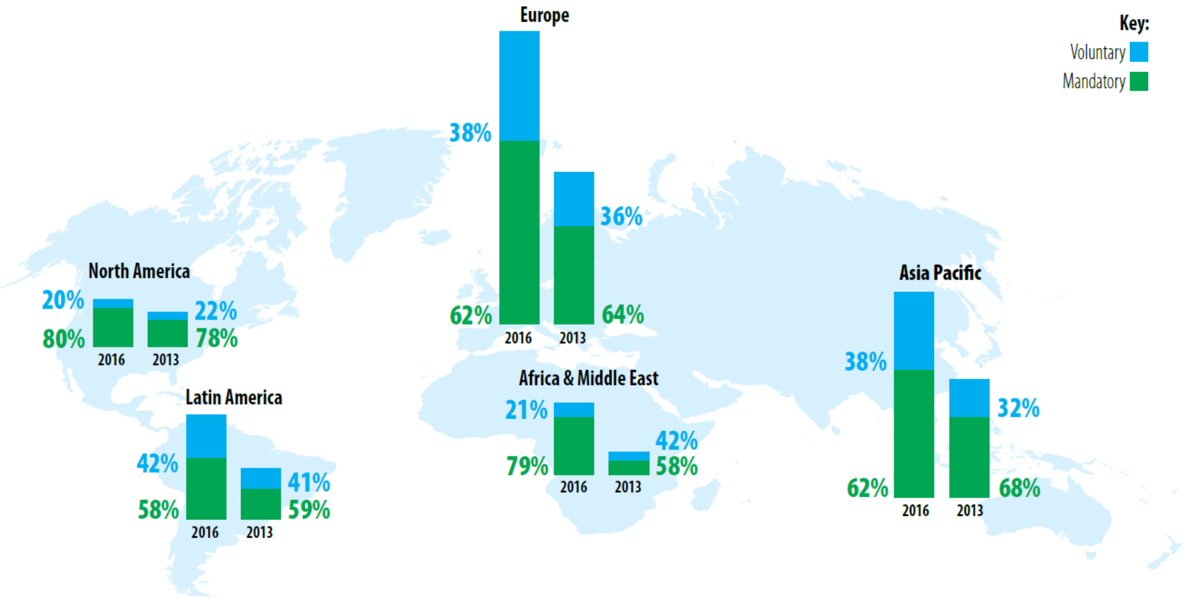

Figure 1-2: Mandatory vs Voluntary standards by region [1]

The same study suggests that majority of the sustainability standards were put forward by the government (Figure 1-3) and around 40% of these standards are applicable to heavy industry (Figure 1-4). Heavy industry is the industry which uses large amount of energy and heavy machinery to produce products. The standards targeting heavy industry were implemented to gauge performance of the industry over environmental and social pillars (Figure 1-5). In all figures, the height of the bar indicates number of sustainability standards.

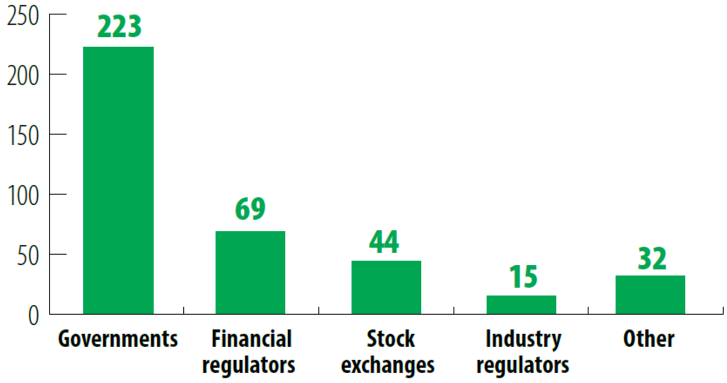

Figure 1-3: Sustainability standards issued by different authorities [1]

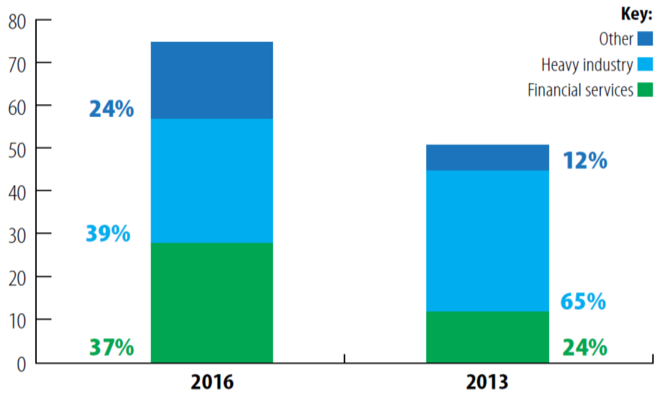

Figure 1-4: Sector specific sustainability standards [1]

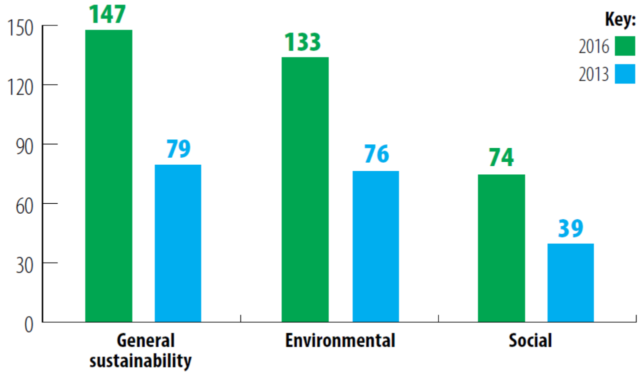

Figure 1-5: Sustainability standards targeting different pillars [1]

The standards could be applicable for measuring performance of an organization over any one or all three pillars of sustainability. These standards usually include the disclosure of site specific data such as GHG emissions, other pollutant emissions, waste generation & disposal, publication of policies or action plans on social impact, biodiversity or employment figures to the government. The standards used to measure and report environmental impact of the organization are usually known as environmental reporting standards. Different standards for disclosure of the environmental impacts caused due to greenhouse gas emissions in an organization could increase globally following the recent Paris Agreement at the UN climate conference in Paris (COP21, December-2015).

In this study, the focus is on environmental reporting standards. The major area of focus under the environmental reporting is disclosure of emissions such as GHG, SO_2, NO_x, PM etc. The examples of direct disclosure to government include European Union-Emission Trading System (EU-ETS), European Pollutant Release and Transfer Register (E-PRTR) etc in Europe and National emissions standard for hazardous air pollutants (NESHAP), Toxic Release Inventory etc in United States of America (USA). [1]

1.3.1 Relationship between Sustainability and Compliance

The Figure 1-6 shows how sustainability and compliance are related to each other.

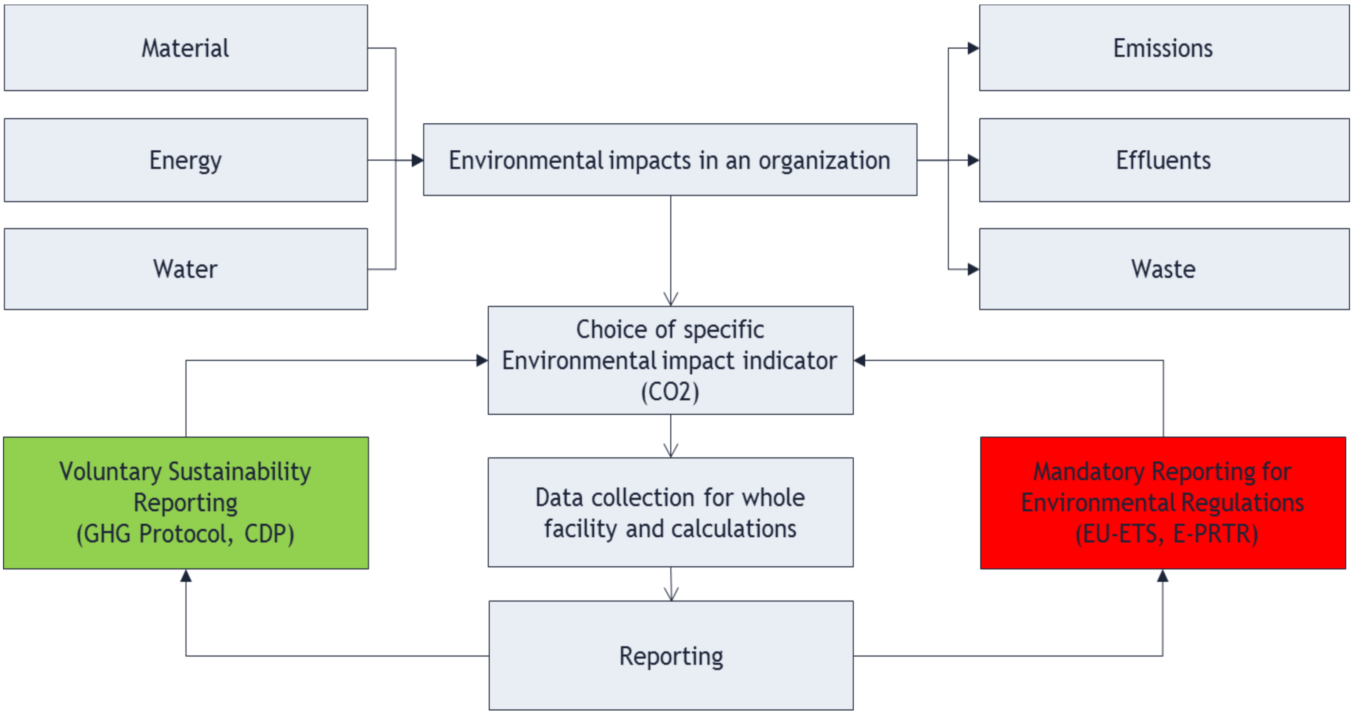

Figure 1-6: Relation between sustainability reporting and environmental reporting

Different industrial facilities can have many impacts on the environment as shown in Figure 1-6 such as use of raw material, energy, water etc and emissions to air, water, generation of waste etc. To assess the impact of the organization on global warming, collection of the GHG emissions data is needed. Collection of these GHG data can be used for two distinct types of reporting. If the industrial facility is in Europe, it has mandatory requirement of reporting the GHG emissions data through EU-ETS and E-PRTR which comes under the umbrella of environmental reporting. Same industrial facilities can also take voluntary initiative to report GHG emissions data to carbon disclosure project (CDP) or other sustainability standards. Similar reporting requirement exist for other pollutants emitted or raw material & energy used by an organization. Therefore, it is important to understand how different regulations lay down monitoring procedures to assess environmental impacts by an organization. Hence, it was decided to study mandatory environmental regulations put forward by the government for monitoring and reporting of environmental impacts by an organization.

1.4 Objectives of the thesis

The scope overview of the thesis is narrowed down as per Figure 1-7 considering recent development on reporting instruments worldwide [1], importance of climate change and air pollution. The main focus is to study mandatory environmental regulations by understanding how pollutant emissions are monitored, quantified, reported and thereby reduced to comply with these regulations. The objectives of the thesis work are as follows:

- To study & compare mandatory environmental regulation in Europe and USA regarding pollution to air from heavy industry and understand their linkages with global & regional regulations.
- To understand how such regulations are implemented, by studying it in the perspectives of pollutant monitoring & quantification in a specific European (Norwegian) aluminum industry case.
- To understand internal mechanisms of reporting processes and to contribute to a system design for implementation of monitoring and reporting process of Industrial Emissions Directive (European regulation) on software systems.

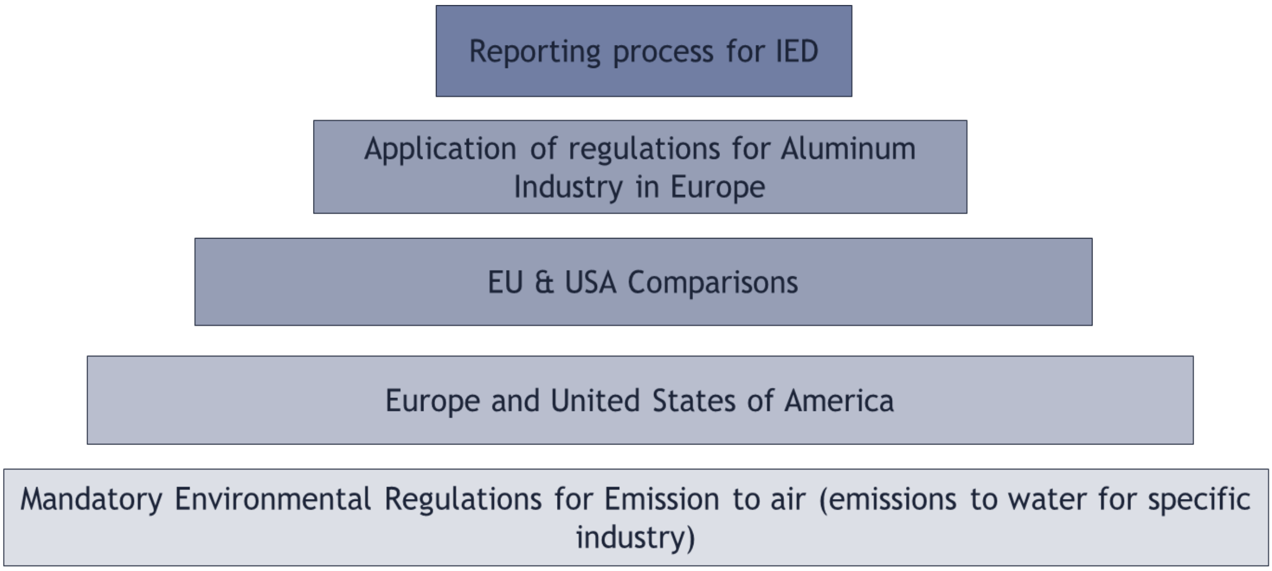

Figure 1-7: Scope of the thesis

During the start of thesis work, the regulations in the US were included in the scope. One of the reasons for the inclusion of US regulation was to investigate how these regulations are implemented on a ground level there. But during the thesis work, there was change in political leadership in US. The new political leadership is declaring a new direction in environmental policies, towards changing or removal of existing or planned environmental regulation. This led to a decision to not go forward and not to conduct a case study for comparison about implementation of US regulations of an aluminum industry similar to the planned European case. Regarding this aspect, the scope was changed somewhat to understand differences between the studied regulations in Europe and US by drawing out comparisons and instead understanding the environmental monitoring and reporting processes in detail and thereby contribute to a system design for implementing monitoring and reporting processes of IED in Europe on software systems.

1.5 Overview and outline of the thesis

The complete overview of the different topics covered during the thesis are shown in the Figure 1-8.

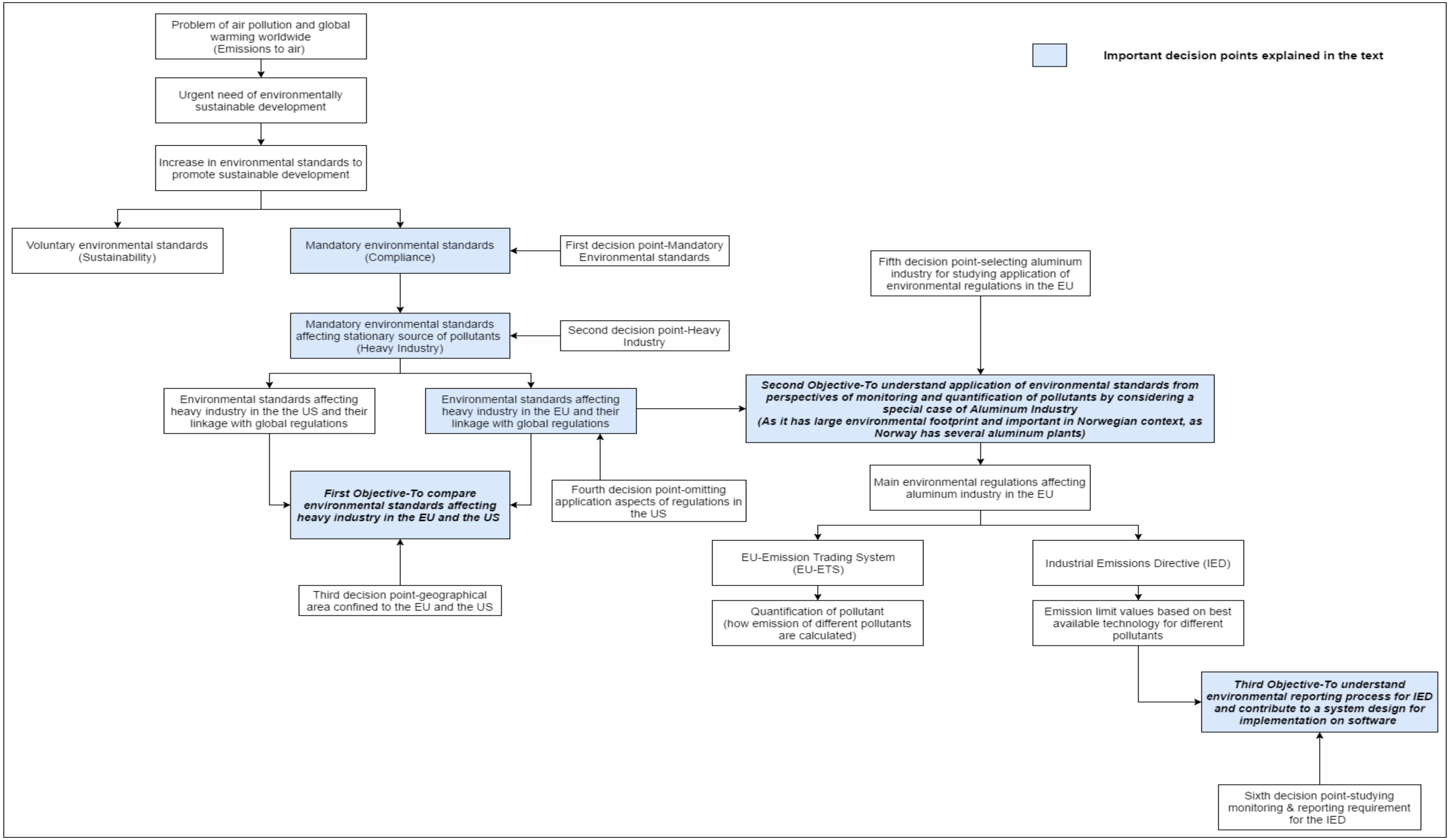

Figure 1-8: Overview of the thesis with objectives, study topics and decision points for chosen study direction

As introduced above, there is a serious concern about growing air pollution and global warming. To address this concern, it is important to implement environmentally sustainable development models. To promote environmentally sustainable development, there are increases in voluntary and mandatory environmental standards (regulations). The thesis was developed through different choices of directions as the work and knowledge evolved, and this is the first decision (Fig 1-8), as to which section of environmental standards should be studied, voluntary or mandatory. The decision was taken to study mandatory environmental standards because these standards are introduced by government authorities and all affected entities are obliged to follow the guidelines prescribed under these standards.

Also, these mandatory standards are applicable to stationary as well as mobile sources of pollution, however the study is limited to the stationary sources of pollution. This is the second decision point (Figure 1-8) and the reason for choosing stationary sources (heavy industry) of pollution is because these heavy industries are among the big polluters of the environment. Since the environmental standards are introduced by the government authorities, different countries have different set of guidelines. In this study, the geographical area of the US and the EU is selected due to the reason that these regions are highly developed regions and therefore will have the best environmental standards in the world. This is the third decision point (Figure 1-8), to confine the study of environmental standards for the geographical area of the US and the EU.

The literature study of mandatory environmental standards in the EU and the US is covered by chapter 2 & 3 respectively, and comparisons of regulations in the EU and the US is covered in chapter 4. As presented in the objective of the thesis, one of the reason for including regulations in the US is to study its guidelines for a particular industry. However, during the thesis work, there was a change in political leadership in the US. The new leadership has a different approach towards environmental policies. Therefore, the application aspect of environmental regulations in the US is omitted from the scope, this is the fourth decision point (Figure 1-8). It is also important to note that even though the application aspects of environmental regulation in the US is not studied, the regulations studied in the thesis from the US are intact and have not been changed/removed by the US-EPA.

To understand the exact guidelines of the environmental regulations, there is a need of selecting a particular industry sector. Therefore, aluminum industry is selected as there are several aluminum plants in Norway and many different environmental regulations affect the aluminum industry. This is the fifth decision point, to select aluminum industry among several other industries (Figure 1-8). The detailed description of how different environmental regulations affects aluminum industry in the EU is covered in chapter 5. The most important environmental regulations affecting aluminum industry in the EU are EU-ETS and IED. Under EU-ETS, calculation methodology of different pollutant is studied. Under IED, emission limit values of different pollutants from specific processes using best available technology based on BREF document is studied.

In general, EU-ETS affects around 11,000 installations across the EU, while IED affects around 50,000 installations in the EU. Therefore, since IED affects large amount of installations, the environmental reporting requirement for the IED was studied in detail and not the EU-ETS.

It was possible to select only one regulation from EU-ETS and IED for studying environmental reporting aspects due to time constraints. This is the sixth decision point of selecting the IED and not the EU-ETS for studying environmental reporting requirement (Figure 1-8). The detailed analysis of general reporting processes and specific methodology for IED is covered in chapter 6. The analysis presented can be implemented in the software system to make monitoring and reporting processes more effective and efficient. Discussion, conclusion and future recommendation are covered in chapter 7, 8 and 9 respectively.

2 Introduction to environmental policy in European Union

In this chapter, different environmental regulations affecting heavy industries in Europe are discussed. The focus is on heavy industries as they are among biggest polluters. Heavy industry is the industry which require heavy machinery and huge amount of energy to produce products. Even though the environmental performance of industries in Europe has improved in recent decades, there is still a significant amount of pollution to air, water and soil as well as generation of waste. Therefore, it is important to understand different regulations available to limit industrial pollution in the European Union. [25]

Before considering environmental regulations targeting heavy industries, it is important to understand how these regulations relate to different global and regional environmental treaties. A top down approach was adopted to the study to understand different environmental treaties signed on global, regional level and how these treaties are adopted by European Commission and transposed into regulations to target source of pollution such as industry in this case.

2.1 Overview of global policy and regulations affecting industries

Different initiatives taken by the European Commission in implementing environmental regulations is often driven by the policies of global and regional organizations such as UN and United Nations for Economic Commissions in Europe (UNECE) respectively. These organizations initiate the process of reducing pollution by considering different environmentally related issues such as human health, global warming, acid rain, transboundary pollution effects, air quality, thinning of ozone layer etc. Figure 2-1 shows the overview of linkage between policies of global, regional organizations to regulations affecting heavy industries in Europe.

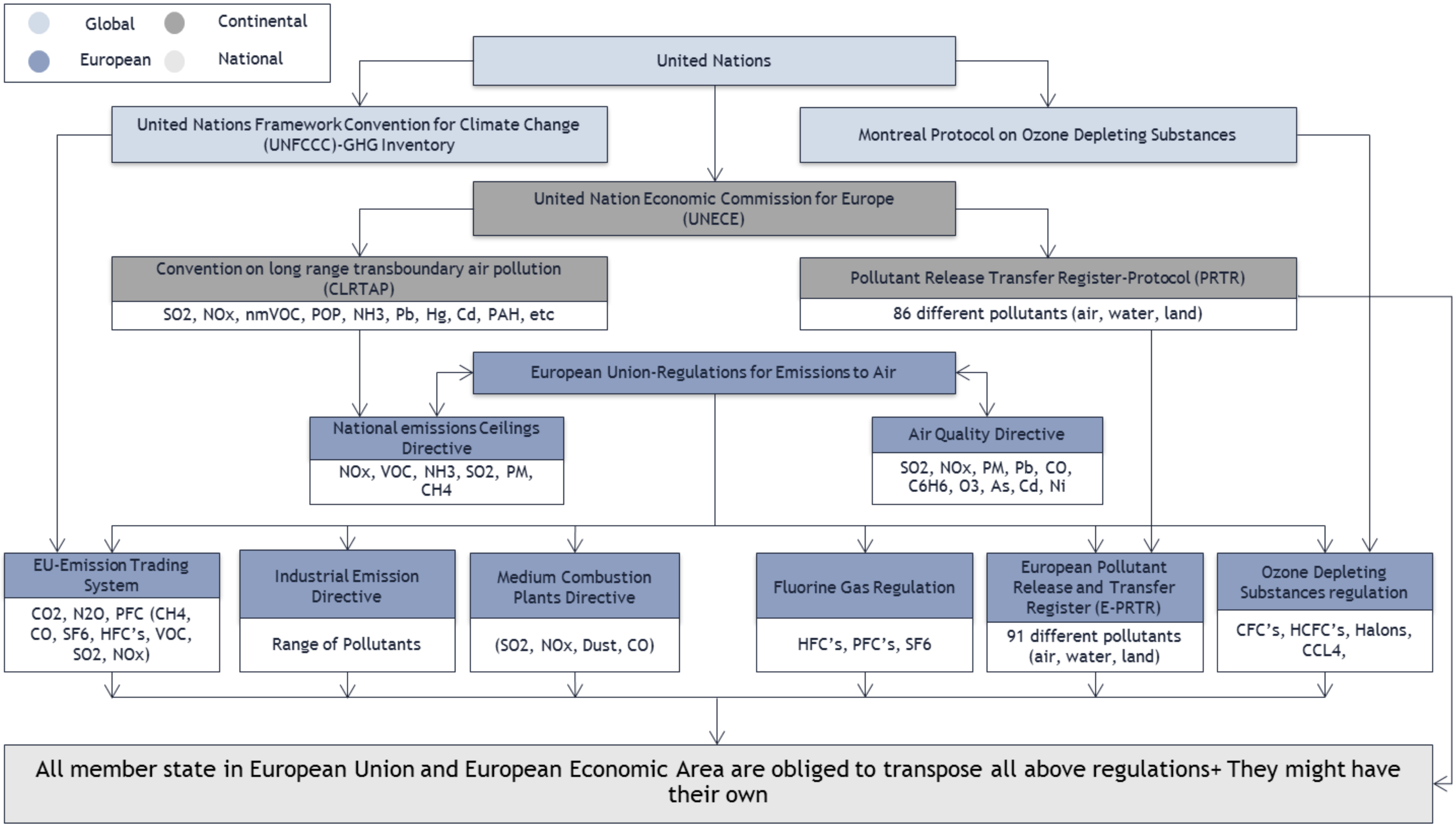

Figure 2-1: Overview of regulations affecting industries in Europe

The initiatives taken by these organizations are implemented through the ways of different directives & regulations by the European Commission. In the next step, these directives & regulations are adopted by each member states. Correspondingly, the industries in each of the member states are obliged to comply with these directives & regulations, if they fall under the threshold of emitted pollutant or being asked to phase out certain substances for protection of environment. [3, 25, 29]

The UN has taken two initiatives targeting climate change and the thinning of ozone layer:

- United Nations Framework Convention on Climate Change (UNFCCC).
- Montreal protocol on Ozone Depleting Substance (ODS).

The UNECE has also taken two initiatives to combat transboundary air pollution and establishing register for reporting of pollutants emissions. [21]

- Convention on Long Range Transboundary Air Pollution (CLRTAP)
- Kyiv Protocol on Pollutant Release and Transfer Register (PRTRs)

Depending on the data reported under CLRTAP by the member states, the European commission then directs member states to reduce emissions under National Emissions Ceilings Directive (NECD) [31].

To protect human health, the European commission lays down the regulations for monitoring local air quality under ambient air quality directive [9]. Finally, by analyzing the data reported under all the above regulations, European commission takes initiatives to curb pollution from diverse sources by implementing different regulations. In this study, the regulations affecting heavy industries are studied. The regulations affecting heavy industries are as follows:

- European Union-Emissions Trading System (EU-ETS)
- Industrial Emissions Directive (IED)
- Medium Combustion Plants Directive (MCP)
- Fluorine gas regulation
- European Pollutant Release and Transfer Register (E-PRTR)
- ODS regulation.

2.2 United Nations (UN)

The UN is an international organization founded in 1945. It is currently made up of 193 member states. The organization works in several areas such as:

- Maintain international peace and security
- Protect human rights
- Deliver humanitarian aid
- Promote sustainable development
- Uphold international law

To promote sustainable development, UN has taken several initiatives. In this study, the measures taken by UN in the field of air pollution and global warming is being studied. [27]

2.2.1 United Nation Framework Convention on Climate Change (UNFCCC)

The UN's Intergovernmental Panel on Climate Change (IPCC) has warned about the risks of climate change due to greenhouse gas emissions and has advised to find the solution before it is too late. The impact of climate change is already being visible in the form of a sea level rise to melting glaciers and extreme weather patterns. In 1992 countries signed an international treaty UNFCCC to combat climate change and limit the rise of global temperature. In 1997, the Kyoto Protocol was signed under the UNFCCC which legally binds developed countries to reduce their greenhouse gas emissions. The protocols first commitment period was started from 2008 to 2012 and second period began on 2013 and will end in 2020. [29]

In 2015, the agreement was signed in Paris to bring all countries together to combat climate change. The central aim of the Paris agreement is to keep global temperature rise this century well below 2°C above pre-industrial levels. According to article-13 of Paris agreement, each party should prepare national inventory of the anthropogenic emissions of the GHG. The GHG inventory should be prepared by the methodologies accepted by IPCC guidelines. Different GHG required to be reported includes CO_2-carbon dioxide, CH_4-methane, N_2O-Nitrousoxide, PFCs-Perfluorocarbons, HFCs-Hydrofluorocarbons and SF_6-Sulphurhexafluoride as well as indirect greenhouse gases such as SO_2-sulphur dioxide, NO_x-Nitrogen oxide, CO-carbon monoxide and nmVOC-non-methane volatile organic carbon. To meet GHG reduction target under Kyoto protocol the EU-ETS was established. The EU-ETS is key instrument to reduce GHG emissions cost effectively. It is world's first major carbon market and biggest one. [2, 29]

2.2.2 Montreal protocol on ozone depleting substances

The Montreal protocol was signed in Montreal, Canada under the umbrella of United Nations Environment Program (UNEP). Montreal protocol was finalized in 1987 and is designed to reduce the production and consumption of ozone depleting substances worldwide. The main gases which are being phased out under Montreal protocol are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, carbon tetrachloride and methyl bromide. Montreal protocol is the first treaty to receive universal ratification by all countries in the world. Montreal protocol has proven to be the successful instrument in phasing out ozone layer depleting substances by 98%. Most of the gases responsible for depleting ozone layer are also potent greenhouse gases. Therefore, phasing out of ozone depleting substances will make significant contribution in reducing the climate change. [30]

The EU and its member states have adopted policies that go beyond the requirements of the Montreal protocol. In 2010, EU and its member states have already achieved its reduction obligation under Montreal protocol 10 years ahead of schedule. Phasing out of ozone depleting substances has led to a robust growth of other gases such as hydrofluorocarbons (HFCs) which has high global warming potential. The EU has therefore in 2015, proposed to amend the Montreal protocol to phase out such gases at global level. This proposal was accepted in 2016 and EU has implemented this amendment under the Fluorine gas regulations in Europe. [30]

2.3 United Nation Economic Commission for Europe (UNECE)

UNECE is one of the five regional commissions of UN. UNECE has 56 member states in Europe, North America and Asia. One of the focus areas of UNECE is to reduce pollution and damage it causes by improving environmental standards in the region covered. UNECE has taken several different initiatives to address environmental concerns. In this study, the focus is on the measures taken to reduce the air pollution around the region covered under UNECE. Protocols signed under UNECE to address the issue of air pollution are CLRTAP & PRTR. [21]

2.3.1 Convention on Long-range Transboundary Air Pollution (CLRTAP)

In 1960, scientists found a link between sulphur emissions in continental Europe and acidification of lakes in Scandinavia. In response to these problems the CLRTAP was signed between 34 governments and European Community in 1979. To this date, 51 different countries have signed the convention. Over the years, it has been extended by eight different protocols to target specific air pollutants under each protocol. Table 2-1 below gives overview of different protocols signed under CLRTAP. Each protocol targets specific sets of pollutants and prescribes control measures that needs to be taken by the member countries to cut their emissions. [3]

The convention was one of the first legislative mechanisms under which signatory countries were required to report data on their annual air emissions. Reporting requirement for air emission data and associated information is defined in the UNECE reporting guidelines. The guidelines are defined for different industry sectors and different pollutants in these sectors for which the reporting is required. The guidelines also define other practical aspects such as submission dates, reporting years and reporting format parties should use to submit emissions data. Database of all emissions reported by parties under the convention is available from the Center on Emission Inventory and Projection (CEIP) website. [31]

Table 2-1: Different protocols under CLRTAP [3]

Protocol Title	**Year of entry into force**	**Main Pollutants covered**
Protocol to abate acidification, eutrophication and ground level ozone (Gothenburg Protocol)	2005	SO_2, NO_x, VOC and NH_3
Protocol on Persistent Organic Pollutants (POPs)	2003	POPs
Protocol on Heavy Metals	2003	Cadmium (Cd), Lead (Pb) and Mercury (Hg)
Protocol on reduction of Sulphur emissions	1987, 1998	SO_2
Protocol concerning the control of nitrogen oxides	1991	NO_x
Protocol concerning the control emissions of VOC	1997	VOCs
Protocol on long term financing of the co-operative program for monitoring and evaluation of long range transmissions of air pollutants in Europe	1998	SO_2, NO_x and VOCs

2.3.2 Pollutants Release and Transfer Register (PRTRs)

The protocol on PRTR became international law in 2009. All the member states in UN can join the protocol. As of 2016, 34 countries and European Union have ratified the protocol.

The main objective of the protocol is to enhance public access to information through the establishment of nationwide pollutant release and transfer registers [5, 32]. Protocol requires each industrial installation to report their annual emissions data of the pollutants if it falls under the threshold limit of the pollutant [32].

The article 7 of the protocol covers reporting requirement of 86 different pollutants comprising of greenhouse gases, acid rain pollutants, heavy metals & carcinogens etc. [32]. This requirement cover pollutants releases to air, water or land along with release of the wastes [32]. Although the protocol doesn't regulate emissions of the pollutant directly, it creates the pressure on the companies to avoid being identified as a major polluter because of requirement to disclose emission information publicly [5].

PRTR protocol covers 64 different industrial facilities listed in annex 1 of the guidance document [32]. The article 7 of the protocol, list down two different selection criteria for mandatory reporting requirement: capacity of industrial facility and pollutant release thresholds on one hand and number of employees and pollutant manufacturing capacity on the other hand [32]. Annex 2 of the protocol contains the list of all pollutants along with the threshold value for the reporting [32]. In the guidance document, the expected release of different pollutants is listed from 64 distinct industrial activities [5]

2.4 Regulations by European Union for member states

2.4.1 National Emissions Ceilings Directive (NECD)

The NECD was adopted in 2001 and covered 4 key pollutants which contribute to acidification, eutrophication and the formation of ground level ozone: sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-methane volatile organic carbon (nmVOC) and ammonia (NH_3) [31]. NECD was adopted to meet requirements of the Gothenburg protocol under CLRTAP agreed in 1999 [3]. NECD sets pollutant specific emission limit values for each country called ceilings. The ceilings in other words are reduction commitments allotted to each country for emission of specific pollutant. For example: The SO_2 emissions for Belgium must be reduced by 66% compared to emissions in 2005 by the year 2030 [7]. At the same time the SO_2 emission in Bulgaria must be reduced by 88% compared to emission in 2005 by the year 2030 [7]. Therefore, under NECD the member state which has the larger amount of total emission are required to have more reduction commitments compared to state which has lesser amount of emissions [7]. The ceilings under NECD were designed with the aim of improving the environment and human health against risk of adverse effects from acidification, health related ground level ozone exposure etc [31] NECD directive was revised in 2016. The new NECD directive has updated national emission ceilings values for six key pollutants (PM, SO_2, NO_x, VOCs, NH_3 & CH_4) proposed for 2020 and 2030. All member states are encouraged to use the same nomenclature for reporting as used for CLRTAP reporting [31]. Emission reporting requirement under NECD was established to monitor progress of the member states in meeting their respective national emission ceiling targets [31]. Reporting must be based on the guidebook used for CLRTAP reporting [31]. The reporting process is handled by European Environment Agency and data is made publicly available through NECD webpage [31].

2.4.2 Ambient Air Quality Directive (AAQD)

The AAQD sets the thresholds and targets for the concentration of air pollutants to protect human health and the environment locally. The idea behind AAQD is to monitor local air quality and try to achieve the compliance with emission limit values. All limit values adopted by AAQD follow guidelines of the World Health organization (WHO). Main pollutants covered by AAQD are SO_2, NO_x, PM_{10}, $PM_{2.5}$, Pb in PM_{10}, CO, C_6H_6, O_3, Arsenic (As), Cadmium (Cd) Nickel (Ni) and Poly Aromatic Hydrocarbon (PAH). AAQD also specifies the monitoring and reporting requirements for each pollutant. In case of exceedance of the threshold values member states are obliged to implement air quality plans to improve air quality. The air quality plans include the shortlisting of potential stationary and mobile sources of specific pollutant. European commission in combination with European Environment Agency lays down new regulation & directive targeting specific sources to limit emission of this pollutant in order to meet the requirement of emission limit value. Currently, the AAQD air quality limit values for PM_{10}, $PM_{2.5}$ and NO_2 are not complied within a considerable number of member states. The important objective of the European air quality policy is to achieve compliance with the air quality values as soon as possible. [8, 9]

2.5 Regulations affecting industries in European Union

In this section, the regulations targeting stationary source of pollution are studied. As studied in previous sections different treaties, directives and protocols require reduction in the emission of several air pollutants across all member states in the EU. These regulation & directives include UNFCCC, CLRTAP, AAQD, NECD. These regulations and directives bind different member states to take actions for monitoring and subsequently on planning to reduce the emissions of several pollutants. To meet all the objectives of UNFCCC, CLRTAP, NECD and AAQD on national level, several regulations are put forward by European commissions which target stationary and mobile sources of pollutants. The interlink between the regulations affecting stationary source (industry) in the Europe and the regulations on global level are shown in Table 2-2.

Table 2-2: Interlinkage between different regulations

Regulation affecting Industry on European Level	**Interlinkage with other regulations on global or regional level**
European Union-Emissions Trading System (EU-ETS)	UNFCCC
Industrial Emissions Directive	NECD & AAQD
Medium Combustion Plants Directive	NECD & AAQD
Fluorine Gas Regulation	Ozone Depleting Regulation and UNFCCC
European Pollutant Release & Transfer Register	PRTR Protocol

2.5.1 European Union-Emissions Trading System (EU-ETS)

EU-ETS was implemented to meet targets of the Kyoto protocol under UNFCCC for reducing GHG emissions. EU-ETS was first implemented in 2005. Table 2-3 below shows overview of different changes adopted by EU-ETS over the years.

Table 2-3: Overview of EU-ETS [11]

Key features	**Phase-1 (2005-2007)**	**Phase-2 (2008-2012)**	**Phase-3 (2013-2020)**
Geography	EU	EU + Norway, Iceland, Liechtenstein	EU + Norway, Iceland, Liechtenstein, Croatia from 2013
Sectors covered	Power stations and other combustion plants >20MW, oil refineries, coke ovens, iron & steel plants, cement clinker, glass, lime, pulp, paper etc	Same as phase 1 + aviation	Same as phase 2 + aluminum, petrochemical, nitric, adipic and glyoxylic acid production
Greenhouse Gases Covered	CO_2	CO_2 + N_2O (Voluntary)	CO_2 + N_2O + PFC from aluminum production

EU-ETS works on cap & trade principle. The cap is overall limit on total emissions. EU-ETS system works by putting cap on total amount of GHG emissions from the industries affected. This cap is then reduced each year so that total emission falls. To meet the requirement of the cap, companies can buy or sell allowances as needed. The cap-trade approach gives companies the flexibility to cut emissions in most cost-effective way. [11]

For example: Assume two industries as A & B. Both industries have 5000 tons of total CO_2 emissions per year. As per cap, the total amount of emission must be reduced by 10% to 4500 tons of CO_2 emissions from each industry per year. Each company is allocated 4500 emission allowances. One allowance accounts for 1 ton of CO_2 emitted. The industry A reduces its total emission by using improved technology to 4000 tons of CO_2 emissions. Since industry A now needs only 4000 allowances to meet its requirement, the extra 500 allowances could be sold in market. For industry B, the cost of emission reducing technology would be more expensive than purchasing additional 500 allowances. Therefore, industry B could purchase this allowance from market (Industry A sells it) to meet its reduction requirement. Finally, overall goal of reducing 10% of total GHG emissions is met. The process of buying and selling allowances is controlled by European Energy Exchange (EEX). [11]

EU-ETS affects around 11000 power plants and manufacturing industries across EU member states plus Norway, Iceland and Liechtenstein. EU-ETS also covers aviation activities in these countries. Total amount of GHG emissions regulated under EU-ETS is around 45% of EU's total GHG emissions. The target for phase 3 which runs from 2013-20 is to bring GHG emissions 21% lower than in 2005 and for phase 4 which runs from 2021 to 2030 is 43% lower than in 2005. The installations covered by EU-ETS must monitor and report their annual emissions checked by an accredited verifier to track the progress of reducing emissions. [11]

2.5.2 Industrial Emissions Directive (IED)

Industrial facilities in the EU are contributing a major share to overall pollution in Europe. To control the emissions from industrial installations in Europe, the EC and the Council on Industrial Emissions has put forward IED 2010/75/EU. IED was adopted in 2010 and had to be transposed in the national law by the member states by January 2013. IED is based on the commission's proposal of recasting and merging seven existing directives which includes Integration Pollution Prevention and Control Directive (IPPC), the Large Combustion Plants Directive (LCP), the Waste Incineration Directive (WID), the Solvents Emissions Directive and three directives on Titanium dioxide (Figure 2-2). [13]

IED aims to both control and prevent pollution from 50,000 large installations operating in various sectors including energy, metal production, minerals and chemical production, waste management etc. Different industrial installations listed in Annex I of IED are required to operate in accordance with the permit granted by authorities in member states. The permit is based on the conditions set in accordance with the principles and provisions of IED. [13]

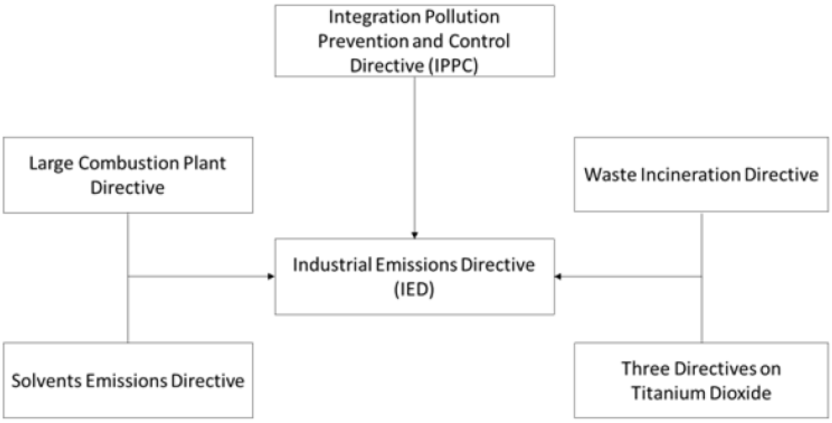

Figure 2-2: Industrial Emissions Directive Recast [12, 13]

The IED is based on factors such as:

1. Integrated approach: Integrated approach means that the operating permit should consider the whole environmental performance of manufacturing facility. The environmental performance includes emissions to air, water and land, generations of the waste, use of raw materials, energy efficiency, noise, prevention of accidents and restoration of site upon closure. [12]
2. Permit Conditions: The conditions in the operating permit must be set according to best available technology reference documents (BREF). BREF documents are developed by concrete research process at EU level by member states, industry and environmental NGOs. The process of developing BREF documents is coordinated by European Integration Pollution Prevention and Control Bureau (IPPC) of the Institute for Prospective Technology studies at the EU Joint Research centers in Seville-Spain. BREF document are available for various industries and contain emission limit values for different pollutants to air and water when best available technology (BAT) is used. BREF documents also contains measures required for increasing energy efficiency, optimum use of raw material, water etc. [12]
3. IED allows competent authorities to set less strict emissions limit values for specific cases. This is only possible where achieving the BREF associated emission levels would cause unreasonably higher cost compared to the environmental benefit. Reasons might be the geographic location, environmental condition or the technical characteristics of the installations. The competent authority shall always document its justification for granting permits with less strict emissions values. [12]
4. IED contains mandatory requirements for environmental inspections every 1 to 3 years by visiting operation sites. In addition, through European Pollutant Release and Transfer Register (E-PRTR) emission data is made available to the public. [12]

2.5.3 Medium Combustion Plants Directive (MCP)

The medium combustion plants are used for energy provision (electricity generation, domestic/residential heating and cooling, providing heat/steam). MCP has the thermal input between 1 and 50 megawatt (Mw). MCP's are an important source of SO_2, NO_x and dust emissions. The estimated number of MCP's in the Europe is around 143,000. To regulate the MCP, EC has introduced Directive 2015/2193 in 2015. This directive should be transposed by the member states in their national laws by December 2017. This directive requires reduction of SO_2, NO_x and dust emissions with the aim of reducing risks to human health and the environment it may cause. The directive also lays down the requirement of monitoring CO emissions. MCP directive was introduced to fulfill obligations under NECD and CLRTAP. [14, 15]

2.5.4 Fluorine Gas Regulations

The Fluorinated greenhouse gases (F-gases) is a group of gases containing fluorine. Most common F-gases in use within Europe are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). F-gases have several different applications in industries e.g. pharmaceutical, electronic, aluminum, magnesium production with the largest application as refrigerants. F-gases are ozone friendly, energy efficient, non-flammable with low toxicity, but have high GWP's. Some F-gases have 23,000 times the warming effect of CO_2. Therefore, the European Union is taking a regulatory action to reduce their emissions. First F-gas regulation was adopted in 2006 and succeeded in stabilizing EU's F-gas emissions. The new regulation replaces the first and must be applied from January-2015. Under new regulation the existing measures are strengthen and plans to cut F-gases emission by two-thirds by 2030 compared to 2014 within the EU. [17]

Table 2-4 below shows how F-gas regulation is planning to phase out the F-gases over the years until 2030 (Annex-V) [17]. European Commission will put a cap on the total F-gases allowed to be placed in the market and reduce the amount in accordance to Table 2-4. European commission is trying to find the availability of climate friendly alternatives to F-Gases which will stimulate innovation and green growth. [17]

Table 2-4: Phase down of F-gases over the years until 2030 [17]

Year	**% to calculate the maximum quantity of hydrofluorocarbon to be placed on market**
2015	100
2016 and 17	93
2018, 2019, 2020	63
2021, 2022, 2023	45
2024, 2025, 2026	31
2027, 2028, 2029	24
2030	21

2.5.5 European Pollutant Release and Transfer Register (E-PRTR)

The European Commission adopted UNECEs PRTR protocol on European level as E-PRTR through Regulation No 166/2006. The regulation is based on PRTR protocol and was adopted in 2006. It requires around 30,000 industrial facilities in European Union, Norway, Iceland and Liechtenstein to report data on their annual emissions. E-PRTR covers 65 different industry sectors in Europe as per Annex I of the regulation. The regulation requires reporting of the 91 different pollutants from Annex II as per the threshold mentioned. [18]

2.5.6 Ozone Depleting Substance Regulation

The European Union has a very strong commitment towards protecting the ozone layer and has put forward the strictest and most advanced legislation in the world to prevent ozone layer deterioration [20]. In European Union, provisions of the Montreal protocol on ODS have been successfully implemented faster than it is required [20]. In 2016, parties to the Montreal Protocol adopted the Kigali Amendment to add Hydrofluorocarbons (HFCs) to the list of the controlled substances [17]. The foreseen phasedown of HFCs will save around 80 Gigatons of CO_2 equivalents GHG emissions worldwide until 2050 [20]. European Union has already planned to implement the Kigali amendment to phase out HFCs along with PFCs and SF_6 under F-Gas regulation [17, 20].

3 Introduction to environmental policy in USA

In this chapter, environmental regulations from the United States of America (USA) affecting heavy industries are discussed. A similar top down approach was adopted as done while studying regulations in Europe, to understand what drives policy makers to design new regulations depending on global and regional treaties. Regulations focusing on emissions to air from industrial facilities were studied.

3.1 Overview of global policy and regulations affecting industries

The initiatives taken by US-EPA to curb pollution is often driven by global, regional treaties along with the status of local air quality. Figure 3-1 shows the overview of linkages between global and regional treaties to regulations affecting heavy industries in USA.

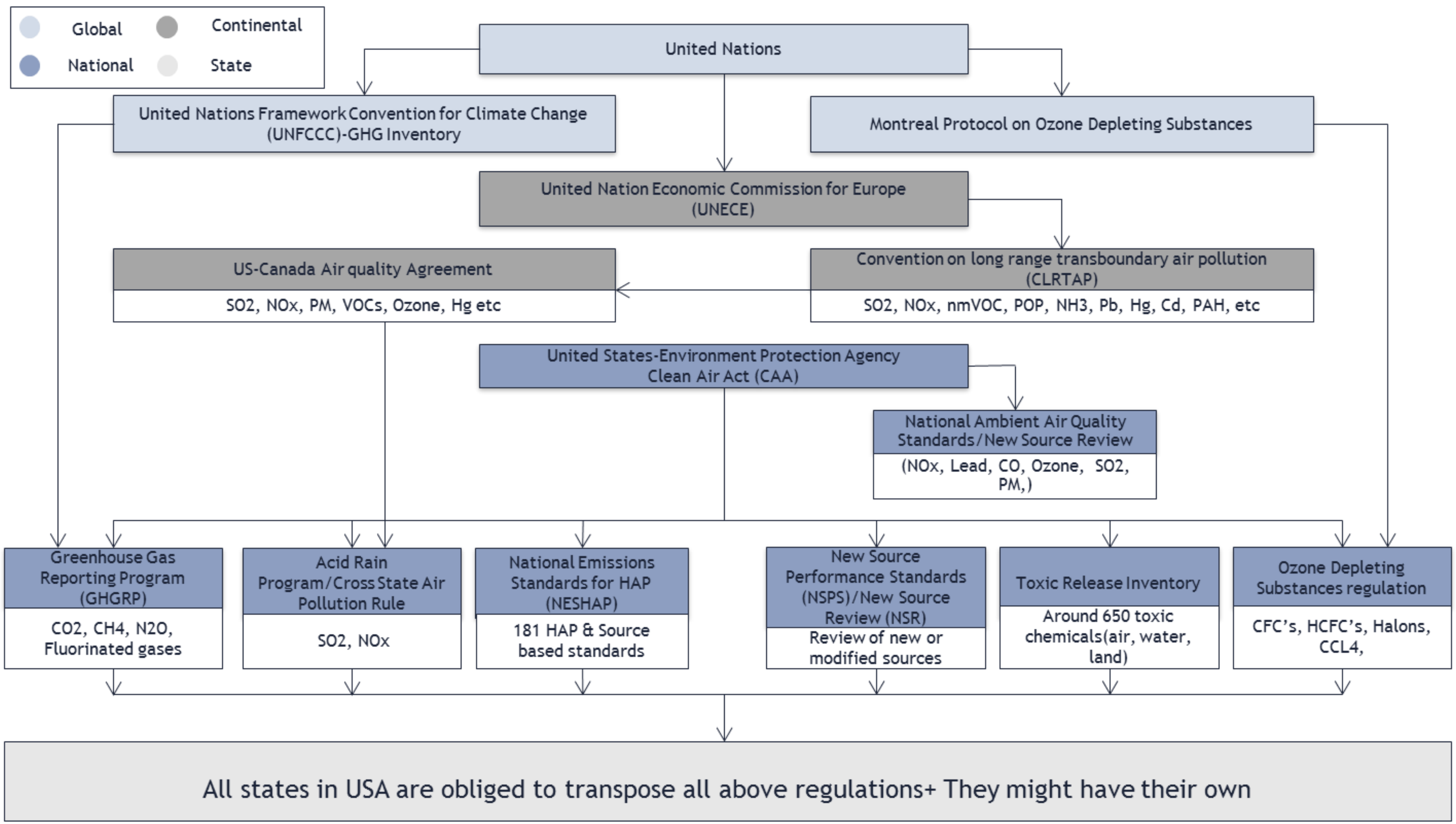

Figure 3-1: Overview of Environmental Regulations in USA

The international organizations affecting the policy making process of the US-EPA are the UN and the UNECE. All initiatives taken by these organizations are then implemented through Clean Air Act (CAA) in forms of standards and regulations. These standards & regulations are adopted by different states in the US. Different states in the US might have their own standards and regulations stricter than standards under CAA.

The UN has taken two initiatives targeting climate change and ozone layer thinning.

- United Nations Framework Convention on Climate Change (UNFCCC)
- Montreal Protocol on Ozone Depleting Substances (ODS)

The USA is a member of UNECE and has signed CLRTAP. According to the emission data available from CLRTAP, the US signed agreements with Canada to limit transboundary air pollution under US-Canada Air Quality agreement.

To protect human health, US-EPA lays down National Ambient Air Quality Standards (NAAQS). NAAQS lists down the requirement of monitoring local air quality. Finally, by analyzing the data from NAAQS & CLRTAP different standards and regulations are implemented to limit pollution from stationary and mobile sources of pollution.

In this study, regulations affecting stationary sources of pollution are studied. Different regulations targeting stationary source of pollution are as follows:

- Greenhouse Gas Reporting Program (GHGRP)
- Acid Rain Program (ARP) - Cross State Air Pollution Rule (CSAPR)
- National Emission Standards for hazardous Air Pollutants (NESHAP)
- New Source Performance Standards (NSPS) - New Source Review (NSR)
- Toxic Release Inventory (TRI)
- ODS regulations.

3.2 United Nations

The initiatives taken by the UN are similar to what's been discussed while studying regulations in the European Union. Two treaties have been put forward by the UN affecting the USA as well as the EU.

1. United Nations Framework Convention on Climate Change (UNFCCC)
2. Montreal Protocol on Ozone Depleting substances

3.2.1 United Nations Framework Convention on Climate Change (UNFCCC)

The USA had signed Kyoto Protocol under UNFCCC. However, the US never ratified the Kyoto Protocol. The decision of not ratifying was taken on the basis that it would harm the US-economy and exempt developing countries from GHG reduction requirements. The US has introduced a mandatory monitoring & reporting program for GHG emissions for industries under Greenhouse Gas Reporting Program (GHGRP) in accordance with UNFCCC. First reporting under GHGRP was in 2011. The previous government in the US had ratified Paris Agreement under UNFCCC to reduce the GHG emissions. [22] However, recently there was a change in government in the USA and new government has pulled out of the Paris agreement [59].

3.2.2 Montreal Protocol on Ozone Depleting Substances

Montreal Protocol is the same as it is explained while studying the regulations in the European Union. The USA ratified the protocol in 1988 and subsequently its amendments. The USA has contributed in achieving successful implementation of Montreal Protocol globally by phasing out chlorofluorocarbon (CFCs) and halon emissions. In 2016, under Montreal Protocol, the Kigali amendment was adopted to phase down the Hydrofluorocarbon (HFCs) worldwide. Kigali amendment opens door for innovation to produce substances which are climate and ozone friendly at the same time. [22]

3.3 United Nations Economic Commission for Europe (UNECE)

The USA is a member of UNECE. To reduce the transboundary air pollution in North America, the USA has been a signatory to CLRTAP put forward by UNECE.

3.3.1CLRTAP & US-Canada Air Quality Agreement

The transboundary effects of the air pollution triggered both USA and Canada to ratify the CLRTAP in its early years. The USA and the Canada implements provisions from CLRTAP through the US-Canada Air Quality agreement signed in 1991. The agreement initially focused on reducing of acidic deposition levels in each country. In 2003, the agreement was amended to address the issue of ground level ozone. Under this air quality agreement, the Canada and the USA have seen significant reduction of NO_x and SO_2 emission. Between 1990 and 2012, the SO_2 emissions declined by 58% in Canada and 78% in the USA. Also between 2000 and 2012 the NO_x emissions reduced by 45% in Canada and 47% in the USA. There is considerable improvement seen in ecosystem acidification and improvement in the air quality. The two countries are making efforts for the scientific cooperation and research to further reduce levels of acid rain, O_3 and particulate matter (PM). The USA implements US-Canada Air Quality Agreement through ARP and CSAPR establish under the CAA. [26]

3.4 Emissions to Air regulations in USA

The CAA in USA regulates the air emissions from stationary and mobile sources. Among other things, the CAA establishes National Ambient Air Quality Standards (NAAQS) to protect public health, welfare and to regulate emission of hazardous air pollutants. CAA is designed to minimize the pollution from the increasing number of mobile sources and from new or modified stationary sources. CAA requires new stationary sources to be built with the best technology and allows less stringent standards for existing sources. [22]

3.4.1 National Ambient Air Quality Standards (NAAQS)

The NAAQS are the center piece of CAA. CAA requires NAAQS to control the six common air pollutants known as Criteria Air Pollutants (CAP). These pollutants are harmful to public health and environment. The six pollutants covered are ground level ozone, particulate matter, carbon monoxide, lead, sulphur dioxide, nitrogen dioxide. NAAQS are set at the levels designed to protect public health and welfare. To maintain the levels of pollutant consistent with NAAQS, the CAA requires different states to develop state implementation plans (SIP's) applicable to relevant sources of pollution. Different states develop SIP's by establishing source specific emission limit for pollutants from specific sources. The SIP is a constantly evolving document which is updated regularly depending upon federal requirements and local atmosphere. [22]

Different industry specific standards are explained in the section below. These standards cover six pollutants under NAAQS and several other pollutants harmful to human health and environment. [22]

3.5 Emissions to air regulations affecting industries in USA

In this section, different standards put forward by CAA to reduce air pollution from industries in USA are discussed. There are several different standards put forward by CAA targeting specific pollutant emissions from corresponding industry sectors.

3.5.1 Greenhouse Gas Reporting Program (GHGRP)

The GHGRP codified at 40 Code of Federal Regulation (CFR) Part-98 [23] requires large emitting facilities such as industrial facilities, fuel suppliers, electric generation units, landfills etc. to report their GHG emissions. The proposed rule covers the six primary greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC), and sulfur hexafluoride (SF_6) as well as certain other fluorinated gases such as nitrogen trifluoride (NF_3) and hydro fluorinated ethers. The facilities are generally required to submit annual report under following conditions.

- If the sources emit more than 25,000 metric tons CO_2e per year.
- In case the supply of certain products will result in emission of over 25,000 metric tons CO_2e of GHG emissions if those products were released, combusted or oxidized.
- If the facility receives more than 25,000 metric tons or more of CO_2 for underground injection.

The reporting threshold affects more than 9000 facilities under 41 distinct categories of industries. In total, the program covers 85-90% of all the GHG emissions from the USA. All facilities must calculate their emissions using the methodologies specified in 40 CFR 98. Each of the affected facilities are then required to report their data to the EPA using the electronic Greenhouse Gas Reporting Tool (e-GGRT). The EPA carries out a multistep verification process to assess if the data submitted are accurate, complete and consistent. The reported data is then made available to the public via GHG data sets page. [22]

3.5.2 Acid Rain Program & Cross State Air Pollution Rule

The Acid Rain Program (ARP) was first begun in 1995. ARP was designed to reduce the harmful effects of acid rain by reducing emissions of SOx and NO_x from powerplants. ARP was the first national cap and trade program in the USA. It works on similar principles as explained in EU-ETS (see 2.5.1). Cap is set on total emission that can be emitted per year. According to this cap the emission allowance is made available by the authorities. Different affected installations must buy allowances to meet their emission targets. Reduction of emissions is based on a market based mechanism, which provides regulated sources flexibility to select the most cost-effective approach. To reduce emissions, sources have alternatives such as using advanced technology, optimizing existing controls, switching fuels, using allowances etc. [22] Each of the affected installations are required to accurately monitor and report emissions according to 40 CFR Part-75 [23].

Another program which supplements the ARP is the Cross-State Air Pollution Rule (CSAPR). CSAPR was updated in 2016 to meet fine particle and ozone NAAQS. CSAPR requires fossil fuel fired power plants in 27 states from the eastern part of the USA to reduce SO_2 and NO_x emissions. The SO_2 and NO_x emissions react in the atmosphere and contribute to the formation of soot pollution. The NO_x emissions also contribute to ground level ozone formation. EPA sets an emission budget for each state covered by the CSAPR. Emission allowances are allocated to the affected sources based on these state emissions targets. Each of these affected sources are then allowed to choose similar alternative described in ARP to meet their reduction requirements. [22]

3.5.3 National Emissions Standard for Hazardous Air Pollutants (NESHAP)

The Hazardous air pollutants (HAP) are pollutants which can cause cancer or other serious health, environmental and ecological effects. EPA under CAA requires control of 187 different hazardous air pollutants. Different HAP includes benzene, perchloroethylene, methylene chloride etc. Most important sources of air toxics could be mobile (cars, trucks, buses) stationary (factories, refineries, power plants) and indoor sources (building material, cleaning activities). CAA plans reduction of HAP from large industrial facilities in a two-step process [22]:

1. The first phase is technology based standards knows as Maximum achievable control technology (MACT). MACT standards are based on the emission levels that are already being achieved by controlled and low emitting sources in the industry. The EPA requires all HAP sources to achieve the MACT standards. [22]
2. In second phase, after 8 years of setting MACT standards, the CAA directs EPA to determine if MACT standards protects public health with an ample margin of safety and protect against the adverse environmental effects. It is a risk based approach called residual risk where the EPA must determine whether more health protective standards are necessary. Also after 8 years of MACT standards CAA requires the EPA to review and revise MACT standards to account for improvements in air pollution prevention techniques. [22]

Since 1990 the EPA has directed to reduce emissions from various industrial sources such as chemical plants, oil refineries, aerospace manufacturers, steel mills etc. The detailed standards for different source categories along with monitoring, record keeping and reporting requirement are available from 40 CFR, part-61 to 63 [23].

3.5.4 New Source Performance Standards (NSPS)/New Source Review (NSR)

The EPA under CAA identifies stationary sources of air pollution which endangers public health and welfare. For different source categories, the EPA then establishes emissions standards which are based on emissions reductions achievable using best available technology. Different emission sources targeted by NSPS includes waste combustors, steam generators, incinerators etc. from potential industry sectors such as petroleum refineries, chemical manufacturing etc. The complete standards for distinct sources along with reporting and record keeping requirement are available from 40 electronic code of federal regulations part-60 [23]. Main pollutants controlled under NSPS are NO_x, SO_2 and particulate matter. Once fixed, the NSPS serve as a minimum level of control that must be achieved by newly constructed or modified sources of pollution under the same category [22].

The NSR program is designed to achieve NAAQS in all areas of the country. It is a pre-construction review for new and modified stationary sources of pollution, and it approves the operation of new or modified industrial facilities by providing the operating permit. [22]

Allocation of permit to the industrial operation is dependent on the measures taken by industries to make operations as clean as possible with minimum emission of pollutants using best available technology. The permit is made available by considering NESHAP, NSPS, GHGRP etc. [22]

3.5.5 Toxic Release Inventory (TRI)

The TRI requires industrial facilities to submit annual reports on certain toxic chemicals that may pose threat to the human health and environment. The requirement of reporting includes toxic release to air, water, land and it is managed through recycling, energy recovery and treatment. Around 595 listed chemicals need to be reported under TRI. TRI program helps the government authorities to develop regulation and policies depending on the inventory of certain chemicals. The requirements under TRI are designed for collecting necessary information on toxic chemicals and subsequently designing pollution prevention methodology to reduce this exposure. Some of the industrial sectors covered under TRI are mining, utilities, manufacturing, hazardous waste etc. [22]

4 Review & Comparisons of Environmental regulations in EU & USA

In this chapter, the environmental regulations regarding emissions to air presented in the previous chapters are compared.

To protect the environment in developing countries often there is a requirement of international assistance from developed countries. In this context, the US and the EU are important players to set examples towards developing countries in the protection of the environment. Environmental policies in the EU and the USA are similar since both areas have similar economic status and similar challenges regarding the protection of environment. [36]

Figure 4-1 gives an overview of corresponding regulations in the EU and the USA. In the next section effort is made to understand the main differences between these environmental regulations.

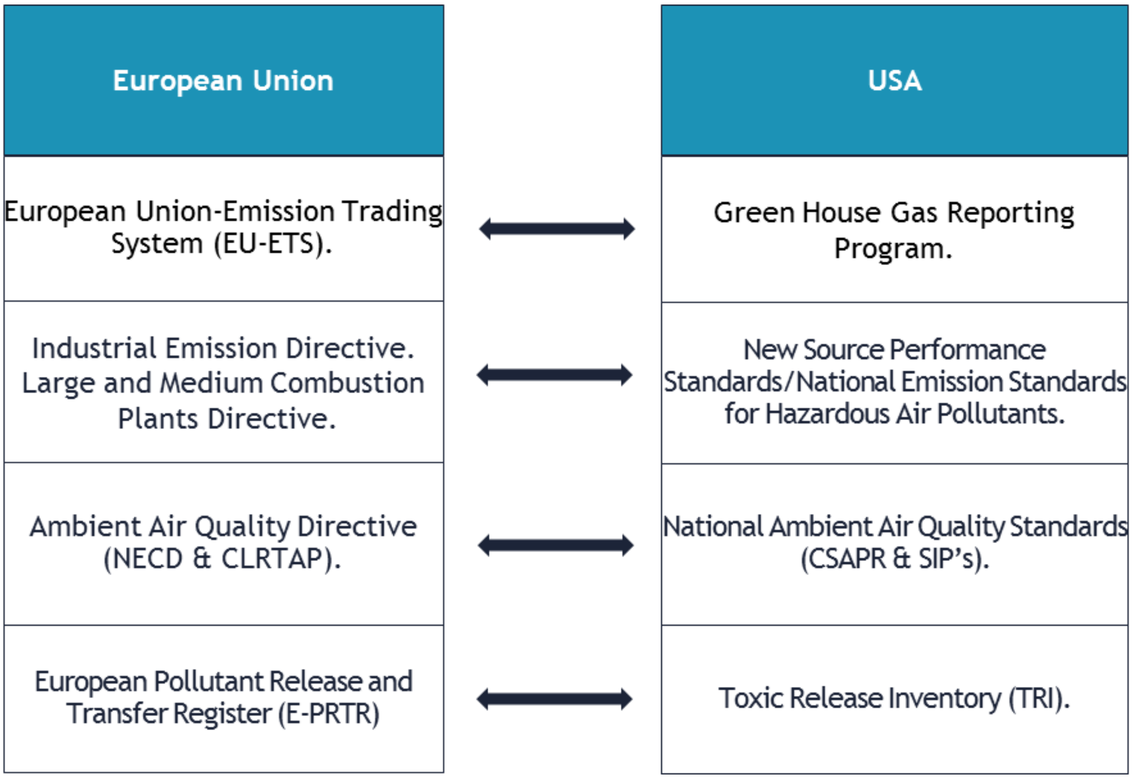

Figure 4-1: Overview of corresponding environmental regulations in the EU & the USA

In the US, the issue of air quality is a federal matter and measures taken by US-EPA need to be applied throughout the country. However, different states might have stricter standards compared to the US-EPA. In the EU, the implementation of air quality policies consists of a combination of regulations between the member states and the European Commission. This means that the EU sets standards and the member states determine how to meet these standards within their territory. In this process, the European Commission helps the member states by providing recommendations & guidelines in the form of directives to comply with these standards under specific time limit. However, the member states might have their own regulations which must be stricter than the one recommended by the European commission. [16]

4.1 EU-ETS & GHGRP

The EU-ETS and GHGRP are the regulations for monitoring & reporting of GHG in the European Union and the USA respectively. Table 4-1 below gives a comparison of essential elements in EU-ETS & GHGRP.

Table 4-1: Overview of essential elements in EU-ETS & GHGRP

Program Elements	**European Union**	**United States of America**
Program Name	European Union-Emissions Trading System (EU-ETS)	Greenhouse Gas Reporting Program (GHGRP)
Inception Date	2005	2009
Geographical Coverage	EU-28+Norway, Switzerland, Lichtenstein	Different industrial facilities in USA
Gases Reported	Mainly CO_2, PFC and N_2O from some industries	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3
Calculations Methods	According to commission regulation (EU) No. 601/2012 [43]: Subsection 2: Activity Data Subsection 3: Calculations Factor Subsection 4: Specific Calculation Factors	Detailed calculations method for specific industries available from 40 Code of Federal Regulations Part-98 [23]
Reporting Threshold	25,000 tons of CO_2e per year, combustion of fuel from installation having thermal input more than 20 MW	25,000 tons of CO_2e per year
Reduction requirements in line with Kyoto protocol	Yes (reduction of GHG required as per provision of Kyoto Protocol under UNFCCC)	No (only monitoring & reporting)

The crucial difference between the two schemes is that EU-ETS was implemented to meet the reduction requirement of GHG under Kyoto Protocol. But the USA didn't ratify Kyoto Protocol and there is no GHG reduction requirements program in the USA.

EU-ETS has also made commitments towards GHG reduction requirements under Paris Agreement under UNFCCC and it is gradually including other economic sectors such as aviation [11].

The USA showed interest in committing towards the Paris agreement under UNFCCC by framing the clean power plan [24]. However, the recent changes in political leadership in the country has pulled out of the Paris agreement [59]. Therefore, the EU is at present altogether ahead in terms of GHG monitoring & reduction requirements when compared with the USA.

4.2 Comparison between air quality standards

In EU, the AAQD sets standard air quality limit values (AQLV's) for specific pollutants and timetables to meet those emission limit values. The AQLV's are established for SO_2, NO_x, $PM_{2.5}$, PM_{10}, lead, CO, benzene, ozone, PAH, cadmium, nickel and arsenic see Table 4-2 [8]. For certain pollutants, the temporary margin of tolerance is set and reduced stepwise to attain limit values. All member states are required to monitor the air quality. The intensity of monitoring is dependent on the degree to which the zone's air quality is in compliance with the AQLVs. Areas where there is a high possibility of exceedance in limit values are monitored closely. Air quality management plans must be developed for these zones to bring pollutant levels below standards set by AAQD. [39]

The system in the US is similarly associated under NAAQS, which establishes standards for air quality limit values across the USA. Currently there are seven pollutants covered under NAAQS: CO, NO_x, SO_2, O_3, $PM_{2.5}$, PM_{10} and lead see Table 4-2 [23]. In the USA, different states are required to develop the state implementation plans (SIP's) to address the exceedance of limit values as per NAAQS. [39]

Both the EU and the USA set air quality limit values according to world health organization guidelines. From Table 4.2, it can be seen that, the air quality standards in the EU are slightly more stringent than in the USA. In addition, the EU has provision for monitoring of benzene, certain heavy metals & PAH. The USA monitors just seven pollutants compared to twelve pollutants in the EU. [39]

Table 4-2: Overview of limit values for different pollutants in the EU and the US. [8, 23]

Pollutant	Averaging Time	Emissions Limit Values	
		European union-Ambient Air Quality Standard (AAQD)	**USA-National Ambient Air Quality Standard (NAAQS)**
SO_2	1 hr. mean	350 µg/m^3 (not to be exceeded more than 24 times in a calendar year)	196.5 µg/m^3 (99th percentile of 1-hour daily maximum concentration averaged over 3 years)
	3 hr. mean	-------------	1300 µg/m^3 (not to be exceeded more than once per year)
	24 hr. mean	125 µg/m^3	-------------
$PM_{2.5}$	24 hr. mean	------------	35 µg/m^3 (98 percentile averaged over 3 years)
	Annual mean	25 µg/m^3	12 & 15 µg/m^3 (annual mean averaged over 3 years)
PM_{10}	24 hr. mean	50 µg/m^3 (not to be exceeded more than 35 times a calendar year)	150 µg/m^3 (not to be exceeded more than once per year on average over 3 years)
	Annual mean	40 µg/m^3	---------------
NO_2	1 hr. mean	200 µg/m^3 (not to be exceeded more than 18 times a calendar year)	188 µg/m^3 (98th percentile of 1 hour daily maximum concentration averaged over 3 years)
	Annual mean	40 µg/m^3	100 µg/m^3
CO	8 hour	10 mg/m^3	10 mg/m^3 (not to be exceeded more than once per year)
	1 hour	-------------	40 mg/m^3 (not to be exceeded more than once per year)
Lead (Pb)		0.5 µg/m^3 (annual average)	0.15 µg/m^3 (rolling 3-month average)
Ozone (O_3)	8 hr. mean	120 µg/m^3 (25 days averaged over 3 years)	140 µg/m^3 (Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years)
Benzene	Annual mean	5 µg/m^3	-----------
Arsenic (As)	Annual mean	6 ng/m^3	-----------
Cadmium (Cd)	Annual mean	5 ng/m^3	----------
Nickel (Ni)	Annual mean	20 ng/m^3	----------
PAH	Annual mean	1 ng/m^3 (expressed as concentration of benzopyrene)	----------

4.2.1Control strategies in the EU

The EU's NECD sets mandatory emission ceiling targets for PM, SO_2, NO_x, VOCs, NH_3 & CH_4. One of the important drivers for NECD is the data available from CLRTAP. The CLRTAP defines the critical set of pollutants and sets national emission reduction targets to ensure that limit values are not exceeded for these pollutants. NECD requires its member states to draw up programs to achieve their reduction targets for the six pollutants to comply with NECD. NECD covers emissions from all sources of the pollutants arising from anthropogenic activities. [39]

The European Commission gives the member states considerable authority to adopt their own air quality management plans. The commission provides guidance and recommendation in the form of directives to assist member states in meeting targets under NECD. Example of these directives are large & medium combustion plants directive. These directives require large and medium combustion power plants to have stringent emission limit values for certain pollutants (SO_2, NO_x etc) to meet ambient air quality standards. Examples also include industrial emissions directive under which EU's wide exercise is carried out to determine best available technology (BAT) for limiting pollutant emissions from different industrial facilities. [39]

The result of this exercise is the continuous development of the BREF documents for different industries. These BREF documents guides authorities in the member states in the setup of permit conditions for emission limit values of different pollutants from specific industries. [39]

IED requires the member states to consider AQLV's provided by AAQD, to set more stringent permit conditions than those achievable using BAT techniques to meet targets under AAQD. [39]

4.2.2 Control strategies in the USA

In the US system, the US-EPA prescribes reduction measures necessary to meet the air quality standards set under NAAQS. The US-EPA proposes standards and regulations to meet these targets under NAAQS. Emissions to air from the industries are controlled with the help of NSPS and NESHAP. These standards are similar to the IED in Europe. NSPS is applicable to new, modified and reconstructed facilities in specific source categories such as cement, glass manufacturing, oil refinery etc. NSPS sets standards for specific pollutants from industrial facilities, for example: standards for SO_2, NO_x and PM from steam generation units, as well as standards for SO_2, PM, VOC etc. from metal smelters, oil refinery etc. [22, 39]

Under NESHAP, 187 different hazardous air pollutants are required to be controlled in releasing to the environment by using maximum achievable control technology. [22, 39]

4.2.3 Summary

It is difficult to identify the exact differences between the NSPS, NESHAP in the USA and the IED in the Europe. A reason for not being able to draw the exact differentiation is that these standards are applicable to a wide range of industries and cover a substantial amount of pollutants. However, some important conclusions which indirectly affect the implementation of these standards are summarized below. [39]

- The EU has a concrete research process to produce BREF documents (explained in 2.5.2) which helps to set up permit conditions for operation of industries under IED. However, the industries in the USA don't have such documents for various industries but rather have different guidelines from US-EPA under NSPS and NESHAP to set up conditions in operating permit. [39]
- In the EU, there is a lack of strict compliance enforcement mechanisms to comply with the guidelines under different regulations and directives. If some member states are not able to attain AQLV's or required reduction, the measures for bringing pressure for compliance on the member state is limited. In the USA, there exist several concrete measures to bind different states and encourage compliance with AQLV's. [39]
- It is widely believed that since 1990, the EU has overtaken the USA as a leader in the most demanding environmental regulations. However, there is lack of robust studies on comparisons between environmental standards affecting industries in the EU and the USA. [19]

  A study was done to address this issue by comparing emissions of benzene from oil refineries in the EU and the USA. Contrary to the expectation, it was found that the benzene emissions from refineries in the EU are three times higher than the refineries in the USA. [19]

  Also, the study concluded that there exist widespread variations and lack of harmonization in the emissions standard achieved by different member state in the EU despite common guidelines from the EU. [19]

Therefore, before making final conclusions on the performance of industries according to the environmental standards in the EU and the USA, it is important to gather the emission data and compare the emission of specific pollutant from similar industry to have more concrete conclusions.

4.3 Comparison between Pollutant release and transfer registers (PRTR's)

PRTR is a generic term used to describe a publicly available database that contains information on the amount of different toxic chemicals released from various industrial facilities to the environment and amounts of waste recycled burned or recovered. The reporting by the industrial facilities to PRTR is usually done annually and the process is handled by countries national environmental authority. [37]

The primary aim of the PRTRs is to increase the public knowledge about the release of toxic chemicals to the surroundings. PRTR data enables the government to monitor progress on effectiveness of different environmental policy initiatives. The analysis of data can help in identifying the requirements of new measures that need to be taken to achieve reduction of certain pollutants by promoting cleaner production processes. Also, exact comparison between two different PRTR's is difficult due to many industry sectors and pollutants involved. However, the TRI from the USA is the most comprehensive register covering substantial number of pollutants when compared with the E-PRTR. In the next section, a brief comparison is made between PRTRs from USA and Europe. [37]

4.3.1TRI

The PRTR system in the US is known as the Toxic Release Inventory (TRI) and is the oldest and most comprehensive PRTR system in the world. TRI covers collected information on pollutants released to air, water, land, underground injection, and transfer offsite for treatment, disposal recycling, and energy recovery. More than 600 distinct toxic chemicals are covered under TRI. The industrial sectors which must report under TRI include a broad range of facilities such as manufacturing, mining, electricity generation etc. There exist different thresholds for reporting based on number of employees and amount of pollutants released. The EPA receives approximately 80,000 reports from around 25,000 facilities every year. [38]

4.3.2 E-PRTR

The European Pollutant Emission Register (EPER) was replaced by E-PRTR in 2006. E-PRTR now covers 27 member states: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom. Additionally, it covers Iceland, Liechtenstein, Norway, Serbia and Switzerland. [37]

Different toxic chemicals covered by E-PRTR are 91, much less compared to the number in TRI. Around 28,510 facilities submitted around 40,000 reports under E-PRTR in 2009. These facilities are similar to the ones covered under TRI. However, the threshold for the amount of pollutant under E-PRTR could be different compared to threshold under TRI. [37]

It is difficult to compare the thresholds for each pollutant because of substantial number of pollutants involved. Different countries included in the system follow the framework of E-PRTR but have some major differences. This results in difficulty to make direct comparisons. For example, in Liechtenstein, reporting of industrial releases to air or water is not required and in Serbia, reporting of waste transfers is not required. Also, only 19 of the total countries under E-PRTR reports on accidental releases. Therefore, it becomes difficult to understand and compare actual environmental impact from each specific country and industry. [37]

5 Specific case-Aluminum Industry in Europe

To understand how different environmental regulations studied in previous chapters affect industrial facilities, the aluminum industry in Europe was selected. The perspective adopted while studying a case of aluminum industry was to understand major pollutants emitted from the industry and methodology prescribed for quantification of this emissions. Aluminum is a material with substantial number of applications in transportation, construction, packaging, household, mechanical and agricultural sectors.

Aluminum industry is the largest of the non-ferrous metal industries. In 2012, there were 28 primary aluminum production plants in European Economic Area (EEA): Rio Tinto Alcan (UK, Iceland, France), Alcoa Europe (Spain, Italy, Iceland & Norway), Hydro Aluminum (Norway & Germany), Trimet (Germany), Alro (Romania), Slovalco (Slovakia), Talum (Slovenia), Mytilineos (Greece), Rusal (Sweden) and Century (Iceland). Recycling of aluminum is carried out by more than 130 industries. [40]

The aluminum is produced by two main process (Figure 5-1).

1. Primary aluminum: Main raw material is bauxite ore which is converted into alumina. Alumina is then converted into aluminum metal by electrolysis process.
2. Secondary aluminum: The secondary aluminum industry recycles old scraps which is recovered from various products at the end of their useful life. [40]

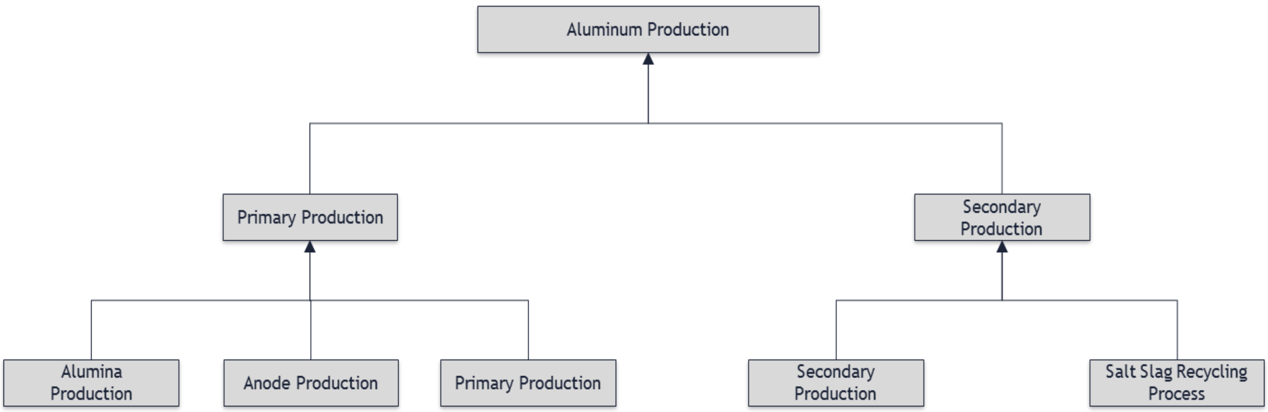

Figure 5-1: Process used for aluminum production and recycling [40]

Aluminum industry is one of the largest contributors to environmental pollution in Europe. Therefore, it is interesting to know what measures the European Commission is taking in forms of environmental regulation to curb pollution from aluminum industry. The idea was to understand methodologies for monitoring & quantification of emissions, best available technology and corresponding emission limit values of different pollutants as prescribed under different regulations. Main focus was on the emissions to air & water. Different processes involved in the primary & secondary aluminum production is shown are Figure 5-1. Table 5-1 highlights main areas studied under each different regulation.

Table 5-1: Areas studied under different regulations

Environmental regulations	**Areas Covered**
Industrial Emissions Directive (IED)	Emission limit values for different pollutants from specific process based on best available technology, monitoring frequency and testing standard.
EU-Emissions Trading System (EU-ETS)	Calculation procedure for greenhouse gases from process and combustion emissions from aluminum industry.
European Pollutant Release & Transfer Register (E-PRTR)	Thresholds for the release of different pollutants for reporting requirements.
Fluorine Gas Regulation	Thresholds for the release of fluorine gas for reporting.

5.1 General monitoring approaches

In this section, general principles that are applied to monitor different pollutants are studied. It is important to implement standard monitoring practices for whole industrial facilities so that results from the measurements are representative, mutually comparable and clearly reflect the relevant operating state of the plant. The measurement of the emissions is done to determine the pollutant in off gases & waste water for reporting, controlling the process or used to predict environmental impact. Different methods and instruments that are used for sampling must be in accordance with the relevant European, National and International standards. [48]

5.1.1 Types of emissions

The pollutant emission from operating the industrial facilities can arise from many different sources. The total amount of emissions from the facility are not only arising from the pipes and stacks but also due to leakage of equipments, emissions during start-up and shut down of the industrial operations etc. These emissions are generally termed as diffuse, fugitive and exceptional emissions which are defined below: [48]

- **Channeled emissions**: Emission of pollutants into the atmosphere through any type of pipes & stacks from industrial operations. These emissions can be easily quantified. [48]
- **Fugitive emissions**: The emission of pollutants because of tightness in the piece of the equipment designed to contain an enclosed fluid. Reason for this emission could be because of the pressure difference or due to leak. Examples include leakage from flange, pump, storage facilities and different process equipments. [48]
- **Diffuse emissions**: Diffuse emissions are the emissions arising from a direct contact of volatile or light dusty substances with the environment under a normal operating condition. The examples include emissions occurring due to transfer of the material between containers, maintenance activities etc. [48]
- **Exceptional emissions**: The emissions which arise when there is deviation of the operation from normal operating conditions. This includes start-up and shutdowns of the facility, by-passes of the treatment unit's due to malfunctioning of the installations etc. Currently, there are no generic rules to identify, handle and report exceptional emissions. The operating permit may include the requirement to monitor emissions in process upset conditions in both foreseeable and unforeseeable conditions. [48]

Generally, it is not difficult to measure channeled emissions. However, it is difficult to quantify diffuse and fugitive emissions from industrial facilities. The fugitive emissions are a subset of diffuse emissions and together they are called diffuse & fugitive emissions (DFE). DFE are important source of emissions in the non-ferrous metal industry. DFE can potentially cause damage to health and environment. It is recommended to include monitoring provisions where it is appropriate and reasonable to monitor DFE in the operating permit. The quantification of DFE is labor and cost intensive. Many distinct types of measurement techniques exist for the quantification but the level of confidence in the results is low. It is possible that the assessment of total amount of DFE could be more cost intensive than the channeled emissions. [48]

However, these techniques are not in the scope of this study. In this study, the focus is on measurement of channeled emissions and their prevention. But it is important to add all the emissions explained above to understand complete environmental impact of the facility. [48]

5.1.2 Monitoring approaches for quantification of emissions

There exist several different approaches to monitor emissions of pollutants from industrial facilities. The choices of selection among these approaches depends on a range of factors such as simplicity, rapidity, cost, required accuracy etc. The operator of the facility can choose monitoring approach but needs the approval of competent authority. The different approaches available for selection by the operators are explained below: [48]

5.1.2.1 Direct Measurements

The monitoring technique of direct measurement can be divided into two types:

- **Continuous measurements**: Continuous monitoring of emissions involves installation of automated measuring instrument permanently on site. For emission sources which could have significant environmental impact, authorities generally specify the use of the continuous measurement system. The methods are available to continuously measure dust, SO_2, NO_x, CO, gaseous fluorine & chlorine, total organic carbon, mercury etc. [48]
- **Periodic measurements**: The periodic measurement is done at specified time intervals using manual or automated methods. Different samples are taken to a laboratory for analysis of the pollutant concentration. [48]

Both continuous and periodic measurements must be done using the recommended monitoring standard mentioned in the BREF documents. The first choice of monitoring standards are generally European standards. In case, European standards are not available for specific pollutants, international or country specific standards can be applied with approval from the competent authority. Annex-II in the reference document for monitoring contains a list of European standards for the measurement of pollutant emissions into air, water, sludge and residues. Table 5-2 shows the description for monitoring frequency which needs to be specified for different pollutants in the operating permit. [48]

Table 5-2: Description of averaging period for measurement of emissions [48]

Emissions	**Monitoring Frequency**	**Description**
Emissions to air	Daily average	Average over a period of 24 hours on valid half-hourly or hourly averages from continuous measurements.
	Average over a sampling period	Average of three consecutive measurements of at least 30 minutes each, unless otherwise stated.
Emissions to water	Daily average	Average over a sampling period of 24 hours taken as a flow or time proportional composite sample at sufficient flow stability is demonstrated.

5.1.2.2 Measurement using surrogate parameters

The surrogate parameters are measurable or calculable parameters which can be directly or indirectly related to direct measurements of the pollutants. Therefore, the surrogate parameters can be monitored and used instead of direct measurements of pollutants. The relationship between surrogate parameters and actual parameters of interest should be clearly identified and documented. Example of surrogate parameter includes measuring of slope coefficient or over voltage coefficient for measurement of PFC emissions in aluminum production which is explained in more detail in subsequent chapter. [48]

5.1.2.3 Mass balances

The principle of mass balance can be used for estimating the amount of pollutants emitted. The mass balance procedure is based on the principle that the total amount of material flow into the system will be equal to the accumulations, output, generation or destruction of the substance of interest, and the difference is accounted for release to the environment. The example of mass balance approach is used to calculate CO_2 emissions from different processes in aluminum smelting. [48]

5.1.2.4 Calculations

The equation or models can be used for calculation of emissions based on physical or chemical properties of the substances combined with mathematical relationship. Use of the models can give reasonably good accuracy provided that the model is based on valid assumptions and if the input data are reliable. Emission of SO_2 depending on amount of sulphur contained in the fuel can be an example of calculating emission by this method: [48]

$$E = Q*C/100*(MW/EW)*T$$

Where E = annual load of the chemical species emitted (kg/yr)

Q = fuel mass flow rate (kg/hr)

C = concentration of the elemental pollutant in the fuel (wt%)

MW= molecular weight of the chemical species emitted (kg/kg mole)

EW = elemental weight of the pollutant in fuel (kg/kg fuel)

T = operating hours (h/yr)

5.1.2.5 Emissions factor

The emissions factor is the value which can be multiplied with the amount of fuel combusted or by the throughput data from the facility to calculate emissions of pollutants from the facility. Emission factors can be adopted from several databases such as IPCC, IEA, US-EPA etc. The example using emission factor is the calculation of CO_2 emission from the combustion of fuel. [48]

Appendix A contains a report 'Emission calculations methodology used in EU-ETS and GHGRP' where emission factors are explained in more detail. The report was written as a part of this thesis.

5.1.2.6 Reference conditions

The emission limit values given in the BREF documents refer to standard conditions at a temperature of 273.15°K and pressure of 101.3 kPa. Therefore, the operator is generally required to monitor/convert measured values to the normalized value. All different off gas parameters should be determined to convert the emission concentration obtained to the standard conditions of measured oxygen content, dry gas, pressure and temperature. The parameters needed to be determined to convert the measured emissions at standard conditions are off gas temperature and pressure in off gas conduct. The measured emissions are expressed at standard percentage of oxygen concentration. [48]

The equation used is $E_B = [(21-O_B)/(21-O_M)] *E_M$

Where E_B = emission expressed at reference oxygen content

O_B = referenced oxygen content (expressed in %)

O_M = measured oxygen content (expressed in %)

E_M = measured emission.

5.2 Industrial Emissions Directive requirement for aluminum production

In this section, different requirements for complying with IED for aluminum production is discussed. According to article 13(3) of IED, best available technology reference (BREF) documents must be built for different industrial facilities. BREF documents are produced by exchange of information between the European Commission, member states, industries concerned and non-governmental organizations promoting environmental protection (Figure 5-2). Most important points focused during building of BREF documents are:

- Identification of key environmental issues for specific industrial sector.
- Identification of the best environmental performance level based on available data in the European union and worldwide.
- Selection of the best available technique, their associated emission limit value, monitoring methodology for different pollutants. [13]

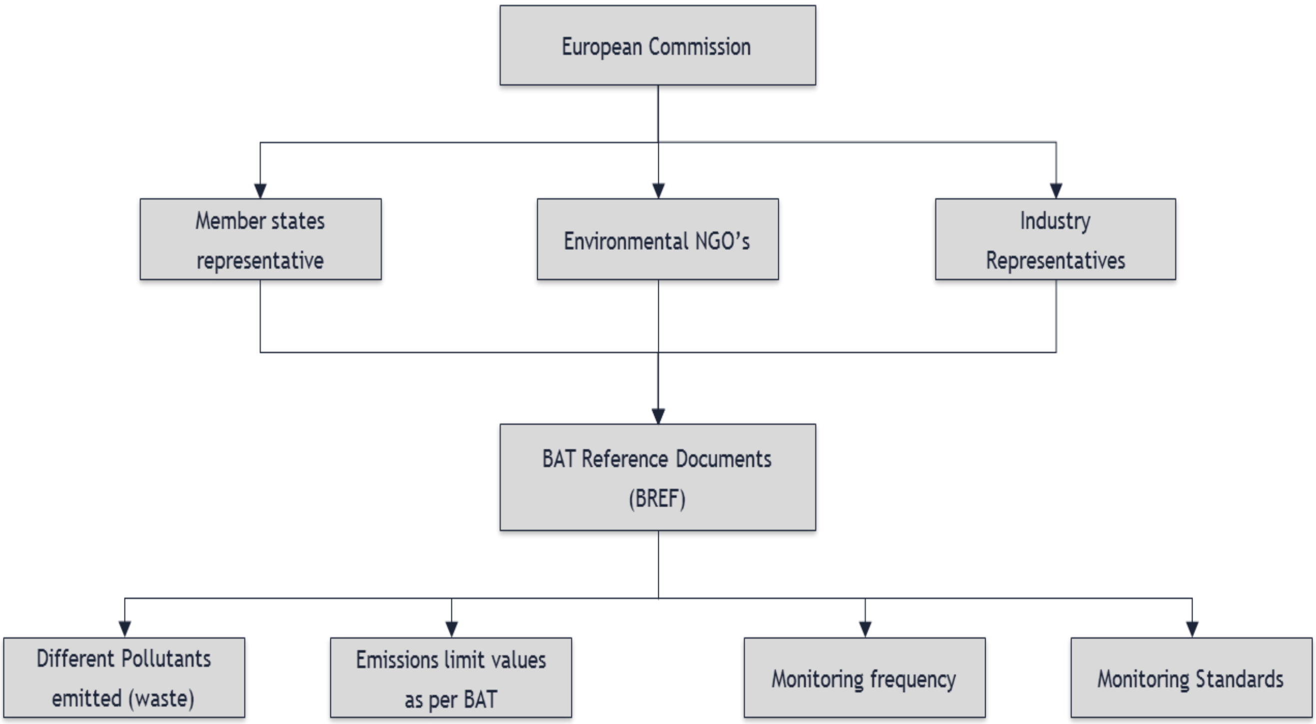

Figure 5-2: Overview of BREF building process [13, 40]

The "BAT conclusion" is a document containing a part of the BREF document laying down conclusions on the best available techniques and corresponding emission limit values for different pollutants from various processes. According to the article 14(3) of the IED, BAT conclusion shall be used as a reference for setting the permit conditions for the operation of installations covered under IED. Similar BREF documents along with BAT conclusions are available for different industry sectors as a part of exchange of information carried out under IED article 13. [10, 13]

In the next section, measures required under IED for different sub processes in primary & secondary aluminum production are discussed. A brief overview of the process is explained and pollutants for which monitoring is required under the IED are listed along with emission limit values (ELV), monitoring frequency & monitoring standard (CEN, EN, ISO).

Aluminum production takes place from two main processes: primary aluminum (from bauxite ore) and secondary aluminum (recycling of scraps). Figure 5-1 must be referred to get an overview of most important sub process under each of two methods for producing aluminum.

5.2.1 Alumina production

A brief overview of the alumina production process is shown in Figure 5-3. Alumina production takes place as per the Bayer's process. In this process, caustic soda is mixed with the bauxite and then heated up to the temperature of about 280°C. The alumina compound of the bauxite gets dissolved at these elevated temperatures in a digester. All non-dissolved material (red mud) is then removed from the process by means of thickeners and/or filters. The saturated liquid is cooled down in presence of the fine particles of aluminum hydrate. The crystalized aluminum hydrate is then removed from the circuit by filters. In the last step aluminum hydroxide is then converted into alumina by calcination. Finally, the alumina produced in the Bayer's process is smelted by an electrolysis process to produce primary aluminum. [40]

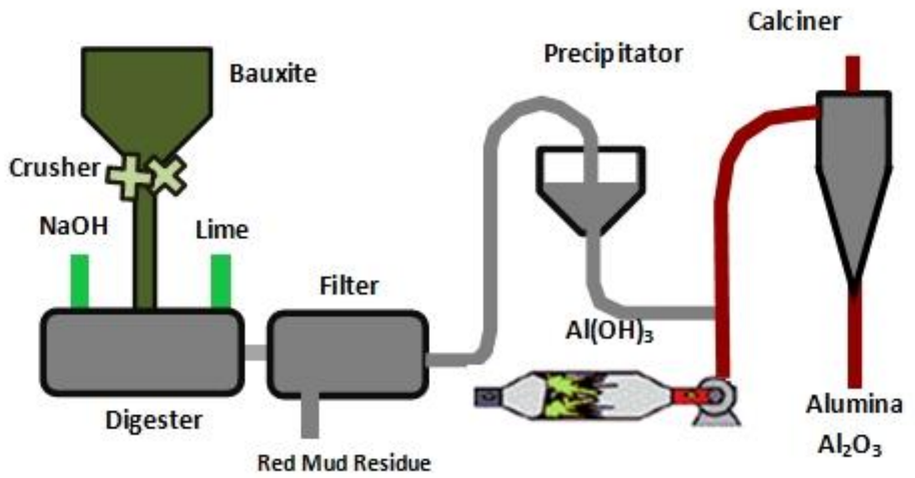

Figure 5-3: Overview of alumina production (Bayer's Process) [56]

The key environmental pollutants generated from the alumina production process include dust, SO_2, CO_2 and NO_x emissions. All different pollutants are generally emitted from the burning of fossil fuels during the digestion and calcination process. The major by-product of Bayer's process is red mud. Red mud could contain tiny amounts of caustic (sodium hydroxide) which causes elevated pH when disposed to a nearby site. Some refineries use high pressure filtration as a last step for red mud treatment. The output from this operation is solid bauxite residue which could be then used in cement production, ceramic industry, construction of roads etc. As Bayer's process is very simple, there is only one condition prescribed by IED for dust emissions from calcination (Table 5-3). The ELV is not mentioned in IED for dust emission from this process. [40]

Table 5-3: IED requirement for Alumina Production as per BREF document [40]

Pollutant	Process Involved	Abatement Technique	Associated Emissions Limit (AEL)	Monitoring frequency	Monitoring Standard
Dust	Alumina Calcination	BAT-59 (Bag Filter)	--------------	As a daily average or average over a sampling period	EN 13284-1/2

5.2.2 Anode Production

Anodes are carbon blocks used in the electrolysis process in primary aluminum production. A brief overview of anode production process is shown in Figure 5-4. Anode production can take place on the same site where primary aluminum is produced or in stand-alone anode production plants. Main raw materials used for production of anodes are petroleum coke, used anode butts from electrolysis cell and coal tar pitch. Petroleum coke and anode butts are crushed and sieved together. The liquid tar pitch is then mixed with crushed petroleum coke and anode butts which act as a binder. The complete mixture is then weighed according to the required dimension and baked in a baking furnace to produce anode blocks. Anode blocks, when ready from baking furnace are cooled down and stored for the use in the production of primary aluminum in the electrolysis process. [40]

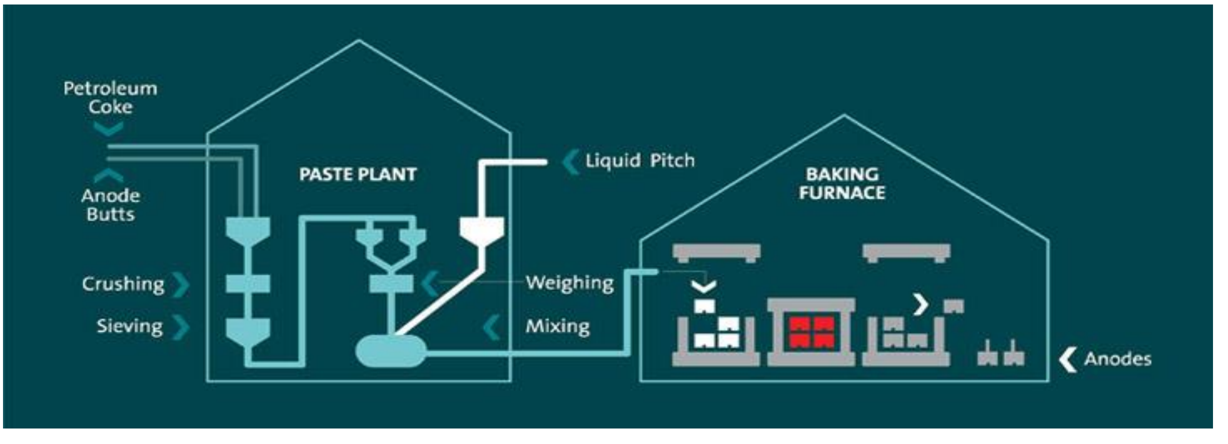

Figure 5-4: Overview of anode production process [57]

Main pollutants emitted from anode production are polycyclic aromatic hydrocarbon (PAHs), volatile organic carbon (VOC), SO_2, dust, fluorides, NO_x, CO_2. Emissions of VOC occur during delivery, transfer, mixing and baking of the anode paste. Dust production occurs during all stages of the process such as storage, transfer, mixing and baking. PAH emission takes place due to combustion of coal tar pitch in the anode. The raw material used for anode production contains sulphur and the fuel used for baking can also contain sulphur which results in small emissions of sulphur dioxide. Fluorides emissions occur when used anode butts from electrolysis process are recycled and mixed with coke in production of fresh anodes. The combustion of a gas or fuel oil for baking of anode results into CO_2, CO, SO_2, NO_x emissions. All other emissions could be diffuse emissions of different pollutants due to age of plant and technology used. Table 5-4 shows the requirements under IED as per BREF document for different processes involved in anode production. Different areas covered in Table 5-4 are pollutants emitted from specific processes, BAT number for use of relevant best available technology, associated emission limit values, monitoring frequencies and monitoring standards required for emission monitoring.

Table 5-4: IED requirements for Anode Production as per BREF documents [40]

Pollutant	Process Involved	Abatement Technique	Associated Emissions Limit (AEL)	Monitoring frequency	Monitoring Standard
Dust	Paste plant-removing coke dust from operation	BAT-61	2-5 mg/Nm^3	As a daily average or average over a sampling period (Continuous/Periodic)	EN 13284-1/2
Dust	Paste plant-hot pitch storage, paste mixing	BAT-62	2-5 mg/Nm^3	As a daily average or average over a sampling period (Continuous/Periodic)	EN 13284-1/2
Dust	Baking plant-integrated with aluminium smelter	BAT-63	2-5 mg/Nm^3	As a daily average or average over a sampling period (Continuous/Periodic)	EN 13284-1/2
Dust	Baking plant-standalone anode production	BAT-64	2-5 mg/Nm^3	As a daily average (Continuous/Periodic)	EN 13284-1/2
PAH	Paste plant-hot pitch storage, paste mixing	BAT-62	0.001-0.01 mg/Nm^3	As an average over a sampling period (at least once per year)	ISO 11338-1/2
PAH	Baking plant-anode production	BAT-63	0.001-0.01 mg/Nm^3	As an average over a sampling period (at least once per year)	ISO 11338-1/2
PAH	Baking plant-standalone anode production	BAT-64	0.001-0.01 mg/Nm^3	As an average over a sampling period (at least once per year)	ISO 11338-1/2
SO_2	Baking plant-integrated with aluminium smelter	BAT-65	--------------------------	Continuous/Periodic	EN 14791
HF	Baking plant-integrated with aluminium smelter	BAT-63	0.3-0.5 mg/Nm^3	As a daily average or average over a sampling period (Continuous/Periodic)	ISO 15713
HF	Baking plant-standalone anode production	BAT-64	3 mg/Nm^3	As a daily average (Continuous/Periodic)	ISO 15713
Total F	Baking plant-integrated with aluminium smelter	BAT-63	0.8 mg/Nm^3	As an average over a sampling period (at least once per year)	------------

5.2.3 Primary Aluminum Production

Primary aluminum is produced by the Hall-Heroult process of electrolytic reduction of alumina. There are two basic technologies available for aluminum production. [40]

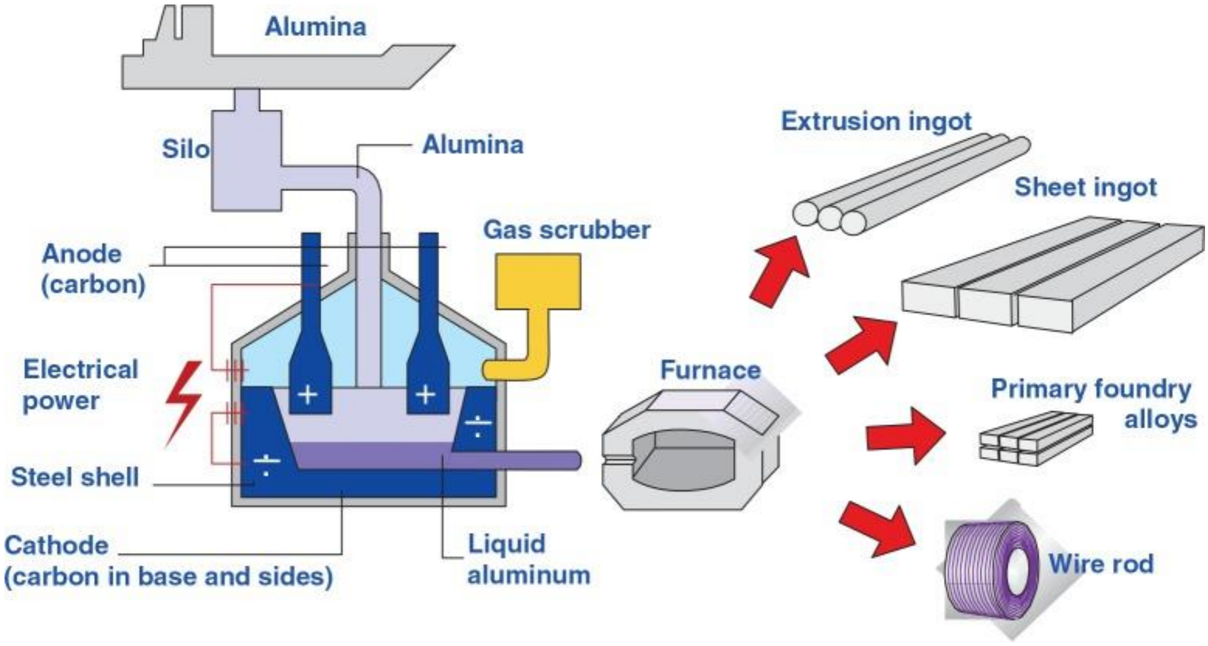

Figure 5-5: Overview of Primary Aluminum Production Process [58]

1. **Prebake technology**: In the prebake technology, the already baked anode blocks are used. The prebake anodes must be removed when they have reacted down to 1/3rd or 1/4th of the original size. All remaining anode material is termed as anode butt which can be recycled in fresh anode production process. [40]
2. **Søderberg technology**: In the Søderberg technology, a continuous anode which is made *in-situ* from a paste of calcinated petroleum coke and coal tar pitch is used. The paste descends through the anode shell and is baked by the heat arising from the molten bath and electric current passing through the anode. Søderberg technology provides a process that doesn't require to change the anodes and separate anode production plants. [40]

The anodes are held in electrolytic cell as shown in Figure 5-5. Alumina is dissolved in an electrolyte mainly containing cryolite and electric current is passed between the carbon anode and the cell base cathode. Electric current reduces alumina to form molten aluminum around 900°C. Oxygen formed during reduction of alumina reacts with carbon in the anode to form CO_2. All molten aluminum is collected at cathode and could then be processed further for casting into different shapes. [40]

The main air pollutants from primary aluminum production are from three distinct sources [40]:

1. Process gases from electrolytic cells
2. Pot room ventilation
3. Degassing and casting

The emissions from electrolytic cells and pot room ventilation are [40]:

- CO_2 and CO from anode consumption
- Perfluoro carbon (PFC) because of anode effects.
- Dust mainly from alumina and fluorinated product handling.
- Fluorides from the surface of the cell.
- SO_2 and other sulphur compounds from anode consumption.
- Tars and PAH in case of use of Søderberg technology.
- Metal compounds
- Oxides of Nitrogen (NO_x)

The potential emissions from degassing and casting processes are dust, organics, chlorides & fluorides associated with the use of fluxing agents, SO_2 depending type of fuel used and NO_x depending on the type of burner used. Table 5-5 shows the emissions limit requirements under IED for primary aluminum production. [40]

Table 5-5: IED requirements for Primary Production as per BREF documents [40]

Pollutant	Process Involved	Abatement Technique	Associated Emissions Limit (AEL)	Monitoring frequency	Monitoring Standard
Diffuse emissions	Electrolytic cells in Søderberg technology	BAT-68	--------------	---------------------------	Several
Diffuse emissions	Electrolytic cells in prebaked anodes process	BAT 69	---------------	---------------------------	Several
Dust	Storage, handling and transport of raw material	BAT-70	5-10 mg/Nm^3	As an average over a sampling period (Continuous/Periodic)	EN 13284-1/2
Dust	Emissions from electrolytic cell	BAT-71	2-5 mg/Nm^3	As a daily average or average over a sampling period (Continuous/Periodic)	EN 13284-1/2
Dust	Emissions from the electrolysis house	BAT-72	1.2 kg/T Al (existing plants) 0.6 kg/T Al (new plants)	As a mass pollutant/mass of liquid aluminium in a year (Continuous/Periodic)	EN 13284-1/2
Dust & Metal	Emissions from melting and molten metal treatment and casting	BAT-73	2-25 mg/Nm^3 (Dust)	As an average of the samples obtained over a year (Periodic)	EN 13284-1/2
HF	Emissions from electrolytic cell	BAT-71	1 mg/Nm^3	As a daily average or average over a sampling period (Continuous/Periodic)	ISO 15713
Total F	Emissions from electrolytic cell	BAT-71	1.5 mg/Nm^3	As an average over a sampling period (at least once per year)	-----------
Total F	Emissions from the electrolysis house	BAT-72	0.6 kg/T Al (existing) 0.35 kg/T Al (new)	As a mass pollutant/mass of liquid aluminium in a year (at least once per year)	------------
SO_2	Emissions from electrolytic cell	BAT-74	2.5-15 kg/T	As a mass pollutant/mass of liquid aluminium in a year	EN 14791
PFC	Emissions to air from primary production	BAT-75	-------------	-------------------	------------
PAH & CO	Primary production using Søderberg technology	BAT-76	--------------	-------------------	------------

5.2.4 Secondary aluminum production

For the secondary production of aluminum, material containing aluminum is melted and refined at the end of their useful life. The scraps are graded on different criteria's such as source, impurities, metal yield etc. and segregated based on chemical composition. All metal scraps are de-coated or de-oiled prior to melting in order to improve the melting rate and to reduce potential pollutant emissions. [40]

Many different varieties of furnaces are used to melt these metal scraps depending on raw material composition, process conditions and required product quality. Molten metal is subsequently refined either in the holding furnace or in the reactor to remove gases and other metals. The potential emissions to air from pretreatment and melting of the scraps are dust, PM_5 & PM_{10}, metal compounds, VOC, polychlorinated dibenzodioxins (PCDD), CO, NO_x, SO_2, Cl_2 (chlorine), HCl (Hydrogen chloride) and HF (Hydrogen fluoride). Table 5-6 lays down the requirements under IED for secondary aluminum production. [40]

Table 5-6: IED requirement for secondary aluminum production as per BREF documents [40]

Pollutant	**Process Involved**	**Abatement Technique**	**Associated Emissions Limit (AEL)**	**Monitoring frequency**	**Monitoring Standard**
Oil and organic compound	To remove oil and organic compounds from the swarf	BAT-81	-------------	---------------------	-----------
Diffuse emissions	Pre-treatment of the scraps	BAT-82	-------------	---------------------	-----------
	Charging or discharging of melting furnace	BAT-83			
	Skimming & dross treatment.	BAT-84			
Dust	Storage, handling and transport in secondary aluminium production	BAT-85	5 mg/Nm^3	As an average over a sampling period (Periodic)	EN 13284-1
Dust & metal	Crushing, milling and dry separation of non-metallic constituent's other than aluminium	BAT-86	5 mg/Nm^3	As an average over a sampling period (Periodic)	EN 13284-1
Dust & metal	Swarf drying process	BAT-87	5 mg/Nm^3	As an average over a sampling period (Periodic)	EN 13284-1
Dust & metal	Charging, melting, tapping and molten treatment	BAT-88	2-5 mg/Nm^3	As a daily average or average over a sampling period (Continuous/Periodic)	EN 13284-1/2
Dust & metal	Remelting in secondary aluminium production	BAT-89	2-5 mg/Nm^3	As an average over a sampling period (Periodic)	EN 13284-1
Organic compound	Thermal treatment of contaminated secondary raw material	BAT-90	TVOC 10-30 mg/Nm^3	As a daily average or as an average over a sampling period (Continuous/Periodic)	EN 12619
PCDD/F			PCDD/F 0.1 ng I-TEQ/Nm^3	As an average over a sampling period of at least 6 hours (Periodic)	EN 1948 (part 1, 2 & 3)
HCl	Thermal treatment of contaminated secondary raw material, melting furnace, remelting and molten metal treatment.	BAT-91	5-10 mg/Nm^3	As a daily average or average over a sampling period (Continuous/Periodic)	EN 1911
Cl_2			1 mg/Nm^3	As an average over a sampling period (Periodic)	No EN or ISO Standard
HF			1 mg/Nm^3	As an average over a sampling period (Periodic)	ISO 15713

5.2.5 Salt slag recycling

In the secondary aluminum production, the scrap is melted in rotary or reverbatory furnaces. The melting of scraps takes place below the bath of molten salt. The salt is typically a mixture of sodium, calcium and potassium chloride containing a low level of fluorides. Salt slag is used to facilitate the refining process and it helps in reducing oxidation losses and promotes removal of other impurities. The salt slag contains substantial amounts of aluminum oxides and impurities separated from the molten metal. The metallic aluminum recovered, constitutes around 4-10% of the salt slag. This salt slag can be completely or partially recycled to recover the valuable components. Different emissions to air during the recycling of salt slag are dust & metal from crushing of the salt slag, as well as ammonia, phosphine and hydrogen sulphide gas during wet milling and leaching of the salt slag. As of 2014, one million tons of salt slag is generated and treated every year in EU. Table 5-7 show requirements for emissions limits under IED for the salt slag recycling process. [40]

Table 5-7: IED requirements for salt slag recycling process as per BREF documents [40]

Pollutant	Process Involved	Abatement Technique	Associated Emissions Limit (AEL)	Monitoring frequency	Monitoring Standard
Diffuse emissions	Salt slag recycling process	BAT-94	--------------	--------------------------	----------
Dust & Metal	Crushing and dry milling associated with salt slag recycling process	BAT-95	2-5 mg/Nm^3	As a daily average or as an average over the sampling period (Continuous/Periodic)	EN 13284-1/2
NH_3	Wet milling and leaching from salt slag recovery	BAT-96	10 mg/Nm^3	As an average over a sampling period (Periodic)	No EN Standard
PH_3			0.5 mg/Nm^3	As an average over a sampling period (Periodic)	No EN Standard
H_2S			2 mg/Nm^3	As an average over a sampling period (Periodic)	No EN Standard

5.2.6 BAT Description for Aluminum Production

In this section, best available technology as per BREF documents for preventing the emissions of different pollutants is summarized. Different techniques listed below are according to the main pollutant they are aimed to abate, which does not prevent them to have a positive impact on the reduction of other pollutants. All different BAT numbers must be referred above in Table 5-3 to 5-7 where the requirement of emission limit values for different pollutants has been summarized according to the BREF documents.

5.2.6.1 Dust emissions

The best available technique for preventing dust emissions from the aluminum production process is generally the use of bag filter (Table 5-8). Bag filter is favorable for most operating conditions and has low investment cost. Different techniques available for the prevention of dust emissions are electrostatic precipitator, cyclone separator, settling chamber etc. [40]

Table 5-8: BAT for dust emissions [40]

BAT Number	Technology	Description
59, 61, 62, 63, 64, 70, 71, 73, 85, 86, 87, 88, 89, 95	Bag Filter or Fabric Filter	The Bag filters are constructed from porous woven or felted fabric through which gases flow and particles are trapped and removed by use of a sieve. The Fabric filter requires a fabric material selection suited according to the operating conditions.

5.2.6.2 NO_x emissions

The NO_x emissions are generally from the burning of fuel in the furnace. Reduction in NO_x emissions can be achieved by different techniques described in Table 5-9. Main approach behind the techniques is to lower down the flame temperature in a burner by adjusting process conditions. [40]

Table 5-9: BAT for NOx emissions [40]

BAT Number	Technology	Description
11	Low-NO_x burners	Formation of NO_x can be reduced by controlling peak flame temperature, availability of oxygen and residence time in the combustion zone through the staged addition of combustion air and fuel. The technique could also include partial flue-gas circulation.
	Oxy-fuel burner	The technique involves replacing the combustion air with oxygen in the burner. Oxygen reduces/eliminates thermal NO_x formation from nitrogen entering the furnace from the air. Residual nitrogen content in the furnace depends on fuel quality, potential air inlet and oxygen supplied.
	Flue-gas recirculation	The flue-gas recirculation into the flame reduces oxygen content in the hottest part of the flame and therefore temperature of the flame.

5.2.6.3 SO_2 emissions

The SO_2 emissions are generally from the burning of a fuel containing sulphur. Some SO_2 emissions can also be from degradation of anodes containing sulphur in electrolysis process from primary production. Different techniques need to be applied to reduce SO_2 emissions are described in Table 5-10. [40]

Table 5-10: BAT for SO_2 emissions [40]

BAT Number	Technology	Description
65, 68, 74	Use of low-sulphur fuels	The use of natural gas or low sulphur fuel oil is to be used to reduce the amount of SO_2 emissions from the oxidation of sulphur contained in the fuel during combustion. In case of primary production, it is recommended to use low sulphur anodes.
	Wet scrubber	In wet scrubber, the gas is allowed to flow in counter current direction with alkaline solution such as sodium hydroxide, hydrogen peroxide etc. Alkaline solution dissolves SO_2 gas and needs to be treated by waste water process before disposal. The insoluble matter is collected by sedimentation or filtration. Off gases downstream of scrubber are saturated with droplets and separation of droplets is required before discharging the gases. The wet scrubber has limited applicability because of space requirement and high gas flowrates.

5.2.6.4 VOC, PAH & PCDD/F emissions

The principle used to limit emissions of VOC and PAH is to combust these compounds using elevated temperature. All PAH emissions are from anode production because due to the liquid pitch addition during the anode production. The use of chlorine and chlorides in salt flux in the secondary aluminum production results in potential emissions of PCDD/F. In addition to Table 5-11, VOC emissions from secondary production are controlled using BAT 90. The following techniques are recommended:

- Raw material selection should be done according to the furnace and abatement technique available.
- The gases are passed through internal or after burner where gas streams react with oxygen in a temperature controlled environment to convert organic carbon to CO_2 and water vapor.

Table 5-11: BAT for VOC, PAH & PCDD/F emissions [40]

BAT Number	**Technology**	**Description**
62, 63, 64, 76, 90 (VOC)	Regenerative thermal oxidizer	The combustion system which achieves pollutants destruction through the process of high temperature thermal oxidation. The system achieves this with control of temperature and residence time of exhaust gases in combustion chamber. Regenerative process utilizes the thermal energy in the exhaust gas by using refractory support beds. Valves are used to alternate the flow of gases between the beds thereby reducing fuel requirement.
	Catalytic thermal oxidizer	The combustion system where decomposition of the pollutants is carried out on a metal surface which act as a catalyst. The metal catalyst helps in decomposition of pollutants at lower temperatures.
90 (PCDD/F)	Activated carbon filter	The process is based on adsorption of PCDD/F molecules in the activated carbon. Carbon surface after reaching maximum adsorption capacity is desorbed as a part of regeneration of the adsorbent. PCDD/F emissions could also be limited by use of the thermal oxidizer or regenerative thermal oxidizer.

5.2.6.5 Fluorides and chlorides emissions

The fluorides emissions occur from electrolysis cell in the form of gaseous fluorides and solid fluorides (total fluorides). Around 50-80% of the fluorides emissions occur as gaseous hydrogen fluoride with remainder being solid fluoride mainly aluminum fluoride and cryolite. Fluorides emissions occur because of the reaction between aluminum fluoride and cryolite with hydrogen from anodes or moist air. Both fluorides and chlorides emissions can also occur during degassing and refining stages. Fluoride emissions can occur from anode production plant if anode butts are used as recycled material. Scrubber generally offers capture efficiency of more than 98%. All captured particulate fluoride is usually trapped into the bag filter which is usually installed downstream of scrubber. The captured fluoride is recycled back to electrolysis cell. Both fluoride and chloride emissions also occur during the treatment of contaminated raw material, melting furnace, remelting and molten metal treatment in secondary aluminum production. Table 5-12 gives a summary of BAT for fluoride and chloride emissions from primary and secondary production. [40]

Table 5-12: BAT for Fluoride and Chloride emissions [40]

BAT Number	Technology	Description
63, 64, 71, 72	Dry scrubber	The scrubber which uses dry powder of alumina or alkaline (lime) which neutralises pollutants through chemical reaction. The new material formed because of the reaction must be removed by filtration process-generally applicable.
	Wet scrubber	The scrubber which uses wet alkaline solution to dissolve harmful pollutants. The resulting liquid must be treated by a wastewater process and insoluble material is collected by sedimentation or filtration. The off gases are often saturated with water vapor which needs to be separated before discharging the off gases-limited applicability depending on space availability.
91 (HCl, Cl_2, HF)	The selection of raw material according to the furnace and abatement techniques used.	
	$Ca(OH)_2$ or sodium bicarbonate injection in combination with bag filter.	
	Proper control of refining process, adapting the quantity of refining gas used to remove the contaminants present in the molten metals.	
	Use of dilute chlorine gas with inert gas	

5.2.6.6 NH_3, PH_3 and H_2S emissions

The salt slag produced during refining of secondary aluminum can be partially or completely recycled depending on the process requirements. Recycling of salt slag has an environmental benefit because it helps in the recovery of salt and aluminum etc. Recycling process however generates some emissions to air such as ammonia, phosphine and hydrogen sulphide gases which needs to be monitored and controlled. Table 5-13 below shows technology recommended for controlling emissions of gases from salt slag recycling process. [40]

Table 5-13: BAT for NH_3, PH_3 and H_2S emissions [40]

BAT Number	Technology	Description
96	Wet acid scrubber	The scrubber which uses acid media (H_2SO_4-sulphuric acid) to clean emissions gases (especially ammonia).
	Activated carbon filter	Gases from wet acid scrubber are cooled down and passed through the carbon filter to remove hydrogen sulphide and phosphine gas. The activated carbon is form of carbon that has been processed to make it extremely porous and thus has very large surface area available for adsorption and chemical reaction.
	After burner	The afterburner is a burner system which employs high temperature between 700 & 900°C and held for a minimum of five seconds to burn off pollutants

In addition to the above described techniques, BREF document mentions several techniques to improve process conditions and operating parameters for limiting formation of certain pollutants in the first place. Different best available technology is often applied in combination with one another depending on the process requirement, pollutants concerned, concentration of pollutant etc. The selection of BAT is done considering number of other factors such as energy requirement, economic feasibility, environmental benefits achieved, space availability and driving force for implementation. BREF documents also covers different areas such as emerging technologies available to improve energy requirements, process conditions and pollutants formation. [40]

The key environmental pollutants from primary production are perfluorocarbons (PFC), PAH and fluorides during electrolysis. PFC's are covered in more detail in next chapter where all greenhouse gases emissions are studied under EU-ETS. Major cost of producing primary aluminum is cost of electricity and thus production has tended to concentrate where low-cost electricity is available. The production and refining of secondary aluminum is much less demanding in terms of energy requirements. Total energy consumption for secondary aluminum per kg is only about 5% of the energy needed for primary production. There are many initiatives taken in Europe to improve the return of aluminum scraps for recycling of the metal and thereby closing the loop. [40]

5.2.7 BAT for Emissions to water

Aluminum production is largely a dry process. The discharge of waste water is usually limited to cooling water, rainwater runoff from surfaces & roofs and seawater from scrubbing off gases. Emissions of water from air wet scrubbers or SO_2 wet scrubbers can contain impurities and need to be treated before disposal. Monitoring of waste water discharge from aluminum industry must be done according to the Table 5-14. Table 5-14 also shows different technologies which needs to be applied to limit the pollutants emitted through the discharge of water. Each of these technologies that should be applied can be independent or in combination of one another depending on the process requirements.

Table 5-14: BAT requirements for emissions to water for aluminum industry [40]

Pollutant	Monitoring Standard	Monitoring Frequency	Abatement Technique	Technology	Description
Aluminium	EN ISO 11885 EN ISO 17294-2	At least once a month (only if a data series demonstrates sufficient stability)	BAT-15	Chemical Precipitation	The technique is to add reagent such as lime, sodium hydroxide, sodium sulphide or a combination of reagents, to adjust the pH value and promote the precipitation of soluble metals
				Sedimentation	The technique is based solid-liquid separation that utilises gravity to separate the insoluble metal complexes and solid particles from the liquid effluent.
Other metals, if relevant				Floatation	The floatation techniques are used to separate large flocs or floating particles like plastic parts from effluent by bringing them back to the surface.
				Filtration	The filtration technique is to separate solid from the waste water effluent by passing it through a porous medium. Sand is the most commonly used filtering medium.
Fluorides	EN ISO 10304-1			Ultrafiltration	The filtration process in which membranes are used to increase the removal efficiency.
Total suspended solids	EN 872			Activated carbon filtration	The filtration process in which activated carbon is used as the filtering medium.
				Reverse osmosis	It is membrane process in which pressure difference applied between the compartments separated by the membrane causes water to flow from the stronger solution to the weaker.

5.3 EU-ETS requirements for Aluminum Production

EU-ETS requires affected facilities to submit an annual report on their GHG emissions. The annual procedure of monitoring, reporting and verification (MRV) of emissions from industrial installation is known as ETS compliance cycle. Two different regulations apply:

1. Monitoring and Reporting Regulation (MRR) [43]
2. Accreditation and Verification Regulation (AVR) [44]

All different industrial activities which have an obligation for complying with MRR & AVR cycle under EU-ETS are listed in Annex-1 of the Directive 2003/87/EC [42]. Different GHG covered by the corresponding industrial activities is mentioned in the Annex-1 of the Directive 2003/87/EC [42]. All industrial installations are required to submit a monitoring plan in line with chapter-II of the regulation no. 601/2012 [43]. Annex IV of the regulation no 601/2012 lays down the rule for the monitoring methodology related to the specific installations [43]. The different equations used to calculate a process GHG emissions for specific industry can be adopted from 2006 IPCC guidelines for national Greenhouse Gas inventories under Volume 3 [50].

In this section, the calculation methodology for GHG emissions from primary and secondary aluminum production is summarized. The GHG which needs to be reported under primary aluminum production are carbon dioxide and perfluorocarbon (PFC) [42]. According to the point 7 of Annex IV, the operator of primary aluminum production should at least consider the following potential source of the CO_2 emissions: fuels for production of heat or steam, electrode production, reduction of Al_2O_3 during electrolysis and use of soda ash or other carbonates used in waste gas scrubbing [43]. PFC emissions which needs to be included are from the anode effects and fugitive emissions [43]. According to the point 7 of Annex IV it requires the use of mass balance methodology for process emissions in accordance with Article-25 [43]. Different equation for calculations of CO_2 and PFC emissions are discussed in the next section. These equations are consistent with the guidelines of GHGRP in the USA [49].

5.3.1 CO_2e emissions from aluminum production

The CO_2e represents all different GHG emissions in terms of carbon dioxide equivalent. The CO_2e of different GHG are calculated by multiplying corresponding global warming potential of the gases. CO_2e emissions from primary aluminum production is from two potential sources:

1. **CO_2 emissions from combustion of fuel**: In case of aluminum production, CO_2 emissions from combustion of fuel in process such as calcination, baking furnace, steam generation, electricity generation etc.
2. **CO_2e emissions from production process**: The CO_2e emissions from different process could be from lime production, soda ash use, coke calcination, prebake process, søderberg process, PFC emissions converted to CO_2e etc.

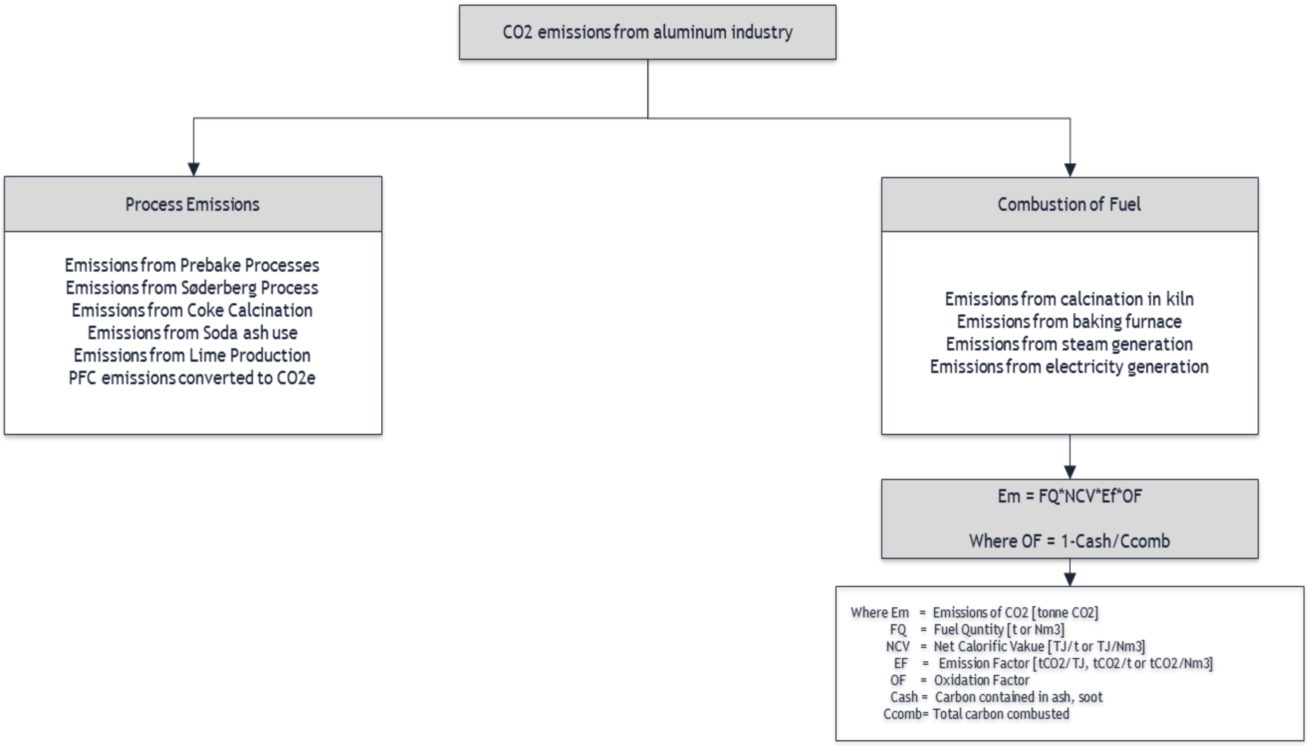

Figure 5-6: Overview of CO_2 emission from various sources in aluminum industry [43, 45]

GHG emissions arising in the production of secondary aluminum are only caused by the combustion of the fuel. Figure 5-6 shows the various sources for GHG emissions in aluminum industry. Different process emissions are from prebake or Søderberg technology & PFC emissions. Under process emissions, CO_2 emissions from coke calcination, lime production and soda ash use are studied.

However, it is important to note that all aluminum production plants might not have these facilities installed. Also, the aluminum plants generally have either of the one technology: prebake or Søderberg technology. Therefore, different equations which are relevant to the specific installations must be used when submitting monitoring plan to the competent authority.

The CO_2 emissions from combustion of fuel is calculated using the equation mentioned under the combustion of fuel in Figure 5-6. Appendix A contains a report where a calculation of CO_2 emissions from stationary combustion is compared between EU-ETS and GHGRP. The mass balance equations for calculating CO_2 emissions are adopted from IPCC guidelines for metal industry [45] and the aluminum sector GHG protocol [46]. Table 5-15 gives an overview of different tiers available to calculate GHG emissions from aluminum production as per IPCC guidelines [45]. The definition of tiers could vary with regulation concerned.

Table 5-15: Different Tiers for Selection of the equation [45]

Tier-1	Default factor method
Tier-2	Specific equations with typical industry parameters
Tier-3	Specific equations with facility specific parameters

- Tier-1 method to calculate CO_2 emissions uses broad cell technology parameters. Tier-1 method is only used if no process specific data is available for the calculation. The default emission factors are multiplied with the total aluminum production capacity to obtain total CO_2 emissions. CO_2 emission values obtained from tier-1 are very uncertain and it is recommended to use higher tiers methods to calculate emissions. [45]
- For both prebake and the Søderberg process, CO_2 emissions are calculated using the mass balance approach. The mass balance approach assumes that the carbon content of the anode or paste consumption is emitted as the CO_2.

  Tier-2 for both prebake and Søderberg processes uses typical industry values for different parameters. Tier-3 method uses values which are measured on site for specific facility.

  Tier-3 gives the most accurate values for CO_2 emissions. Different tiers explained here are as per IPCC guidelines [45]. Different tiers for PFC emissions are as per the guidelines from EU-ETS. These guidelines are slightly different from IPCC guidelines. However, the approach is similar, and the calculated value from the use of higher tier will be more accurate than the lower tier.

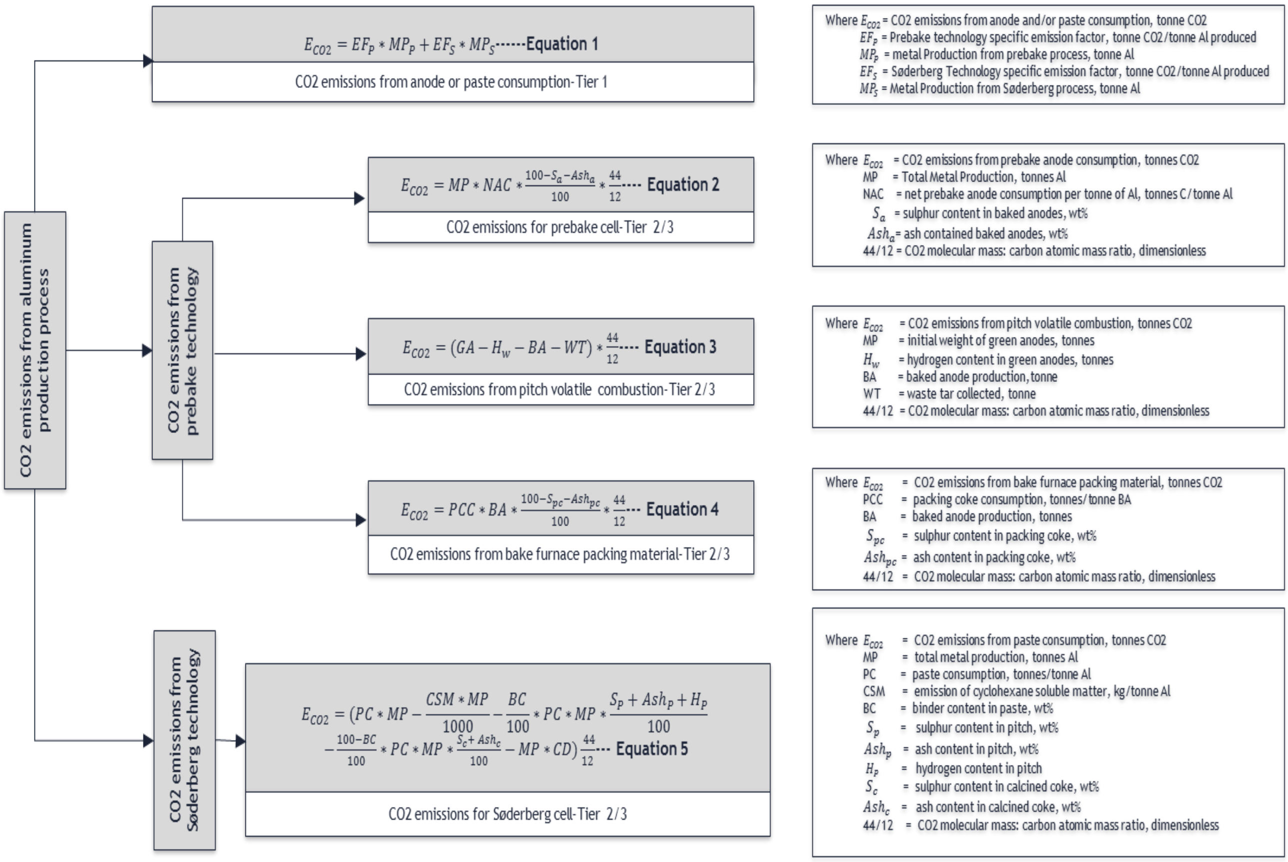

Figure 5-7: Equations for calculation of process CO_2 emissions [45, 46]

5.3.1.1 CO_2 emissions from anode or paste consumption

Equation 1 from Figure 5-7 is used to calculate the CO_2 emissions if no process specific data is available. The default emission factors are multiplied with the amount of aluminum produced. This method is used in tier-1 and gives the value of CO_2 emissions which can be highly inaccurate. The use of this equation is generally not recommended. [45]

5.3.1.2 CO_2 emissions from prebake anode consumption

The CO_2 emissions from prebake anode consumption needs to be calculated by the addition of four different processes:

1. CO_2 emissions from combustion of fuel in anode baking furnace
2. CO_2 emissions from pitch volatile matter combustion during baking of anodes
3. CO_2 emissions from combustion of packing material in furnace
4. CO_2 emissions from prebake anode consumption in electrolysis cell.

Equation 2, 3 & 4 from Figure 5-7 are used to calculate the CO_2 emissions in combination with equation for the combustion of fuel. All the four values from these equations must be added together to have total CO_2 emissions from aluminum production using prebake anode technology. Tier 2/3 must be used in accordance to the availability of the typical industry data or specific facility data respectively. [45]

5.3.1.3 CO_2 emissions from Søderberg anode

CO_2 emissions for the aluminum production using Søderberg technology are calculated using equation 5 from Figure 5-7. Similar tiers are used when calculating emissions from prebake anode consumption facility. [45]

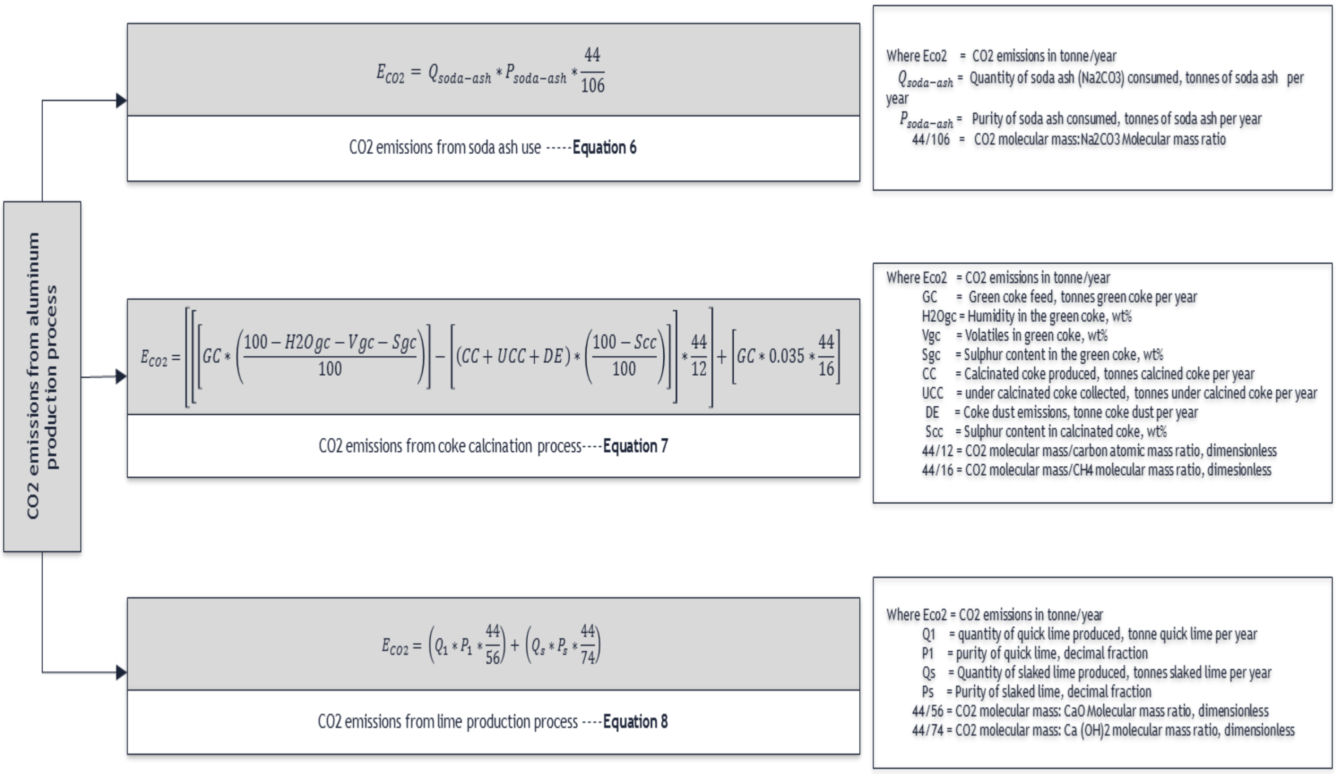

Figure 5-8: Equation for calculations of CO_2 emissions from indirect process [46]

5.3.1.4 Indirect CO_2 emissions

Different aluminum production plants might have various process facilities such as coke calcination, lime & soda production. The operator is required to include CO_2 emissions from these processes if they have these facilities installed. Coke calcination is the operation to remove volatile matter from coke before using it for the anode production. Lime is used in the alumina production whereas soda ash is used in waste gas scrubbing process. The equation 6, 7 & 8 from the Figure 5-8 are used for calculation of CO_2 emissions from soda ash use, coke calcination and lime production respectively. [46]

5.3.2 PFC emissions from aluminum production

Fluorine gases such as CF_4 (tetrafluoromethane) and C_2F_6(hexafluoroethane) are collectively referred to as PFCs. During electrolysis of alumina, the anode reacts with cryolite (Na_3AlF_6), rather than alumina, during a process upset condition known as anode effect. Anode effect is the process upset condition where insufficient alumina is dissolved in the electrolyte, which causes voltage to rise than the normal operating voltage and anode reacts with cryolite instead of alumina to produce PFCs gases. [46]

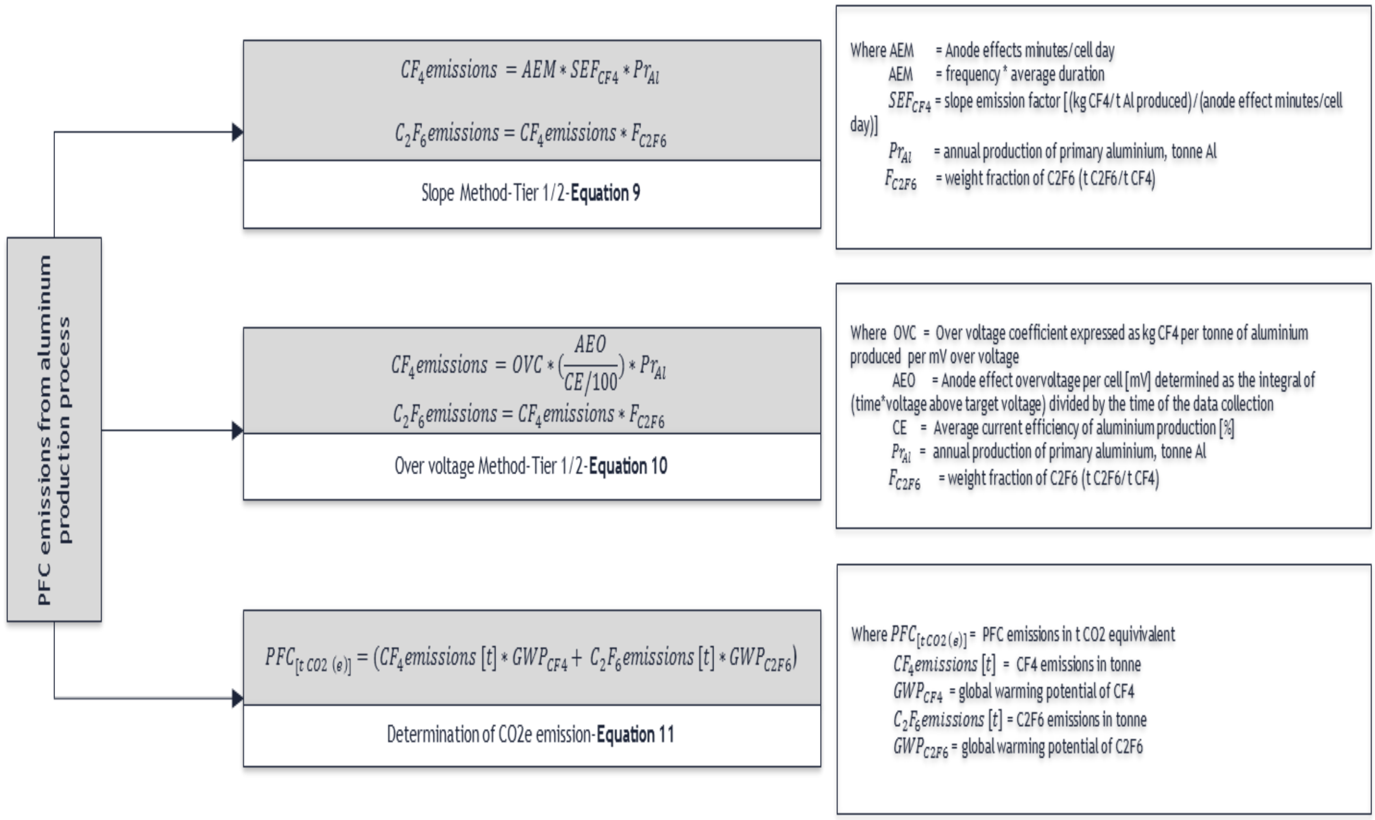

Figure 5-9: Equation for calculation of PFC emissions [46]

The annex IV of MRR provides two methods for the calculation of PFC emissions based on relationship between anode effect and performance [45]. Method A is a slope method where emissions are calculated using equation 9 from Figure 5-9. Method B is over-voltage method where emissions are calculated using equation 10 from Figure 5-9. Tier-1 requires operators to use technology specific emissions factor made available in annex IV of MRR [43]. Tier-2 requires operator to use installation specific emission factors. These are established through continuous or intermittent field measurements [43]. Equation 11 from the Figure 5-9 is used to convert the amount of PFC emitted into equivalent CO_2 emissions.

5.4 E-PRTR requirements for aluminum industry

The E-PRTR regulation requires all the activities in annex-I to report on the emission of pollutants if the activities are above the capacity threshold. Total number of industrial facilities are 65 divided into 9 sectors [18]. Total number of pollutants covered by the regulation are 91 which are divided into 7 groups as per annex-II [18]. Reporting by the facility must cover quantity of pollutants release to air, water and land along with hazardous and nonhazardous waste (Figure 5-10) [47].

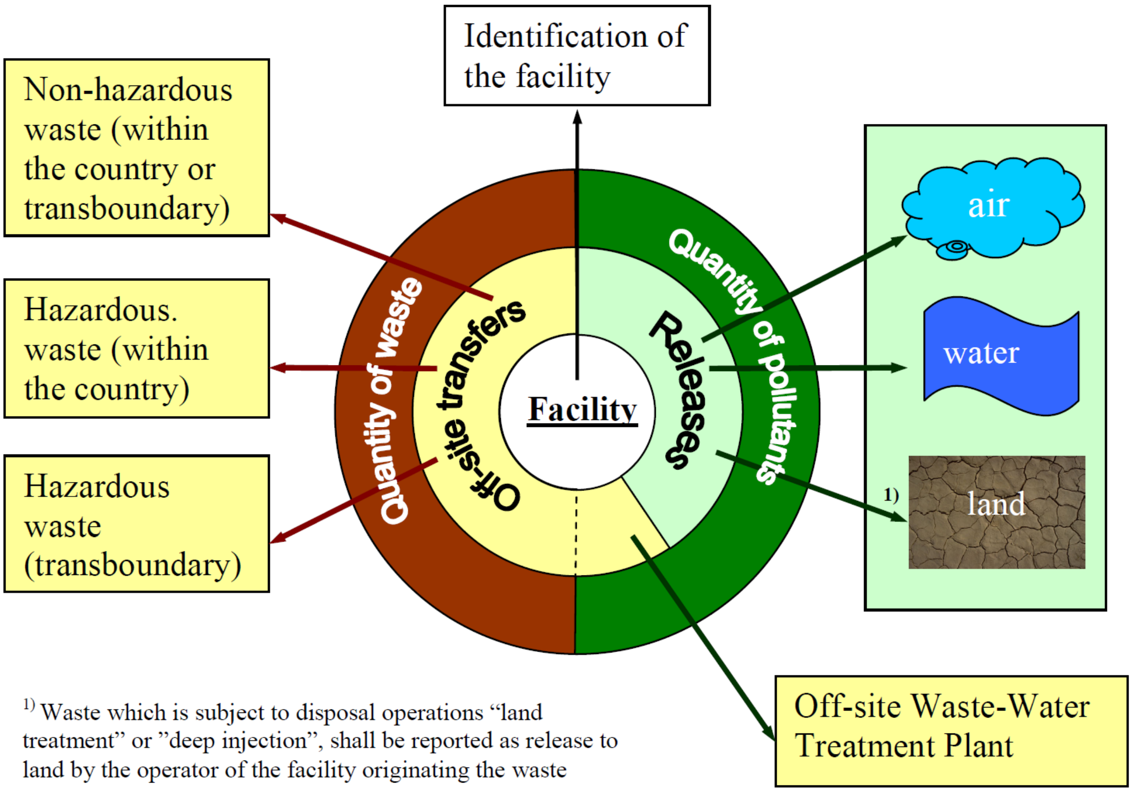

Figure 5-10: Overview of reporting requirements for facilities under E-PRTR [47]

Table 5-16 shows the threshold for the release of major pollutants from the primary aluminum production. If the annual release of pollutants exceeds the threshold in E-PRTR (Table 5-16), the operator of the industrial facility must submit reports under the E-PRTR regulation. [18,47]

Table 5-16: Pollutant threshold for reporting under E-PRTR for Primary production [18]

Pollutant	**Pollutant release thresholds for reporting under E-PRTR**		
	Release to air (kg/year)	**Release to water (kg/year)**	**Release to land (kg/year)**
CO_2	100 million		
CO	500,000		
nmVOC	100,000		
NO_x/NO_2	100,000		
PFC	100		
PAH	50	5	5
Total Fluorides		2,000	2,000
HF	5,000		
PM-DUST	50,000		
SO_2	150,000		

Similar threshold values for all the major pollutants from secondary aluminum production is in Table 5-17.

Table 5-17: Pollutant threshold for reporting under E-PRTR for secondary production [18]

Pollutant	**Pollutant release thresholds for reporting under E-PRTR**		
	Release to air (kg/year)	**Release to water (kg/year)**	**Release to land (kg/year)**
CO_2	100 million		
CO	500,000		
nmVOC	100,000		
NO_x/NO_2	100,000		
NH_3	10,000		
HCl	10,000	-	-
PCDD/F (as I-TEQ)	0.0001	0.0001	0.0001
HF	5,000		
PM-DUST	50,000		
SO_2	150,000		
Chlorides-Total Cl	-	2 million	2 million

5.5 Fluorine gas regulation

The primary aluminum production produces PFCs because of the anode effects in electrolysis cell. Some other fluorine gases are used in small amounts as a shield gas in aluminum industry in casting process. According to article-13 of fluorine gas regulation, the operators of the facilities are required to report on fluorine gas emissions if the emissions are above threshold as per Table 5-18. The thresholds for different pollutants are in CO_2 equivalent therefore it is necessary to convert PFC, SF_6 emissions to CO_2 equivalent. Annex-I & II of the fluorine gas regulation list values for global warming potential of different fluorine gases. [17]

Table 5-18: Fluorine gas thresholds for reporting [17]

Pollutant	**Pollutant release thresholds for reporting under F-gas regulations**
PFC, SF_6	1 metric tonne or 1000 tonnes of CO_2e (produced, imported or exported)
	1 metric tonne or 1000 tonnes of CO_2e (destroyed)

6 Best Practice for Environmental Monitoring & Reporting

Reporting on environmental performance of organizations is becoming increasingly important. In highly developed countries it is mandatory to report on the environmental performance of an organization. There exist several environmental standards which lay down various criteria based on which organizations must submit their environmental compliance reports. These environmental standards in the European context include EU-ETS, E-PRTR, IED etc. These standards prescribe guidelines based on which organizations must submit their environmental performance reports annually, quarterly etc.

Similar reporting frameworks exists for other aspects such as social and financial. The reports that cover social and ethical aspects are known as corporate social responsibility reports and the reports that cover economic aspects are known as financial reports. Sustainability reports summarize all social, economic & environmental aspects together. Different reports prepared based on one or several of these criteria could be submitted in a range of media including company's website, direct submissions to the government agencies or in promotional media etc. [1, 53]

In this study, the focus is on environmental reporting. The reporting on environmental aspects contribute with several benefits to an organization such as: -

- Understanding the environmental risk associated with the organizations operation and thereby prepare a proactive plan for mitigating those risks. [53]
- Increasing the internal efficiency of operations, increase transparency of data thereby driving reduction of environmental footprint of an organization. [53]
- Addressing specific challenges or concerns of stakeholders and thereby to plan and inform the stakeholders about how these challenges can be dealt. [53]

Therefore, it is important to understand internal mechanisms for collection and segregation of data to prepare environmental, social, financial and sustainability reports. In this study, effort is made to simplify the process which goes into different types of reporting on an organizational level. Also, in depth analysis of environmental reporting is done by studying monitoring and reporting requirements of the industrial emissions directive in the EU. This chapter covers the objective of understanding environmental reporting process for IED and thereby contribute to a system design to implement the monitoring and reporting processes on software systems.

6.1 Internal mechanism of reporting process

Despite having a great interest by stakeholders in published data on performance of social, environmental and economical aspects of an organization, there is limited research underlying the internal mechanisms on how data are collected and consolidated on different levels to prepare these reports [54]. Therefore, it is important to analyze the internal systems and processes that support external reporting.

For example: as shown in Figure 6-1, let's assume an organization in Europe which has four different business functions oil & gas production, aluminum production, power production and consulting. The same organization has different departments distributed into groups: human resource, health-safety & environment, finance and information technology etc. Also, the business function of aluminum production has two aluminum production sites in the Europe. [54]

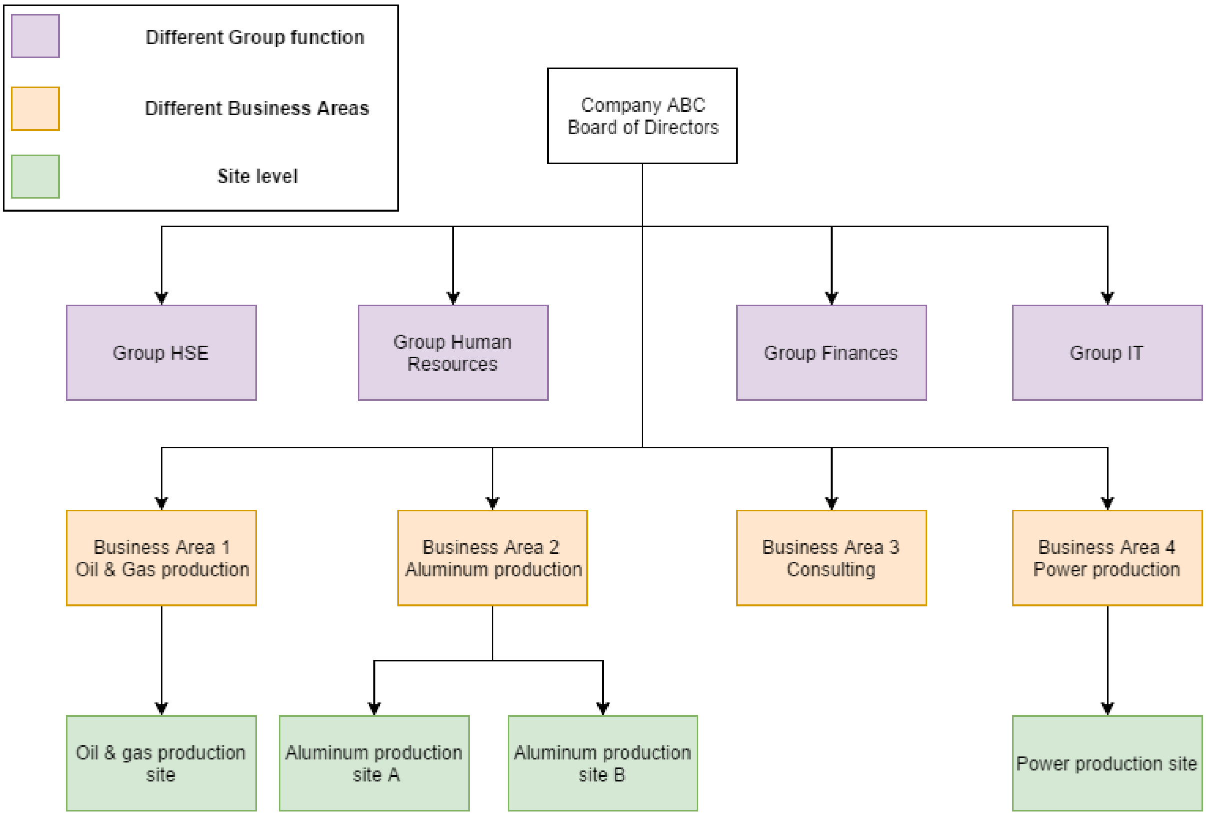

Figure 6-1: Overview of different functions in an assumed organization

Figure 6-2 below shows an overview of the data flow through the assumed organization in Figure 6-1 by a bottom up approach associated with it's aluminum production activities.

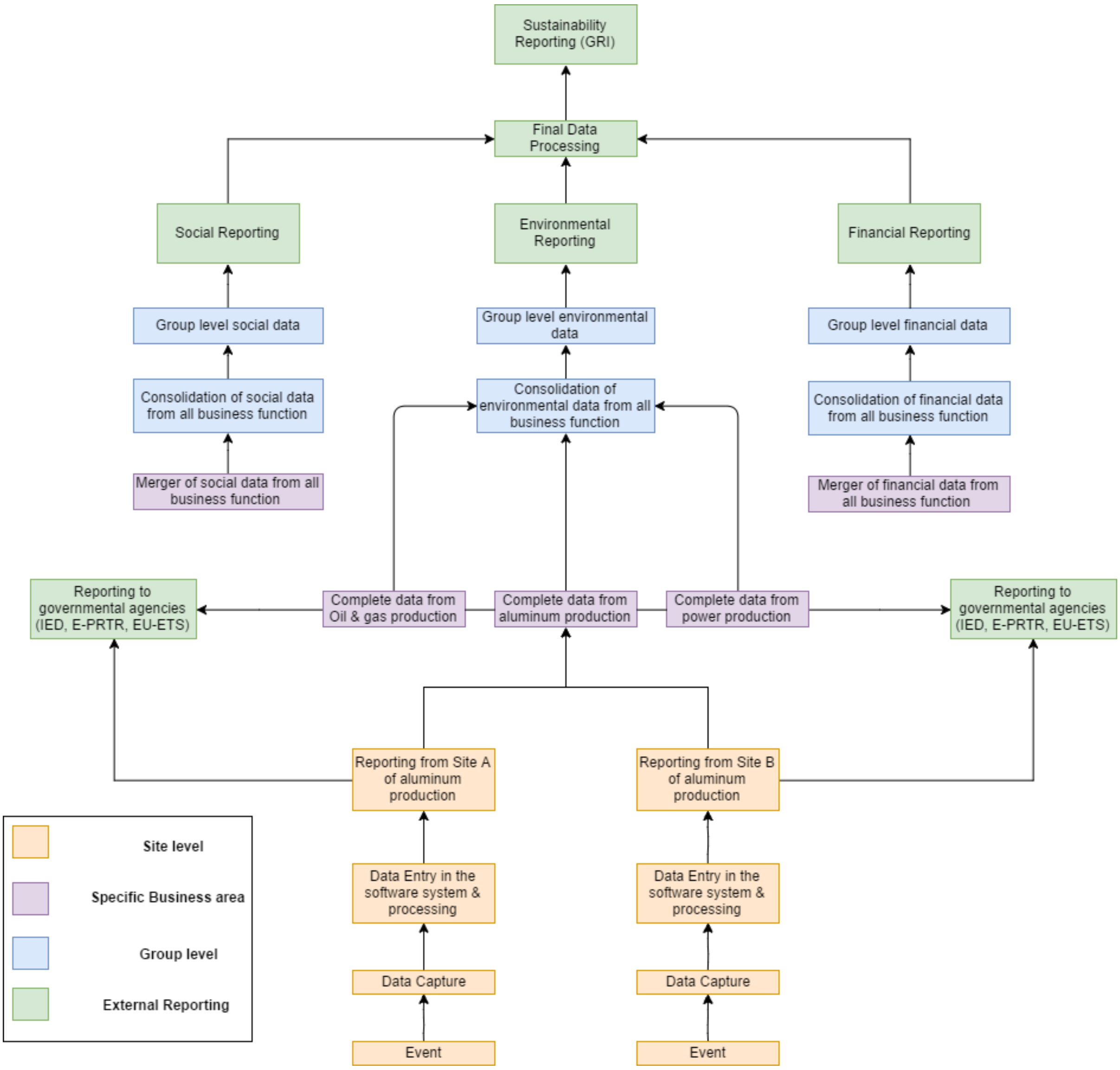

Figure 6-2: Overview of the data flow through an organization

The data at higher levels in the figure are generic to any of the production activities. Data of any kind, be it social, environmental or economic is generated by a particular event. In the context of this study, the example of this event can be the emission of a pollutant on (the aluminum) production site. Concentration of this pollutant released is estimated by one of the methods described in section 4.1. The measured or calculated value of the pollutant is entered in the software system/MS excel, which records the data of pollutant emitted from particular operation on the site. This data is collected over a period of time and combined together to generate mandatory environmental compliance reports. Example of these reports includes IED, EU-ETS, E-PRTR etc in the European context, which are submitted to the government agency. These environmental reports are submitted directly from the site, therefore in this case individual reports from site A and site B must be submitted to the government agency.

In the next step, data collected at different sites within the same business function are merged together to produce business level data.

For example: In this case, the organization has aluminum production facilities at two different sites in Europe, site A & site B, the data from both of these sites are consolidated and processed together to generate business level data for aluminum production. This procedure helps in understanding complete environmental impact by a particular business area. Similarlly, data is generated on business level for oil & gas and power production.

In the next step, the data collected from different business function is consolidated to generate a group level data for whole organization. For example: CO_2 emissions from aluminum production is added to CO_2 emitted from oil & gas and power generation etc. This will give the total amount of CO_2 emitted from different operations in whole organization. Similar consolidation of the data is done for other pollutants. The data generated on the group level on pollutant emission by merging data from different business areas is used to prepare the environmental reports of an organization. Similarlly, the data is collected from all business areas on social & financial aspects. This data is merged together to create group level social and financial reports.

Finally, the data from these reports is processed and merged to prepare the sustainability report for various stake holders. The example explained above is on the general basis. Each organization will have their own specific way of creating a dataset to comply with environmental regulations and prepare sustainability report. The important steps in this process are the consolidation of data on business level and group level. The procedure adopted in consolidation of data must be in such a way that, the data generated is accurate and easily tracebale for audit purposes. [54] In the next section, monitoring and reporting requirements described under the industrial emissions directive are discussed.

6.2 Monitoring & reporting requirement under IED

As discussed in previous chapter, the IED is one of the largest and most comprehensive pieces of environmental legislation in Europe. It affects more than 50,000 industrial installations such as power stations, chemical manufacturing, metal smelters etc. IED requires all the affected industrial installations to be operated in line with the operating permit issued by the competent authority. This operating permit usually defines emission limit values for all different pollutants based on the industry specific BREF document. The operating permit also describes the procedure for monitoring and reporting of pollutants emitted from the affected installations. In this section, the methodology which needs to be adopted for monitoring and reporting of the pollutant under the IED is discussed.

6.2.1Monitoring requirement under IED

The requirement for emission monitoring & reporting is summarized by reviewing an operating permit for industrial installation in the United Kingdom. It is assumed that the operating permit in other EU member states will have similar requirements because the process of permit allocation is handeled centrally by the European comission and the European Environment Agency. The emission monitoring methodlogy has to be adopted in accordance to the flow diagram presented in Figure 6-3 through a top down approach.

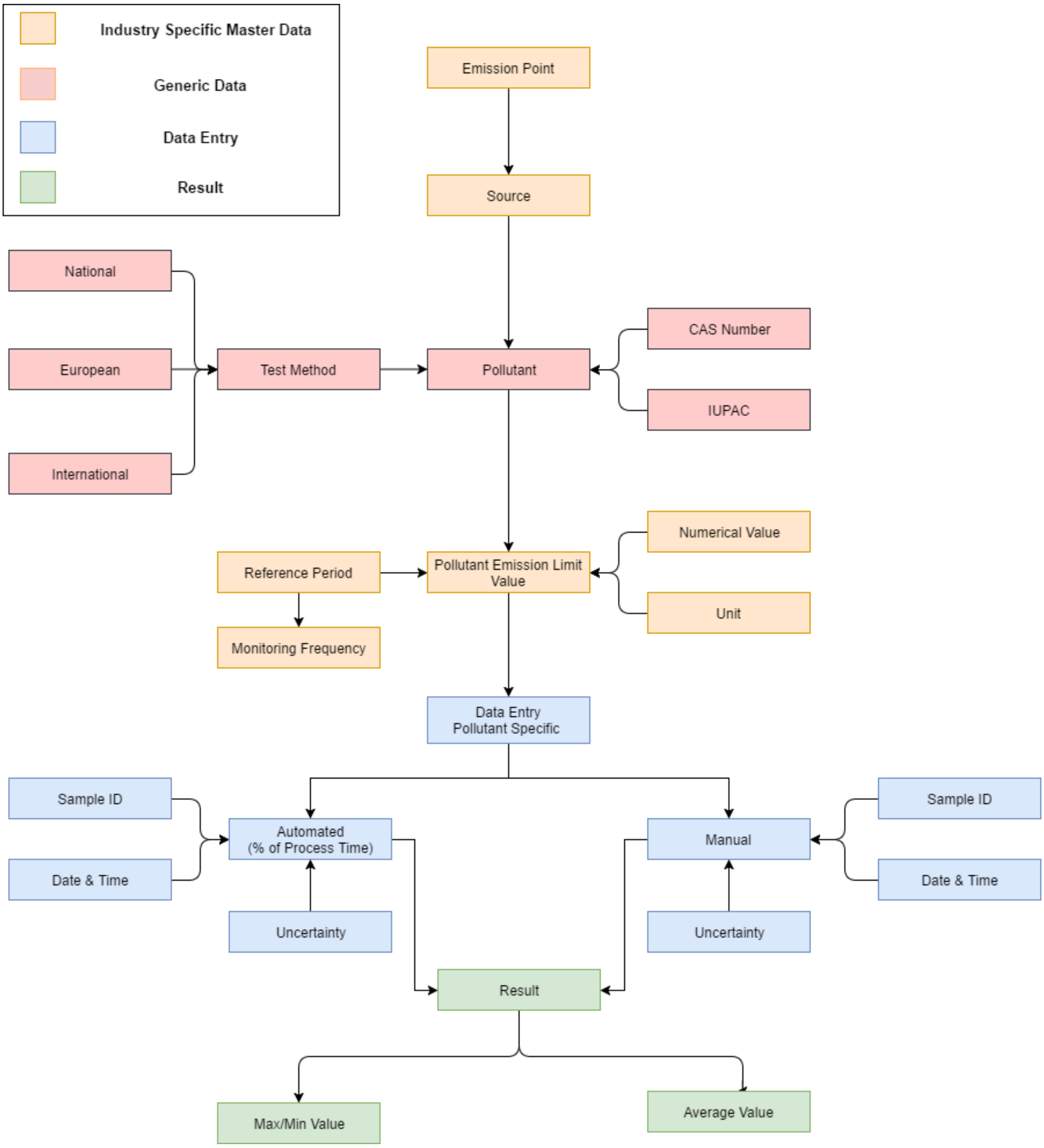

Figure 6-3: Overview of system design for emission monitoring process under IED

According to the operating permit, all emission point of emissions to air, water and land through stack or pipes must be listed in the monitoring form. These emission point must include their location reference on the operation site. Under each of these emission points, the source of emission must be defined. For example: at a particular point in an operation site, a stack is located for releasing exhaust gases to air. These exhaust gases are generated through some process in the facility and might contain several harmful pollutants. To limit the emission of particular pollutants into the atmoshphere, the exhaust gases are passed through the equipments such as scrubbers, bagfilter, activate carbon filter etc. The source from which the exhaust gases are generated and the abatement technology used must be mentioned under the source. The information about different emission point and ELVs of pollutants emitted through this emission points is similar for a particular industry.

Following this, all different pollutants present in the exhaust gases must be listed. These pollutants are defined by their Chemical Abstract Services (CAS) name or by International Union of Pure and Applied Chemistry (IUPAC) name. The operating permit requires the operator to estimate the concentration of all harmfull pollutants before releasing it to the atmosphere. The concentration of pollutants must be measured in accordance to the European, National or International testing standards. These testing standards for different pollutants are available in the Annex-1 of the reference document on monitoring [48]. Accuracy by which the testing standards can measure the pollutant is often defined with the standards. These data of pollutants i.e CAS/IUPAC name along with corresponding testing standard is generic data for all industrial facilities.

Later, the permit contains pollutant specific emission limit values (ELV's) based on the source of an exhaust gases and abatement technology used. The ELV's are usually defined by concentration units and can have maximum/minimum values for an emission of a pollutant. It is important to note that, the pollutant emitted in the atmosphere should not exceed the ELV's defined by the permit. ELV's for each pollutant are set for a particular reference period and monitoring frequency as defined under the reference period. For example, for particulate matter emissions, let's assume that the ELV is 5 mg/Nm^3, the reference period for this ELV could be monthly average and monitoring frequency is continuous. Similarly, for other pollutants the reference period could be daily average and monitoring frequency could be periodic for 6 times in a day. These reference periods and monitoring frequencies are defined for all different pollutants depending on several factors such as how harmful is the pollutant, initial concentration of pollutant in the exhaust gases and investment costs involved in abatement technologies etc.

Subsequently, the pollutant must be measured continuously/periodically depending on the monitoring frequency defined in the permit. Continuous measurements are carried out by automated instruments installed on the site while periodic measurements are usually done by taking samples and analyzing the sample in the lab. These measurements must be done by corresponding testing standards and uncertainty associated with the result is noted. For continuous measurement, the percentage of process operating time covered by the result should be recorded. For both continuous/period measurement sample ID, sample date and time must be recorded for each measurement. Operators of the industrial facilities are obliged to follow the methodology explained above for monitoring of pollutants emissions and maintain records of this process.

6.2.2 Reporting requirement under IED

Reporting of the results involves summarizing and presenting the data collected during the monitoring process and related information in an effective way which will help for compliance assessment in a simple manner. The different elements required in reporting of the monitoring results are presented in Figure 6-4.

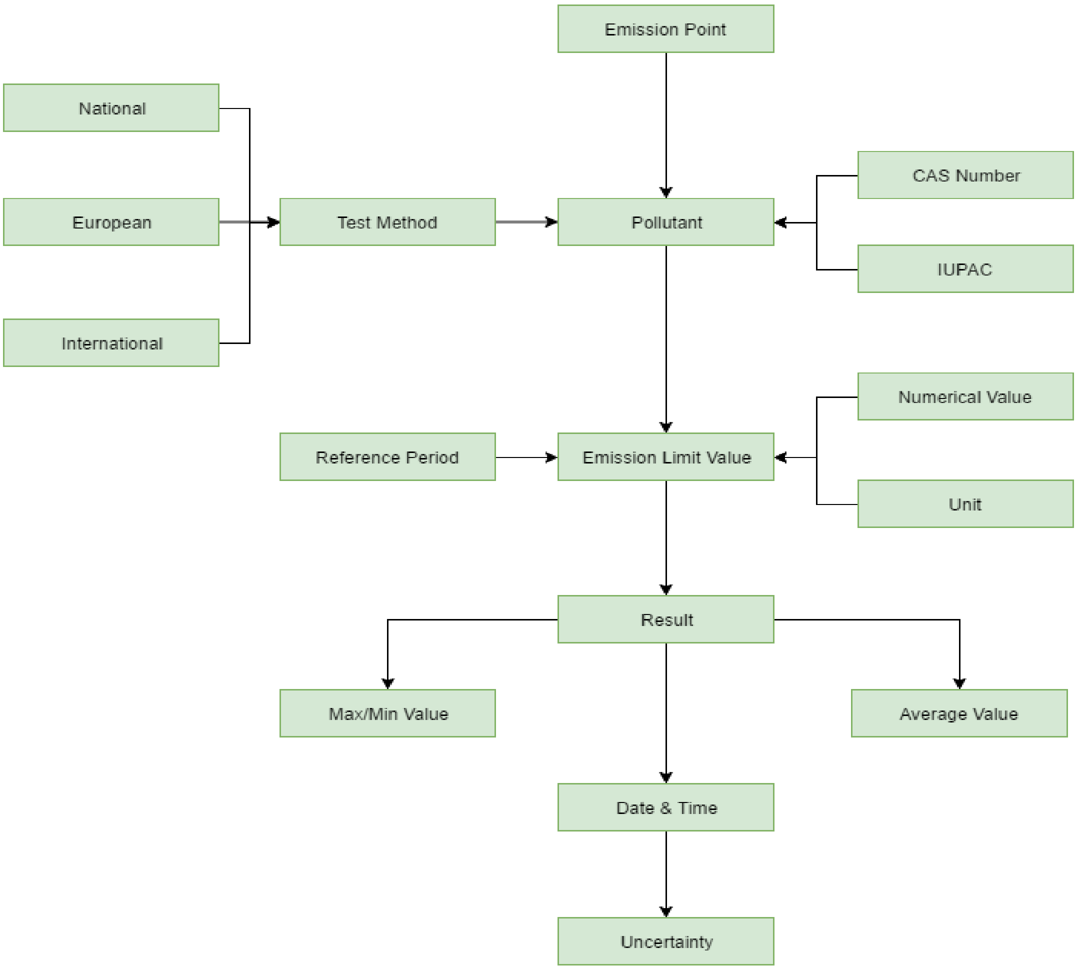

Figure 6-4: Overview of system design for emission reporting process under IED

6.2.2.1Data collection

Data collection must be done based on the guidelines of an operating permit. The operating permit contains schedules which state how, when, by whom and to whom the data needs to be reported and what type of data is acceptable. For example: calculated, measured, estimated. Data collection must be done in the units described by the permit and if required, the values must be changed to the standard condition of temperature and pressure. The standard forms must be used to record the concentration values of the pollutant. These forms are usually available in paper/electronic medium along with prescribed reporting format of different elements as presented in Figure 6-4.

The forms contain a column for providing operation details. For example: emission point location from where the pollutant was emitted, prevailing process, abatement equipment used etc. These forms require inclusion of the test method used for monitoring, sampling and analysis of the pollutant along with the date and time of recorded data. The reference number for internationally approved test method must be mentioned in the form. In case, if other testing method is used in agreement with the environment agency, the appropriate identification of the method must be stated. For example: gas chromatography provided by xyz. Data reporting requires mention of uncertainties and limitation in the measurement. Examples include details of detection limit of instruments, number of samples etc. Some other details such as reference period as explained in monitoring requirement along with sample date and time of each measurement need to be included.

6.2.2.2 Data management & presentation

Permits usually specify how and when the data need to be reported to the environment agency. The details of different tools such as software packages or statistical methods used for analysis and condensation of the data can be provided with the reported data. Data must be systematically archived so that records of the past data is readily available and easily traceable during internal/external verification and audit purposes. The presentation of data can set the results in context by showing the trends over time. Comparisons of the results with corresponding ELV’s can help in understanding the amount of deviation in concentration of pollutant in relation with the ELV. This analysis helps in taking necessary measures to bring down pollutant concentration by changing operating parameters such as temperature, pressure etc.

7 Discussion

7.1 Environmental regulations in Europe and the US

In the EU and the US, the responsibility of framing and implementing environmental policies is divided between the central government and the member states. In this study, the environmental regulations affecting stationary source of pollutants (heavy industry) are studied and compared. In case of climate change policies, important initiatives and commitments to reduce emissions of GHG have been implemented in the EU member states within the framework of EU-ETS. By contrast, in the US, there is no regulation from central government to reduce GHG emissions but there exist GHGRP which defines mandatory requirement for monitoring and reporting of GHG emissions in the US. The monitoring requirements for EU-ETS in the EU and GHGRP in the US are quite similar. But when it comes to commitment for the reduction of GHG emissions, the gap between climate change policies in the EU and the US is substantial due to no reduction requirements in GHGRP.

Previous government in the US had introduced a clean power plan to reduce GHG emissions from oil & gas fired power plants by upto 30% below 2005 levels by 2030 [24]. The clean power plan was developed to comply with the GHG reduction commitments agreed in the Paris agreement under UNFCCC [24]. However, the present government in the US has pulled out of the Paris agreement under UNFCCC [59]. The decision of the US government to pull out of the agreement contributes to huge uncertainty around the world for meeting GHG reduction commitments under UNFCCC. This is the area of concern and it would be interesting to follow the developments about how different countries move forward when it comes to following the Paris agreement.

Air quality standards in the EU are little more stringent than in the US [16]. Also, the EU has included heavy metals and PAH’s in their air quality monitoring requirements but these compounds are not included in the US [16]. To maintain these air quality standards, several directives and regulations exist both in the EU and the US [16, 39]. These regulations control the emission of pollutants to air, water and land from stationary and mobile sources. In the EU, the air quality directive requires the member state to consult with each other in achieving air quality standard across the EU. But there is no mechanism outside the NECD to ensure that the different member states work together for solving the issue of air quality [39].

In the US, the federal government under the EPA can implement compulsory regional planning programs between the states to develop cross border co-operation [39]. However, there are some member states in the EU and the US that don’t fulfill the requirement of these air quality standards [9]. A major difference between environmental regulations in the EU and the US is seen in the area of compliance [19, 39]. The US has a mandatory compliance systems in place which is strictly enforced by the EPA in the form of severe penalties [19, 39]. On the other hand, the EU has weak enforcement mechanism to comply with the regulations [19, 39].

In this study, the guidelines of regulations for stationary source of pollutants was studied with the example of an aluminum industry in the Europe. The objective was to understand the quantification methodology prescribed under the EU-ETS and the IED in the EU. The study suggests that there exists a good framework for monitoring and restricting the emission of pollutants from heavy industry (aluminum industry) in the EU. Environmental regulations in the US also have a good mechanism to restrict the emissions of these pollutants. However, how exactly these regulations are implemented in the US was excluded from the scope of this study due to the current change of environmental policies.

7.1.1 Monitoring and reporting of data

It is important to efficiently quantify and record the pollution data from different processes in the industry. Information about organization's environmental performance is important for both internal and external stakeholders. For internal stakeholders, the collection and analysis of the environmental data on the organizational level helps in assessing the risks associated with mandatory compliance requirements from the government agency. Summarizing the data on an organizational level helps in understanding and identifying the major hotspots in operational activities. This process helps in developing innovative solutions to make industrial operations efficient, cleaner and sustainable, and subsequently to reduce the overall environmental footprint of the organization [53]. There exist several mandatory and voluntary environmental standards which provide guidelines for monitoring and reporting of the data [53]. In this study, effort was made to elaborate on the internal mechanisms of monitoring and reporting processes by discussing the monitoring and reporting guidelines under Industrial Emissions Directive in the EU.

7.2 Aluminum industry in Europe

The aluminum industry is a key industry sector that can make significant contributions to Europe's transition mission towards a low carbon and resource efficient sustainable economy. The European Aluminum Association (EAA) has developed a roadmap for making this aspiration into a reality. EAA was founded in 1981 and includes primary producers, downstream manufacturers, producers of recycled aluminum and national aluminum associations. To achieve the target of being a sustainable and competitive industry, the EAA has made three comprehensive commitment's: [41]

1. Main focus is on responsible aluminum production by minimizing environmental footprint of the production. This is done by optimizing energy consumption, reducing GHG emissions and by improving resource and waste management. [41]

2. The second approach is focused on promoting innovative applications of aluminum products in transportation, packaging, construction etc. Main objective of this approach is to create a circular economy. This is done by closing the loop of aluminum and recycling aluminum in this loop continuously. [41]
3. Third category is socio-economic contribution to society which focuses on employee related commitments and broader CSR engagement. [41]

In the next section the key measures taken by the EAA in each of the three points listed above are discussed.

7.2.1 Responsible production of aluminum

To achieve a responsible aluminum production, the EAA members will purchase the raw material from sources which employ the best practice of environmental, economic and social standards in their operations. EAA members will define a core criteria based on best social, economic and environmental practices. These criteria will form as a basis for all of its members when sourcing the raw material from anywhere in the world. EAA members will further develop this criteria with the concept of 'sustainable sourcing' by consulting various stakeholders involved. [41]

In next step, the EAA members are committed to safeguard & protect the environment at all stages of the value chain by applying the best available technologies in production. These best available technologies are described in BREF documents based on European legislation of Industrial Emissions Directive. EAA members actively participated in the development of this document, thus providing a higher level of industry ownership and commitment. This document forms the basis for operating permits of primary and secondary aluminum production sites across the EU. BREF documents cover all major pollutants emitted from aluminum production that may have harmful effects on human health & environment. This document establishes emission limit values of all pollutants based on the use of best available technology. European aluminum industry members are committed to efficiently manage consumption of water and energy use by developing innovative technologies. Energy saving is the key driver for competitiveness, as electricity account for 40% of the costs for primary aluminum production. The idea is to deploy renewable energy sources or balance the power in the grid by renewable energy sources. EAA members are also committed to protect environment by reducing and recycling as much as possible of all the industrial waste and abandon the landfill of recyclable hazardous industrial waste. [40, 41]

EU-ETS is an important policy instrument for achieving reduction of both direct and indirect GHG emissions from the aluminum industry in Europe. EAA members are trying to introduce the renewable energy sources which will contribute to the decarbonization of the energy supply. Also, efforts are made to carry out research and development in promoting advanced smelting technologies to reduce direct GHG emissions. [41]

Aluminum industry in the EU has reduced its CO_2e emissions by around 50% since 1990. The combined effect of reduction from direct emission and from European power generation have a total reduction potential of up to 79% by 2050 compared to 1990 (see Figure 7-1). The scenario in Figure 7-1 assumes that EU's power sector achieve the CO_2 intensity reduction as projected by the European Commission. [52]

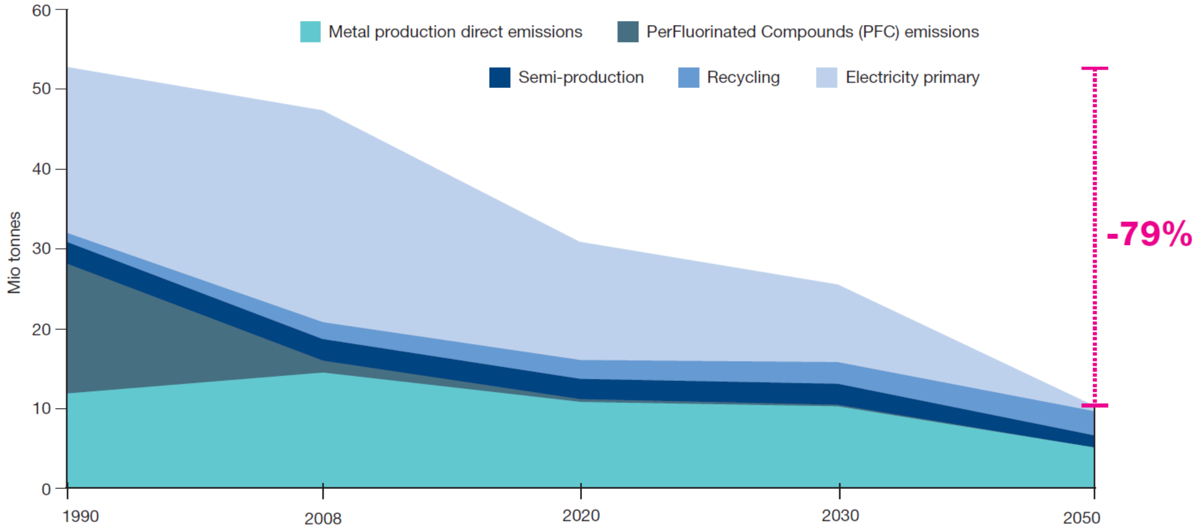

Figure 7-1: Reduction of CO_2e emissions from aluminum industry in Europe [52]

7.2.2 Sustainable Products & recycling of aluminum

Aluminum is increasingly becoming a material of choice for many applications such as automobiles, construction, packaging etc. The main reason for promoting use of aluminum in several different applications is due to its endlessly recyclable property and light weight. The recycling of aluminum saves up to 95% of energy when compared to the production of primary aluminum from bauxite ore. Therefore, in line with different stakeholders, EAA members are finding out alternatives to expand the application of aluminum in many different areas. This expansion is planned carefully by establishing partnership across the supply chain to close the loop and thereby recycling maximum amount of aluminum in the loop. [41]

Example of this partnership includes promoting use of aluminum in cars, trucks, buses, tramways, metros, railways. The use of aluminum in transportation comes with a dual benefit: reduction in GHG emissions in transportation by improving vehicle efficiency due to lower weight of aluminum and recycling the aluminum scrap at the end of their useful life. For example: reducing the mass of car by 100 kg saves 8g CO_2 emissions per kilometer. Similarly, the use of aluminum can be promoted in buildings which has a benefit of increased durability, energy efficiency, safety and low maintenance requirements. Subsequently, an aluminum recycling loop for construction industry can be developed and implemented. The use of aluminum in buildings can decrease energy consumption in buildings by up to 50%. [41]

EAA members are promoting the use of aluminum in a variety of packaging items. In 2012, 7 out of 10 beverage cans were recycled in Europe. EAA members are committed towards achieving 80% recycling rates of beverage cans by 2020. The industry members have also planned to phase out the landfill of recyclable consumer packaging waste by 2025. This can be done by improving the collection-sorting-recycling process. The demand for aluminum is growing worldwide, as aluminum is material of choice for several different applications as discussed above. Increasing recycling contributes in reducing energy consumptions and GHG emissions. As of now, the recycling rates in Europe are over 90% in construction & automotive sectors and 60% of packaging sector. [41]

7.2.3 Socio-economic contribution

Aluminum industry contributes around 36.8 billion euro to the European economy and employs around one million people directly and indirectly. EAA members have established several programs to increase competence and ensure proper working conditions at all levels for the employees. This is done by implementing training programs in different disciplines such as technical, managerial, behavioral etc. EAA members are committed to maintain highest health and safety standards by collecting information on every incident occurred at the work place and thereby drawing out areas of improvement. Finally, the EAA members are working towards incorporating all CSR aspects such as gender equality, human rights and international labor standards. [41]

7.2.4 Cost of EU regulations and carbon leakage

Primary aluminum industry in the EU is facing a challenging time ahead. Despite growing demand of aluminum worldwide, ten primary aluminum production plants have been shut down in the EU since 2003. A study was conducted by Center for European Policy Studies (CEPS) on behalf of the European commission [51]. This study was carried out to assess the cumulative cost of EU’s environmental legislation on European aluminum industry, as well as an evaluation of how these costs affect the competitiveness of this industry in international market. The study concluded that the cost of EU’s legislation was between 8-10 % of the total production costs over a period from 2002-2012. For most of the plants surveyed under the study, EU-ETS contributed around 86% of the total cost of regulation. This is followed by the environmental regulations and product regulations. It is important to note that, the study did not consider the environmental, health and other possible benefits because of these regulations. [51]

Electricity generators in the EU face increase in the operation cost due to requirement of purchasing allowances for meeting CO_2 reduction targets under the EU-ETS. This increase in the cost is passed on downstream to the consumer (primary aluminum industry). Around 40% of the total cost of primary aluminum production comes from electricity purchase which are higher in the Europe compared to other regions. Owing to the common global pricing platform for aluminum at London metal exchange, the aluminum industry in Europe are unable to pass on the high electricity cost to the customer. These factors have made significant contribution towards 'carbon leakage' [51].

There exist several definitions of carbon leakage, one given by EU-ETS regulation is "In the event that the other developed and devloping countries do not participate in an international agreement to reduce GHG emissions, this could lead to an increase in GHG emissions in developing countries where industry would not be subjected to comparable carbon constraints (carbon leakage), and at the same time, put certain energy-intensive industrial sectors at an economic disadvantage if they operate in an area where there is carbon constraints policy in place, due to common market. Eventually, this situation of uneven policy makes energy intensive industrial facilities to shift their operations to an area where there is less policy constraints on emissions of GHG and other pollutants, thereby contributing to the leakage of carbon. This could undermine the environmental integrity, benefits and actions taken by the countries who are implementing these policies [51].

If the current loss of competitiveness for primary aluminum production is not addressed, Europe will become increasingly dependent on importing the aluminum. The most important drawback of this scenario is that Europe will be responsible for 178% more GHG emissions as the imported aluminum will have much higher carbon footprint compared to aluminum produced in the EU. Therefore, retention of primary aluminum industry in Europe is important from a global perspective on emission reduction. [52]

The retention of aluminum industry in Europe requires following measures to be taken as soon as possible. [52]

- Full compensation is required for indirect effect of the emission trading scheme on electricity prices as long as the rest of the world has not adopted identical measures.
- Full compensation for implementation of renewable energy.
- Promotion & development of innovative solutions by advanced technology to have an advantage over technology.
- An ambitious EU's industrial policy giving a 25 years' visibility to potential investors in terms of long term electricity contracts.
- Support for aluminum industry to help the EU become the best recycling society in the world. As recycling of aluminum consumes only 5% of the energy required for primary production this measure can come with a significant energy and cost savings. [52]

The European Commission is taking initiatives to compensate the issue of carbon leakage from aluminum industry. This is done by allocating free allowances for direct emissions to the primary aluminum plants. Also, the member states can use the state aid to compensate energy intensive industries through state aid provision. In addition, the EU-ETS scheme is itself under a review and changes in the scheme could bring in some relief for an aluminum industry.

Around the world, there are many other cap and trade systems emerging similar to EU-ETS. Therefore, the industries in the EU will not be the only ones facing ETS costs and competitive disadvantages. [51]

8 Conclusion

Air quality management is becoming increasingly important both from the perspective of human health and global warming. It is important to examine the policies and instruments available on global, continental, national and local level in order to understand existing or establish new efficient control procedures for air pollution and global warming. In this study, these policies and instruments were studied for the EU and the US. In both cases the set of instruments differ but have a common aim of maintaining best possible air quality. The EU member states and the US have achieved significant reduction in air pollution and GHG emissions, however if the goal is to achieve considerable reduction of industrial environmental footprint, then improvements seem to be needed both in terms of monitoring and reporting mechanisms as well as in reduction of emissions. For the latter, it will be both in the form of mechanisms of enforcement (particularly in Europe) and GHG reduction commitments and plans (particularly in the US). The major findings in this thesis regarding this can be summarized in the following three points.

- **Study and comparisons of regulations in the EU and the US**: The comparisons of environmental regulations on air pollution from industrial facilities in the EU and the US suggest that when it comes to regulatory outcomes, the US is still the environmental leader. The policies in the EU are not always leading to better environmental performance from industries compared to the US. Main reasons for this outcome are strict enforcement mechanisms and severe penalties for environmental crime in the US. By contrast, in the EU even though having a good framework for limiting air pollution, the weak enforcement mechanism makes it difficult to exactly implement the measures on the ground level.

  When it comes to environmental regulations for GHG reductions (climate change), the EU is somewhat ahead of the US. The EU has a comprehensive policy framework for mandatory monitoring and reduction of GHG in the form of EU-ETS, while the US has a framework only for mandatory monitoring and not reduction of GHG in the form of GHGRP. However, it is important to note that the monitoring methodologies adopted under the EU-ETS and GHGRP are similar.
- **Aluminum industry in the EU**: The main environmental regulations for reducing air pollution and climate change effects from aluminum industry in the EU are IED and EU-ETS. By studying guidelines and requirements under these regulations for aluminum industry, it can be concluded that there exists a very good framework for monitoring and reduction in emission of pollutants from aluminum industry in the EU. However, the primary aluminum industry in the EU is at competitive disadvantage due to cost of environmental regulations.

On the other hand, the secondary aluminum industry in Europe is booming due to innovative ideas about circular economy. Secondary aluminum industry has minimal environmental impact compared to primary aluminum industry due to large amount of energy savings and cleaner production. EU has made a significant progress for efficiently collecting, sorting and recycling aluminum thereby closing the aluminum production loop which makes great contribution towards a sustainable production.

- **System design for monitoring and reporting process under IED**: Different stakeholders (Internal & External) are having a great amount of interest in external reports such as environmental, sustainability, financial reports of an organization. However, there is limited information available on standard practices and internal mechanisms that contributes to prepare such external reports. The internal mechanism of reporting is explained by assuming different business units in hypothetical organizations. This may constitute a high-level system design for industry reports under IED. The overview of system design was created for monitoring and reporting of emissions under IED. This overview of system design can be used as a basis for implementation on software system for easy recording and maintenance of pollutants emission data under IED in the EU.

Finally, since the air pollution and the climate change are global issues, a unified action from all countries around the world seems to be needed in order to completely eradicate these problems. The US has achieved a considerable success in reducing air pollution from industrial facilities while the EU has made a good progress in reducing GHG causing global warming. Therefore, the US and the EU have until present achieved a considerable success in fighting with this cause compared to the rest of world. But recently, the US government has pulled out of the Paris agreement for reducing GHG emissions under UNFCCC. This brings in more uncertainty going forward, about how other countries will react to the decision by the US. Therefore, a more coordinated approach between developed and developing countries is needed to achieve consensus between economic development and better quality of environment worldwide.

9 Future recommendations

The study of environmental regulations affecting stationary source of the pollutants can be applicable in several different areas. Some of these recommendations are discussed below. In this study, monitoring and reporting requirements of aluminum industry under IED in the Europe was studied. Therefore, it can be interesting to study similar requirement of regulations for aluminum industry in the US. If possible, the most important point which must be included in this study is to collect the actual reported data on all different pollutants from aluminum production plants in the EU and the USA. The collected data can be compared to make a conclusion about which aluminum industry has a better environmental performance. These comparisons must be done between the production units with the same production capacity or pollutant emitted per unit mass of aluminum produced. The conclusions from this kind of study can be helpful in analyzing the areas of improvement for the aluminum industry that yields the poorer results.

Data for comparisons can be accessed from publicly available pollutant release and transfer registers. It would also be interesting to study what technologies and environmental practices better performing aluminum industry has implemented. These practices and technology can then be integrated into other aluminum industries to produce better results. Finally, this kind of comparative studies can be done for many different industries which has a reputation of emitting large amount of harmful pollutants. Examples of these industries include chemical manufacturing, other metals production (copper, iron & steel, zinc, tin etc.), oil & gas exploration and refinery, pharmaceuticals production etc.

Also, it could be interesting to analyze the quantification methodologies implemented for calculations of GHG emissions by different industries. Since there are different tiers available based on which GHG emissions can be calculated. It is important to use the highest tier for having the best accuracy of GHG emitted. Therefore, if some industries are using lower tier for estimation of GHG emissions, the recommendation must be made to use the highest tier possible.

During an introduction to this study, the increase in environmental standards is discussed. The increase in these standards is significant from countries in Asia pacific and Africa. Therefore, it can be interesting to study about the standards from countries in these regions and compare it with the best standards in the world.

In a study carried out by ‘Yale Center of Environmental Policy and Law’ to evaluate best performing countries on high priority environmental issues such as protection of human health and ecosystems. Within these two priority issues the index was developed called Environmental Performance Index (EPI) and countries were ranked on their EPI score. Countries in Scandinavia were the highest ranked when it comes to the protection of environment. Therefore, it can be interesting to study the environmental regulations in Scandinavia and their guidelines. These standards and practices from Scandinavian countries could be used as a benchmark for better industrial environmental performance in other countries. However, it is also important to note that these countries are highly developed with reasonably less populations. Therefore, it is not so difficult to have best standards for environmental protection compared to the countries that are still in a developing stage and has much larger populations. [55]

Finally, the kind of monitoring and reporting practice implemented by any organization determines how successful an organization is towards meeting environmental standards. In this study, different elements involved in this practice were studied in detail (Figure 6-3 and 6-4) for the IED in the EU. This system can be implemented in the software for easy recording, maintenance and accessibility of the data. In any heavy industry, there are large number of emission points, processes and pollutants involved, therefore the software solution makes it easy for operators to enter data and maintain record of all pollutants emitted from specific processes. The software solution makes it easy to retrieve the required data easily for internal/external audits, preparation of different compliance reports to the government agency and for analyzing environmental performance of industrial facilities with the help of graphs charts etc. Eventually, this helps in planning to reduce emissions of certain pollutants and improving environmental footprint of an organization. Also, similar studies could be done for all different environmental standards such as NESHAP, NSPS, GHGRP, TRI etc in the US and EU-ETS, E-PRTR, MCP, F-Gas in the EU.

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Appendix A Emissions Calculations methodology

Candidate: Mehul Vora

Title: Emission calculation methodology used in EU-ETS and GHGRP

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Abbreviation

AD	Activity data
AP-42	Compilation of air pollutant emission factor
AVR	Accreditation and Verification Regulation
CEMS	Continuous Emissions Monitoring system
EF	Emission factor
Em	Emission
EU-ETS	European Union-Emission Trading System
FQ	Fuel quantity
GHGRP	Greenhouse Gas Reporting Program
HHV	Higher Heating Value
IPCC	Intergovernmental Panel on Climate Change
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
MRR	Monitoring and Reporting Regulation
MRV	Monitoring, Reporting and Verification
NCV	Net calorific value
Nm^3	Normal meter cube
OAQPS	Office of Air Quality Planning and Standards
OF	Oxidation factor
t	ton
t CO_2	ton of CO2
US-EPA	United States-Environment Protection Agency

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10 Introduction

This report has been primarily written to understand the monitoring and emission calculation approaches put forward by European Union-Emission Trading System (EU-ETS) and US-EPA's Greenhouse gas reporting program (GHGRP) for reporting of carbon dioxide (CO_2). Report covers general approaches adopted for stationary sources of fuel combustion. The methodology adopted for measuring of pollutant emission plays a key role in credibility of data reported by any organization [2]. The methodology adopted by different industries for measuring a pollutant is extremely important for any environmental regulation to work effectively. The key principle of monitoring, reporting and verification to create trust in reporting systems are as follows [2].

- Completeness: all emission from different sources needs to be included
- Consistency: the results should be comparable over the time
- Transparency: the data and assumption should be recorded
- Trueness: the results should reflect true data
- Cost effectiveness: the data should balance accuracy and cost
- Improvement of performance: the operator should be able to improve performance based on data

The scope of this report is to summarize CO_2 measurement methodology available in EU-ETS and USA-GHGRP legislation and to understand the principle behind calculations.

11 GHG emissions calculations methodology in EU-ETS

Annual process of monitoring, reporting and verification (MRV) together with all associated process makes a basis for EU-ETS compliance cycle. The detailed rules related to compliance cycle are set out in two regulations adopted by the EU. [3]

- Monitoring and Reporting Regulation (MRR)
- Accreditation and Verification Regulation (AVR)

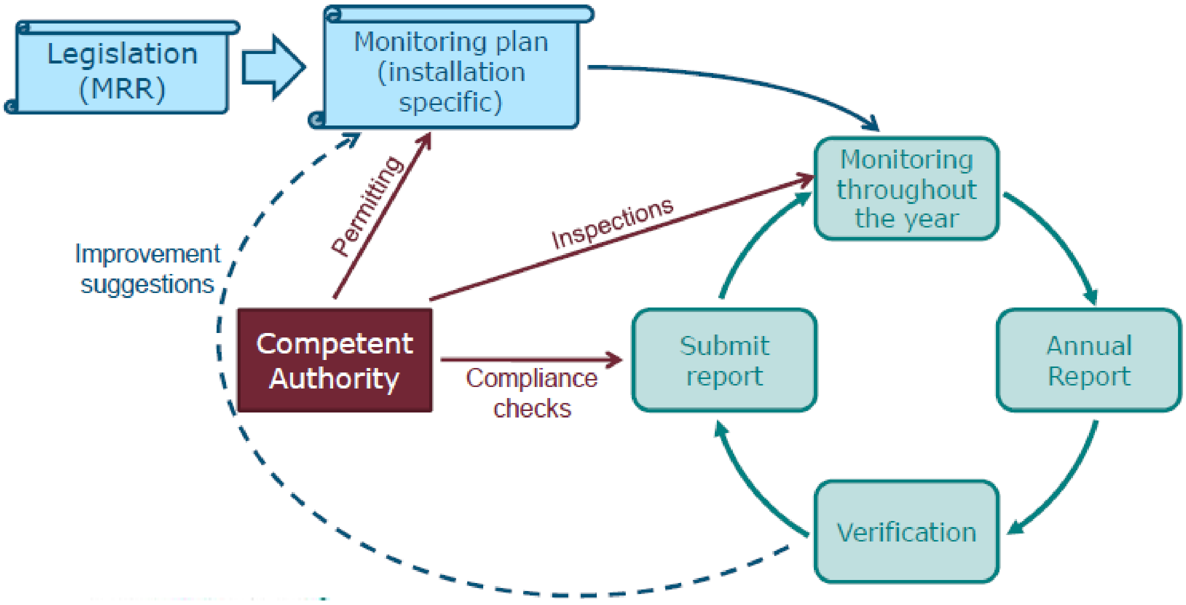

Figure 1: Principle of EU-ETS compliance cycle [3]

The Figure 1 above shows the overview of different stages in compliance cycle for EU-ETS. The key elements of compliance cycle are as follows [2]

- Operator: develops monitoring plan according to requirements of legislation.
- Competent authority: reviews and approves monitoring plan.
- Operator: implements and runs the monitoring system.
- Verifier: check implementation and operators report.
- Competent authority: has a final decision on data presented.

In this report, the focus is on important concepts and terms needed for developing monitoring plan specifically monitoring approaches by operators in line with MRR. The MRR allows the operator to choose the monitoring approach from the regulation which is as follows [2, 3]

1. Calculation based approaches:
    - Standard methodology (distinguishing combustion and process emissions)
    - Mass balance
2. Measurement based approaches
3. Methodology not based on tiers (Fall back approach)
4. Combination of approaches

11.1 Standard methodology

The principle of this method is to calculate the emission by taking into account amount of fuel consumed. Amount of fuel consumed is then multiplied by an emission factor and other factors such as oxidation factor to calculate the final amount of pollutant emitted. The standard approach is straightforward which is applied in cases where fuel consumption is directly related to emissions. The standard methodology can be classified into two different types as follows. [3]

11.1.1 Combustion emission

The emission from combustion of fuel is calculated as per this equation

$$Em = AD*EF*OF \qquad (1)$$

Where Em = Emission [t CO_2]

AD = Activity data [Nm^3 or t]

EF = Emission factor [t CO_2/Nm3 or t CO_2/t]

OF = Oxidation factor [dimensionless]

The activity data of the fuels are expressed as net calorific value (NCV)

$$AD = FQ*NCV \qquad (2)$$

Where FQ = Fuel quantity [t or Nm^3]

NCV = Net calorific value [TJ/t or TJ/Nm^3]

The oxidation factor is calculated as

$$OF = 1 - C_{ash}/C_{comb}$$

C_{ash} = carbon contained in ash, soot or other non-oxidized forms of carbon excluding carbon monoxide

C_{comb} = Total carbon combusted [3]

11.1.2 Process emission

The emission from process are calculated as follows

$$Em = AD*EF*CF$$

Where Em = Emission [t CO_2]

AD= Activity data [Nm^3 or t]

EF = Emission factor [t CO_2/Nm3 or t CO_2/t]

CF = Conversion factor [dimensionless]

11.2 Mass balance approach

The mass balance approach also uses calculation based methods for determining emission from a stationary source. Mass balance approach is applied where the emissions are not directly related to individual input materials. The example of use of mass balance equation is calculation of process CO_2 emissions from prebake technology in aluminum production. Mass balance equation is generally used when products and wastes contain significant amounts of carbon and thus it requires complete balance of carbon entering and leaving the system. The following formula is applicable for mass balances of carbon in complicated system. [3]

$$EM_{mb} = \sum (f*AD*CC) \qquad (3)$$

Where EM_{mb} = Emission from all source stream included in mass balance [t CO_2]

f = factor for converting the molar mass of carbon to CO_2.

AD = mass of material or fuel under consideration. Ingoing material are taken as positive while outgoing is taken as negative.

CC = carbon content of component under consideration. Always dimensionless and Positive

11.3 Measurement based approach

In contrast to calculations based approach, the greenhouse gases are object of measurement in measurement based approach. This approach is difficult to implement where many emission points are in place. The approach is also impossible where fugitive emissions have to be taken into account. The strength of measurement based approach is that it is independent of the number of different fuels and materials used for combustion. The measurement based approach is based on a continuous emission measurement system (CEMS) which always require two elements for measurement. [3]

- Measurement of greenhouse gas concentration
- Volumetric flow of gas stream where the measurement takes place

11.4 Fall back and combination approach

The EU-ETS system provides different building blocks for monitoring methodologies. Different parameter required for calculations of the emission can be selected based on different levels of data quality which are called tiers. Table 1 shows the building blocks available to select tiers for different parameters. Table 2 shows the tier system applicable to CO_2 emission from combustion activity as an example. In general, it can be said that lower tiers are less accurate than the higher tiers.

In case where tier system is not technically feasible or leads to unwanted cost to an operator, the Article-22 (of EU regulation no 601/2012) allows the operator to apply non-tier based methodology also known as fall back methodology. The operator may use a monitoring methodology not based on tiers, provided all of following conditions are met [2, 3]

- Applying at least tier 1 under the calculation-based methodology for one or more major or minor source streams is technically not feasible or would incur unreasonable costs.
- A measurement based approach for the correlated emission source using tier 1 is not possible without incurring unreasonable costs.

Table 1: Building blocks for selecting tiers [1]

Fuel quantity	Net calorific value	(prelim.) Emission factor	Biomass fraction	Oxidation factor
Tier 4	Tier 3	Tier 3	Tier 2	Tier 3
Tier 3	Tier 2a / 2b	Tier 2a / 2b	Tier 1	Tier 2
Tier 2	Tier 1	Tier 1		Tier 1
Tier 1				

Table 2: Tier system for combustion activity [1]

Tier Level	Activity Data		Emission Factor	Biomass Fraction	Oxidation Factor
	Maximum uncertainty in fuel amount	Net Calorific Value			
Tier 4	± 1.5%	Factors determined by analysis	Factors determined by analysis	Factors determined by analysis	Factors determined by analysis
Tier 3	± 2.5%				
Tier 2	± 5%	Country specific factors / value from fuel invoices	Country specific factors / proxy values from analysis		Country specific factors
Tier 1	± 7.5%	Standard factors from Annex VI of the MRR	Standard factors from Annex VI of the MRR	Standard factors	1

The MRR also allows the operator to combine seamlessly the calculation and measurement approaches discussed in previous sections. The condition for combining these approaches is to not have impact on data quality and there should not be any double counting. This approach is known as combination of approaches. [3]

12 GHG emission calculations methodology in GHGRP-USA

Greenhouse gas reporting program (GHGRP) uses two main methods for calculation of GHG from stationary combustion sources:

- Direct measurement
- Analysis of fuel input

The combustion from stationary combustion sources results in GHG mainly CO_2, CH_4 and N_2O. The stationary sources include boilers, heaters, furnaces, kilns, ovens, flares, thermal oxidizers etc. Direct measurement is performed through Continuous Emission Monitoring System (CEMS). The fuel analysis is essentially a mass balance approach where carbon content factors are applied to fuel input to determine emissions [5].

12.1 Direct measurement

The direct measurement is done by using continuous emission monitors which continuously measures pollutants emitted into the atmosphere in exhaust gases from industrial process. Different EPA regulatory program such as acid rain program, new source performance standards, greenhouse gas reporting program and maximum achievable control technology have provision regarding use of continuous emission monitoring system (CEMS). The principle behind CEMS for GHGRP is as follows. [5]

- A monitor measuring CO_2 concentration percent by volume of flue gas. The flow monitoring system measuring a flowrate of flue gas. These two parameters can be combined together to calculate mass emission of CO_2.
- A monitor measuring O2(oxygen) concentration percent by volume of flue gas. The flow monitoring system measuring flowrate of flue gas. The above two parameters can be combined together with theoretical CO_2 and flue gas production by fuel characteristics to determine CO_2 mass emissions.

The CEMS cannot be used to calculate CH_4 (Methane) and N_2O (nitrous oxide) emission, in this case fuel analysis method is used which is described below. The fuel analysis is also used by organization with no CEMS installed. [5]

12.2 Fuel analysis method

The fuel analysis method uses carbon content data of the fuel combusted using either fuel specific information or default emission factors to quantify CO_2 emissions. There are three different equations available which can be used to calculate CO_2 emissions. Two of these three equations can also be used to calculate CH_4 and N_2O emissions. The appropriate equation to be used depends on what information is known about the fuel which is being combusted. [5]

Equation 1:	Equation 2:	Equation 3:
Emissions = Fuel x EF_1	Emissions = Fuel x HHV x EF_2	Emissions = Fuel x CC x 44/12
Where:	Where:	Where:
Emissions = Mass of CO_2, CH_4, or N_2O emitted	Emissions = Mass of CO_2, CH_4, or N_2O emitted	Emissions = Mass of CO_2 emitted
Fuel = Mass or volume of fuel combusted	Fuel = Mass or volume of fuel combusted	Fuel = Mass or volume of fuel combusted
EF_1 = CO_2, CH_4, or N_2O emission factor per mass or volume unit	HHV = Fuel heat content (higher heating value), in units of energy per mass or volume of fuel	CC = Fuel carbon content, in units of mass of carbon per mass or volume of fuel
	EF_2 = CO_2, CH_4, or N_2O emission factor per energy unit	44/12 = ratio of molecular weights of CO_2 and carbon

Figure 1: Equations for determining amount of pollutant emissions [5]

Equation 1 is used when the fuel consumption is known in mass and volume units and no information is available about fuel heat content and carbon content. The use of this equation for calculation is least preferred as it brings huge amount of uncertainty into the calculations. The uncertainty comes from the default emission factors which are based on default fuel heat content rather than the actual heat content. [5]

Equation number 2 is recommended when the actual fuel heat content is known. Equation 2 is preferred over the equation 1. The emission factors used in equation 2 are based on the energy units as opposed to mass units in equation 1. The emission factors based on energy units are more accurate. The reason being the carbon content of the fuel is more closely related to the heat content of the fuel than to the total physical quantity of the fuel. [5]

Equation 3 is recommended when actual carbon content of the fuel is known. Equation 3 is the most preferred for the CO_2 emission calculation because CO_2 emission data are directly related to the fuels carbon content. Equation 3 is only applicable for the CO_2 emission. [5]

Table 1: Tiers in 40 CFR 98 for CO_2 *calculations* [7]

Tier	Method
Tier 4	Calculate emissions using CEMs data.
Tier 3	Calculates emissions from solid and liquid fuels using annual average carbon content from fuel sampling and an annual average molecular weight for gaseous fuels.
Tier 2	Calculates emissions using an annual average high heat value (HHV) from fuel sampling and a default emission factor.
Tier 1	Calculates emissions using a default HHV and a default emission factor.

Table 3 shows calculation methodologies needs to be adopted under the different tiers. The USA-GHGRP has different tiers based on which pollutant emissions are calculated.

- Tier 1 uses the default value of the emission factor and the high heating value (HHV) along with the estimated fuel quantity to calculate emissions.
- Tier-2 uses a mix of the default data for emission factor and specific data of fuel consumed. A default emission factor and measured HHV in conjunction with estimated fuel quantity to calculate mass emissions.
- Tier-3 uses the measured carbon content and molecular weight of the fuel in conjunction with the fuel quantity to calculate mass emissions.
- Tier-4 uses CEMS which monitors both the stack CO_2 concentration and the gas flowrate to calculate mass emissions. [4]

The equation 1 from the Figure 2 is used for tier 1. Equation 2 in Figure 2 is used for both tier 1 and tier 2. The difference between using equation 1 and 2 is that in tier 1, the default high heat value of fuel is used while in case of tier 2 annual average high heat value of fuel is used. Equation 3 from the Figure 2 is used for tier 3. [7]

13 Discussion

The most important parameter in calculating any emission without CEMS is the use emission factor. Emission factor is the stoichiometric factor which converts the carbon content of a material into the equivalent mass of the CO_2 assumed to be emitted. Emission factors for fuel combustion are generally adopted from Intergovernmental Panel on Climate Change (IPCC). IPCC has emission factor database updated in 2006 and contains large amount of data for different fuels used by various industry. EU-ETS generally uses values available from the IPCC emission factor database. Different values for emission, oxidation and conversion factor are chosen based on the tiers. In EU-ETS, the lower tier can select default values while higher tier generally requires chemical analysis of fuel in laboratory. [3]

Table 4: Overview of tier definition for use of emission factor in EU-ETS [2]

Source stream type	Factor	Tier EU-ETS	Tier definition EU-ETS
Combustion emission	Emission Factor	1	Type-1 default values
		2a	Type-2 default values
		2b	Established proxies
		3	Laboratory analysis

Table 4 above shows different tiers available in EU-ETS for selection of emission factors values. The similar tiers are available for selection of other parameters such as net calorific value, oxidation factor, carbon content etc. In EU-ETS for emission factor, type-1 default values are either standard factor (adopted from IPCC values) or values provided by the supplier or analysis carried out in the past but is still valid. The type-2 default values are values used for national GHG inventory normally published by competent authority or other literature values which are agreed by competent authority. The values used in established proxies are based on empirical correlation as determined at least once a year in accordance with requirement of laboratory analysis. The proxy correlation could be based on density measurement of specific oil and gases and net calorific values for specific coal types. The final tier uses strict values from laboratory analysis in accordance with ISO/IEC 17025. [2]

The USA in 1972 had published first document under Office of Air Quality Planning and Standards (OAQPS) containing EPA's emission factors and supporting documents (AP-42) [6]. In addition to AP-42, Locating and Estimating (L&E) document series was developed in 1984 for pollutants not covered under AP-42. The emission factors are accessible through online database tool WEBFire [6]. The EPA has also given quality ratings for emission factor values e g A for excellent and E for poor accuracy based on engineering judgement. The rating of emission factor is determined by a two-step process [8].

1. First step involves estimation of data quality. The estimation involves reliability of basic emission data which will be used to develop the factor [8].
2. Second step is to assess how well the factor can stand as a national average emission factor for the source activity [8].

The logic used while allotting ranks is that emission factor which has robust data quality and minimum variability is placed on the top. Data obtained from unknown test methods and high variability has low ranking. The AP-42 ratings assigned are as follows

A. Excellent: The data used to produce emission factor is robust with minimum variability.
B. Above Average: The data used here is robust but with some variability.
C. Average: The data quality is poor compared to A and B. The data also is not exactly good representative of random facility.
D. Below Average: The data set has a poor quality and also high variability.
E. Poor: The data quality is unacceptable and doesn't represent random facility at all. [8]

The most important factor in choosing emission factor is the applicability of the emission factor. If the emission factor is used in submitting annual emission reports or regulatory and compliance requirement, then it is important that emission factor data has a very good quality with minimum variability. [8]

Calculation methodology adopted by US-GHGRP and EU-ETS follow mostly similar approach. The main difference in calculating emissions was found in the use of heating value of fuel, units used for calculation, selection of emission factor data, use of oxidation factors etc. Main comparisons between EU-ETS and GHGRP are summarized in Table 5.

Table 5: Comparisons between EU-ETS and GHGRP

EU-Emission Trading System	**Greenhouse Gas Reporting Program**
The EU-ETS requires control and reduction of greenhouse gases.	The GHGRP requires only monitoring and reporting of greenhouse gases.
The emission factors used in EU-ETS are generally adopted from database of Intergovernmental Panel on Climate Change.	The emission factors used in GHGRP are provided by Office of Air Quality Planning and Standards-AP (42).
In EU, lower heating value is used for calculations.	In US, higher heating value is used for calculations.
The units for measurement used in EU are generally System International units.	The units for measurement in US are Imperial system of units.
Methane and fluorinated gases are not included in the regulation.	Methane and fluorinated gases are included in the regulation.
Oxidation factor is used in the calculations.	Oxygen factor is not mentioned in regulation.

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