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Environmental Impact Assessment for Outer Space Activities as a Measure to Prevent and Mitigate Environmental Impacts on Earth, in Space and on other Celestial Bodies

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
a.o. Univ.-Prof. Mag. Dr. Irmgard Marboe

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Affidavit

I, **JULIA KRAFT, BA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ENVIRONMENTAL IMPACT ASSESSMENT FOR OUTER SPACE ACTIVITIES AS A MEASURE TO PREVENT AND MITIGATE ENVIRONMENTAL IMPACTS ON EARTH, IN SPACE AND ON OTHER CELESTIAL BODIES", 112 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

Outer space activities have entered a period of continuous expansion through privatization, tourism, military and other efforts, simultaneously increasing the concern for potential environmental impacts caused by the increased amount of space operations on the Earth, space and other planetary ecosystems.

With an interdisciplinary approach including a strong technical focus, assessing environmental pollution on the earth, space and planetary environments, as well as a strong legal focus, determining potential legal requirements for the conduct of procedures assessing environmental impacts of a proposed action previous.

The analysis is based on the three largest emission sources of spaceflight: (1) Launching- and Flight-Stage Pollution, including rocket propulsion emissions, hazardous materials, and air, water, soil contaminations inter alia, (2) Space Debris, and (3) Planetary Contamination, including backward and forward pollution on earth and other planetary systems.

The definition, aim, and structure of terrestrial Environmental Impact Assessment procedures are discussed, including the relevant national, European and international legal basis and application. The thesis continues by evaluating legal norms and regulations governing the use of Environmental Impact Assessments for outer space projects.

This thesis seeks to assess if national, European and international legislation and guidelines establish a requirement for the conduct of EIAs including the establishment of prevention and mitigation measures for environmental consequences arising from the use and exploration of outer space.

The legal and technical frameworks are further assessed in the case study of NASA's Mars 2020 Mission and the therefore published Environmental Impact Statement.

Recommendations are given with respect to widening the legal application not only on the requirement of assessing potential harm by a space mission but also in establishing obligations on the oversight of compliance with prevention and mitigation measures for the minimization of environmental consequences set up in an Environmental Impact Statement.

Keywords:

Environmental Impact Assessment, Outer Space, Environment, Emissions, Mars, Space Debris

Table of Contents:

List of Relevant Abbreviations

AP	Aluminum Peroxide
CCAFS	Cape Canaveral Air Force Station
COPUOS	Committee on the Peaceful Uses of Outer Space (UNOOSA)
COSPAR	United Nations Committee on Space Research
DOE	United States Department of Energy
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
ESA	European Space Agency
GEO	Geostationary Earth Orbit
GPIM	Green Propellant Infusion Mission
GRASP	Green Advanced Space Propulsion
GTO	Geo
IA	Impact Assessment
IAA	International Academy of Astronautics
IADC	Inter-Agency Space Debris Coordination Committee
ILC	International Law Commission
ITU	International Telecommunication Union
KSC	Kennedy Space Center

LEO	Low Earth Orbit
LWRHU	Light-Weight Radioisotope Heater Units
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act (USA)
NPR	Nuclear Procedural Requirements (NASA)
NPS	Nuclear Propulsion System
ODS	Ozone-Depleting Substances
OST	Outer Space Treaty
RGU	Radioisotope Heater Units
RTS	Radioisotope Thermoelectric Generator
SEA	Strategic Environmental Assessment
SNSB	Swedish National Space Board
TEG	Thermoelectric Generator
UNOOSA	United Nations Office for Outer Space Affairs
UVP-G	Umweltvertraeglichkeitspruefungsgesetz

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Introduction

"*It's not rocket science: leaving the planet costs the Earth*" (Hickman 2009).

Outer Space activities have quantitatively reached an all-time high through increased privatization and commercialization efforts by some countries, as well as the increasing importance of space for scientific earth observation, and for military defense strategies.

With an increase in space mission launches, the potential of negatively affecting the earth and space environment on a short- and long-term basis has risen. To prevent and mitigate any severe environmental consequences, an a priori assessment could define possible pollution scenarios.

This thesis will assess the problematic of the potential impact of spaceflight on the earth, space and planetary environments through an interdisciplinary approach including two research questions, one of legal and one of technical nature. The first enquires if an obligation to an Environmental Impact Assessment for Outer Space Activities exists, and if not, if it can be deduced from international, European, and national legal norms. The second question asks if the three major emissions arising from a space operation are adequately addressed in an Environmental Impact Assessment.

Due to limited resources and a generally existing scientific research gap, it will neither be possible to directly measure the impact of such an assessment on the earth and space environment, nor to determine if it is a sufficiently effective measure for the prevention and mitigation of environmental consequences.

The thesis will be structured in three parts. The first part will discuss the three main environmental emission sources of spaceflight operations. The second part will address the aims and definition of a general terrestrial Environmental Impact Assessment including the legal norms and guidelines establishing obligations or recommendations to conduct such an assessment. This second part will continue to determine the legal requirements for an EIA conduct for outer space projects and programs. The third part will give an example of an Environmental Impact Statement for a deep space activity, the Mars 2020 Mission, which will be concluded by an assessment of the applicability of the beforehand discussed legal provisions for an outer space EIA, including any potential problematics arising from the conduct of an EIA for spaceflight missions.

The hypotheses set up before commencing with a detailed analysis of the problems at hand are: (1) Outer Space Missions are the cause for irreversible harm to the earth and space environment. (2) The major emission sources from space operations are addressed in Environmental Impact Assessments. (3) The conduct of an Environmental Impact Assessment and the publishing of an Environmental Impact Statement are ideal tools to incorporate environmental values and scientific analyses into decision-making processes.

1. General Basic Definitions

Spacecraft:

Spacecraft are categorized by their respective missions, such as Earth, lunar, interplanetary, or trans-solar satellites, as manned or unmanned; as well as respective to their usage, such as for communication, navigation, weather analysis, scientific exploration, observation, reconnaissance, deep space exploration, as well as for launches and others purposes (Sutton and Biblarz 2017: 20f).

Launch vehicle:

A launch vehicle is any type of vehicle which has the ability to transport to and place one or more objects in outer space, as well as any sub-orbital rocket. The term launch vehicle orbital stage refers to a stage where any launch vehicle is left in earth orbit (Inter-Agency 2014: 10).

Protected regions:

Operations in outer space recognize the special nature of the following earth orbit regions (Inter-Agency 2014: 11):

Low Earth Orbit (LEO) is a sphere extending from the earth surface up to 2,000km.

Geosynchronous Region is found at a geostationary altitude minus and plus 200km.

Geostationary Earth Orbit (GEO) is a circular orbit at an altitude of 35,786km and has zero eccentricity and inclination.

Geostationary Transfer Orbit (GTO) is or is used as a transfer zone for spacecraft or to transfer one orbital stage to another.

Operation Phase (Inter-Agency 2014: 13)**:**

The Launch phase starts when the spacecraft or launch vehicle is released from physical contact with the ground via ignition and ends with the arrival of the vehicle at the destination.

The mission phase is the time when a space mission is conducted.

The disposal phase should reduce all remaining hazards of the spacecraft to other vehicles and orbital stages.

2. Impact and negative consequences of spaceflight on the environment

An increasing number of countries, organizations and private corporations are operating in outer space, resulting in an increasingly diverse number of existing satellites and launchers and an escalation of commercial investment in current and future space missions. While this expansion of space operations has many benefits for mankind, these activities generate an increasing amount of emissions and space debris, the two largest impacts of spaceflight operations on the earth and space environments. The third emission to be discussed is the planetary impact of a space mission to another planetary system, such as the Mars in the Case Study NASA's Mars 2020 Mission.

This chapter will analyze these three major emissions of spaceflight on the earth environment, the space environment as well as the environment of other planets and list technological efforts to conquer these impacts.

2.1. Launching- & Flight-Stage Pollution

Many pollution types are the same at all launch sites and flight-stage operation. This following section will analyze those on the base of the in 2002 conducted Environmental Impact Assessment on routine payloads of space operations by the National Aeronautics and Space Administration including the publishment of the results as a so-called 'Finding of No Significant Impact' (NASA 2011a):

(1) Hazardous Materials and Waste,

(2) Human Health and Safety,

(3) Water Quality,

(4) Air Quality,

(5) Noise and Vibration,

(6) Biological Resources,

(7) Historic and Cultural Resources,

(8) Global Environment (Troposphere, Stratosphere),

As a detailed analysis of the environmental impacts from launching stage operations will be conducted in the case study, this following section will serve only as a brief introduction to the existing hazards from outer space missions.

Air quality can generally be affected by vehicle preparation, traffic, power generation and other routine operations. Most countries have set up national air quality standards or must comply with internationally agreed emission limits. Previous NASA emission assessments have determined that at all NASA launch site propulsion engine emissions would not have long-term effects on human, or ecosystem health (NASA 2011a).

Some spacecraft carry radioactive materials. The exhaust of radioactive materials in case of a launching accident is minimized through advanced technological protection and mitigation measures. Some missions transport lasers for usage in space operation. Those lasers could, if no compliance with standards for the safe use is guaranteed, impact human health. But generally speaking, NASA has advanced safety measures in place, to avoid any such effects (NASA 2011a).

Hazardous materials include compounds with a potentially negative effect on human health and the environment. The use and transport of liquid propellants such as liquid oxygen, or hydrazine, pose potential risks on the environment if emitted in large amounts. NASA has adopted safety measures and hired specific handling experts who store these hazardous materials in special basins and guarantee the safe conduct of operation in accordance with the Resource Conservation and Recovery Act of the United States (NASA 2011a).

Noise pollution and sonic booms are general features of a space launch. As long as it is guaranteed that no population residencies are situated in close proximity to the launching state, noise pollution will not cause any adverse effects on human health. Compliance with animal protection standards ensures that no long-term harm is done to animals in that regard (NASA 2011a).

Cultural Resources are not affected during normal launch operations. Solely the construction of new launching pads might interfere with cultural or historic properties (NASA 2011a).

Socioeconomic effects must be analyzed previously to any space operation activity to ensure that no negative effects will be noticeable with regards to tourism, health, public activities, and etcetera (NASA 2011a).

Many hazards for the earth environment as well as human health and safety can arise from the preparation of a space launch and from the launch itself in close proximity to the launching site. Relevant precautions must be taken to ensure that the negative impact of any space rocket or space launch vehicle launch is minimized.

2.1.1. Propulsion Emissions

While most of the emissions listed above will be analyzed in detail in the case study, this chapter will focus on number 8 of the above-included list on space launch operation emissions. The global environment including the stratosphere and the troposphere are mainly impacted by emissions from rocket propulsion systems. An assessment of propulsion emissions from space flight and their effect on the environment will be conducted in the following section.

2.1.2. Propulsion Definition

Propulsion, originating from the Latin propeller, propolus, has the meaning of "*to drive away*" (Sutton and Biblarz 2017: 1).

Propulsion is defined as the action of change in the motion of a system in the inertial frame of reference. The provision of forces to the inertial movement, standstill or the overpowering of retardation forces, are the general acts of propulsion systems (Sutton and Biblarz 2017: 1).

Jet propulsion in general terms provides a reaction force for a vehicle via the ejection of matter momentum. Rocket propulsion as a form of jet propulsion produces motion by ejecting working fluid or the propellant, completely stored within the flying rocket. Another class of jet propulsion is duct propulsion, including ram- and turbojets, using air-breathing engines, mainly utilizing the surrounding matter as a propellant, including the energy from fuel combustion. Some applications have used a combination of rocket and duct propulsion systems, but are rather rare and will not be considered in the following thesis as rockets are not considered duct engines (Sutton and Biblarz 2017: 1).

Table 1 explains the most important propulsion concepts, their respective energy sources and propellant types (Sutton and Biblarz 2017: 1f).

Table 1: Energy Sources and Propellants for Propulsion Concepts (Sutton and Biblarz 2017: 21f)

	Energy Source[a]			
Propulsion Device	Chemical	Nuclear	Solar	Propellant or Working Fluid
Turbojet	D/P			Fuel + air
Turbo–ramjet	TFD			Fuel + air
Ramjet (hydrocarbon fuel)	D/P	TFD		Fuel + air
Ramjet (H_2 cooled)	TFD			Hydrogen + air
Rocket (chemical)	D/P	TFD		Stored propellant
Ducted rocket	TFD			Stored solid fuel + surrounding air
Electric rocket	D/P		D/P	Stored propellant
Nuclear fission rocket		TFD		Stored H_2
Solar-heated rocket			TFD	Stored H_2
Photon rocket (big light bulb)		TFND		Photon ejection (no stored propellant)
Solar sail			TFD	Photon reflection (no stored propellant)

[a]D/P developed and/or considered practical; TFD, technical feasibility has been demonstrated, but development is incomplete; TFND, technical feasibility has not yet been demonstrated.

One specific use of the application of solid propellant rocket motors is for military purposes, specifically in strategic missiles aimed at military targets, or tactile missiles, for defense purposes. Table 1 shows specific rocket propulsion systems for certain applications (Sutton and Biblarz 2017: 21f).

These military appliances can be used via a surface launch, launching from ground, ship or sea, or from air, as shown in table 2 below (Sutton and Biblarz 2017: 21, 23).

Table 2: Selected Military Applications Using Rocket Propulsion Systems (Sutton and Biblarz 2017: 21, 23)

Category	Vehicle/System	Comments/Examples
Military Satellites	Reconnaissance/Observation	Rely on existing vehicles, such as Delta IV or Delta II and Atlas V
	Secure communications	
	Early warning of ICBM launches	
Strategic Weapons	ICBM—silo launched	Minuteman III; Trident; SPRMs; 5000 to 9000 km range;
	ICBM—submarine launched	Tomahawk with SPRM booster and turbofan engine
	Cruise missile (subsonic flight)	
Surface-to-Surface Tactical Weapons	Intermediate range ballistic missile	Pershing II (2 stages)
	Battlefield support (very short range)	Guided or unguided
	Ship launched to ship or shore	All use SPRM and single-stage,
	Small shoulder-fired missile	Redeye is a surface-to-air shoulder-fired missile
	Wire-guided small missile	
Surface-to-Air and Surface-to-Incoming-Missile Tactical weapons	Local area defense (e.g., airfield)	Standard missile, Patriot missile,
	Large area defense	Multistage vehicle with SPRM
	Battlefield support	booster and LPRE divert top stage
	Shoulder-fired small missile	Guided or unguided SPRM, Redeye
	Ship defense	Unwinding wire to control flight path of local battlefield missile
Air-to-Surface Missiles	Short range	All use SPRMs
	Long range	Larger guided missiles
Air-to-Air Missiles	Carried under aircraft wings	Guided, SPRM, Phoenix, Sparrow
Specialized Weapons or Devices	Antitank missiles	With armor piercing warhead
	Antisubmarine missiles	Hawk, TOW, SPRM
	Anti-radar missiles	Subroc, SPRM
	Torpedo propulsion	Homing air launched SPRM
	Rocket-assisted artillery	Gas generator, SPRM
	Aircraft pilot seat ejection	Up to 20,000g_0 in gun barrel, increased range
		Emergency maneuver, SPRM

ICBM, intercontinental ballistic missile; LPRE, liquid propellant rocket engine; SPRM, solid propellant rocket motor.

2.1.3. Rocket Power & Propulsion

Artificial space objects such as satellites or rockets require a reliable general power source at the following stages (Agency, 2005: 2):

- Launching of the space vehicle,
- Maneuvering,
- Communication and instrumentation,
- Cooling and warming,
- Lighting,
- Experiments, etc.

The most commonly used power source for launches is chemical rocket thrusters, as they can provide energy of up to 60000 kW for a duration of up to a few hours. Chemical fuels, however, do not provide long-term energy security after the launch, which is why for operation in near earth orbits radiation energy is used as a substitute to provide long-term energy supply. Radiation energy originates from the sun or other sources such as ground-based laser beams and microwaves. (Agency, 2005: 3; Sutton and Biblarz 2017: 1).

The third most used power source next to fuel and radiation power is nuclear power. Nuclear energy is generated by either fission or fusion, generally speaking, the transformation of mass in atomic nuclei. While nuclear reactors can maintain an unlimited energy source, they are impracticable in less than 10 kW applications. Radioisotopes on the other hand are most effective for applications below 10 kW and vie a time span from one year, which is why they are mainly used for energy supply for communication purposes as well as for experiments on long-term missions outside the earth orbits (IAEA 2005: 3f; Sutton and Biblarz 2017: 1).

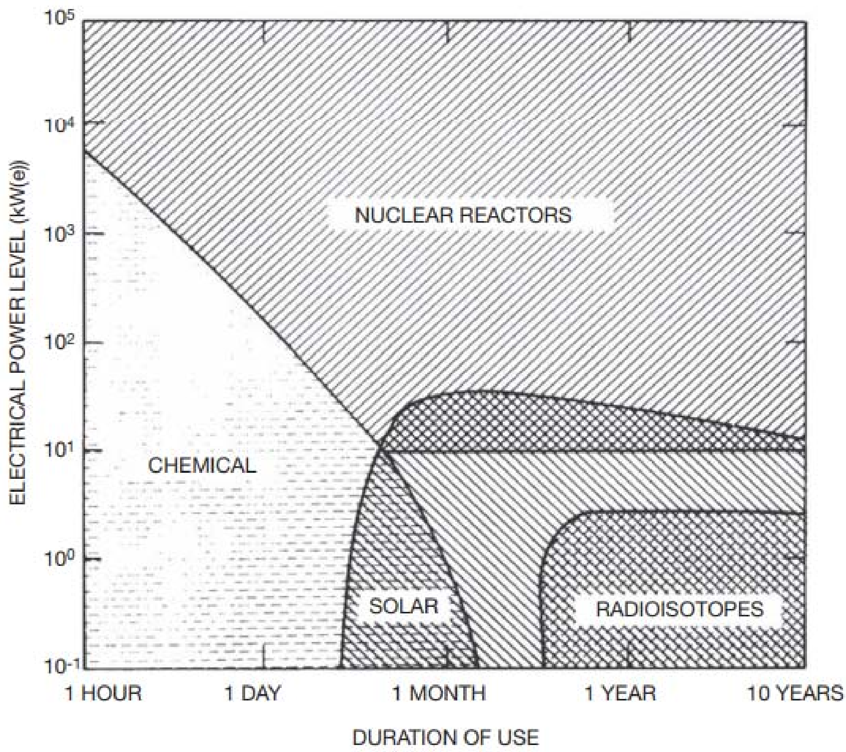

Figure 1: Regimes of potential power application in outer space (IAEA 2005: 3f)

Figure 1 above depicts the regimes of possible space power applicability over different time spans and confirms the above statement that chemical power sources while providing a very high electrical power output, are inefficient over a time span of more than a few hours. Solar energy is also limited in its time span and electricity output, while nuclear reactors produce high and long-term reliable electrical power output higher than 10 kW. Radioisotopes are best applied for long time usage below 10 kW applications (IAEA 2005: 3f).

2.1.4. Spacecraft Propulsion Systems

Rocket propulsion systems primarily utilize the conversion of input energies into kinetic energy of the ejected exhaust gas in two or more physical states (Sutton and Biblarz 2017: 2)

Propulsion systems can generally be classified as follows (Moss and Stark 2016):

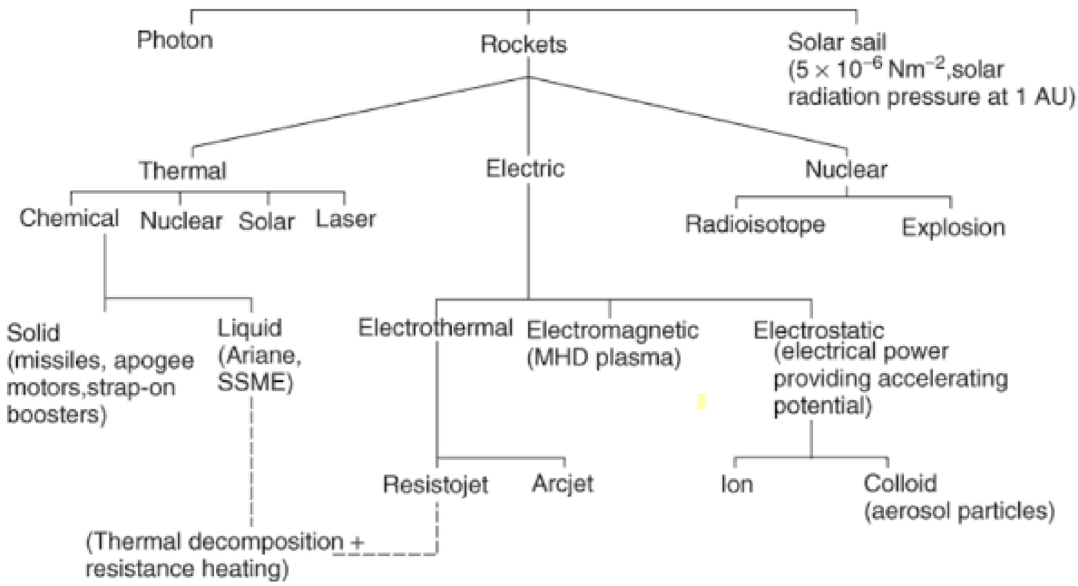

Figure 2: Propulsion System Classification (Moss and Stark 2016)

Specific fields of application are performed solely by rocket propulsion due to its unparalleled performance, either for primary or secondary propulsion functions. Primary propulsion includes the acceleration for and during the flight path, for ascension, orbit insertion, orbit change maneuvers, etc. Secondary propulsion is used for spin and attitude control, momentum wheel and gyro unloading, stage separation, rendezvous in space, as well as for the filling of liquids in tanks. A diverse range of different rocket propulsion systems is needed in spacecraft, ranging from a variety of 4 to 50 thrusters (Sutton and Biblarz 2017: 20).

For primary and also secondary propulsion most spacecraft and space launch vehicles apply liquid propellant engines due to their superiority in performance. Some spacecraft apply solid propellant rocket motors for orbit injection or for boosts. Other vehicles use electrical propulsion for attitude control, or for primary and secondary propulsion in long-distance space flights, with however much longer velocity change times. Spacecraft with less than 100kg mass, newly have started using micro-propulsion, incorporating several different concepts of propulsion such as electrical propulsion, small gaseous propellant rocket motors, or low thrust liquid mono- and bipropellant rocket engines (Sutton and Biblarz 2017: 20f).

The table below gives a detailed overview of the wide ranges of typical performance parameters for the various spacecraft and space launch vehicle propulsion systems (Sutton and Biblarz 2017: 30).

Table 3: Ranges of Typical Performance Parameters for Rocket Propulsion Systems (Sutton and Biblarz 2017: 30)

Engine Type	Specific Impulse[a] (sec)	Maximum Temperature (°C)	Thrust-to-Weight Ratio[b]	Propulsion Duration	Specific Power[c] (kW/kg)	Typical Working Fluid	Status of Technology
Chemical—solid or liquid bipropellant, or hybrid	200–468	2500–4100	10^{-2}–100	Seconds to a few minutes	10^{-1}–10^{3}	Liquid or solid propellants	Flight proven
Liquid monopropellant	194–223	600–800	10^{-1}–10^{-2}	Seconds to minutes	0.02–200	N_2H_4	Flight proven
Resistojet	150–300	2900	10^{-2}–10^{-4}	Days	10^{-3}–10^{-1}	H_2, N_2H_4	Flight proven
Arc heating—electrothermal	280–800	20,000	10^{-4}–10^{-2}	Days	10^{-3}–1	N_2H_4, H_2, NH_3	Flight proven
Electromagnetic including pulsed plasma (PP)	700–2500	—	10^{-6}–10^{-4}	Weeks	10^{-3}–1	H_2 Solid for PP	Flight proven
Hall effect	1220–2150	—	10^{-4}	Weeks	10^{-1}–5×10^{-1}	Xenon	Flight proven
Ion—electrostatic	1310–7650	—	10^{-6}–10^{-4}	Months, years	10^{-3}–1	Xenon	Flight proven
Solar heating	400–700	1300	10^{-3}–10^{-2}	Days	10^{-2}–1	H_2	In development

[a]At $p_1 = 1000$ psia and optimum gas expansion at sea level ($p_2 = p_3 = 14.7$ psia).
[b]Ratio of thrust force to full propulsion system sea level weight (with propellants, but without payload).
[c]Kinetic power per unit exhaust mass flow.

To understand the physical processes of propulsion, the following terms are relevant (Sutton and Biblarz 2017: 31-36):

- Thrust is the physical reaction energy produced by a rocket propulsion system, mainly from the propellant at high speed, resulting in movement of a vehicle.
- Efficiencies allow the understanding of the energy balance in rocket propulsion systems, which are divided up into the production of energy, often the transfer of stored energy to available energy, and the conversion of that energy to the mode from which a thrust reaction is possible.
- The term specific power is utilized to define the utility of the mass of a propulsion system, which equals the ratio of the jet power to the loaded propulsion system mass.

For combustion power propulsion system this implies that the source of energy input into the rocket propulsion system is created by combustion. The combustion efficiency for chemical rockets is the actually released energy divided by the ideal heat of reaction per unit of the mass propellant. Multiplying the power input with the combustion efficiency gives the chemical power which is available to the rocket propulsion system, where a conversion to kinetic energy is completed. The power transmitted to the respective space vehicle is the multiplication of the thrust with the vehicle velocity. On the other hand, the internal efficiency of the propulsion system can be established by the ratio of the kinetic power of the vehicle to the available chemical power (Sutton and Biblarz 2017: 31-36).

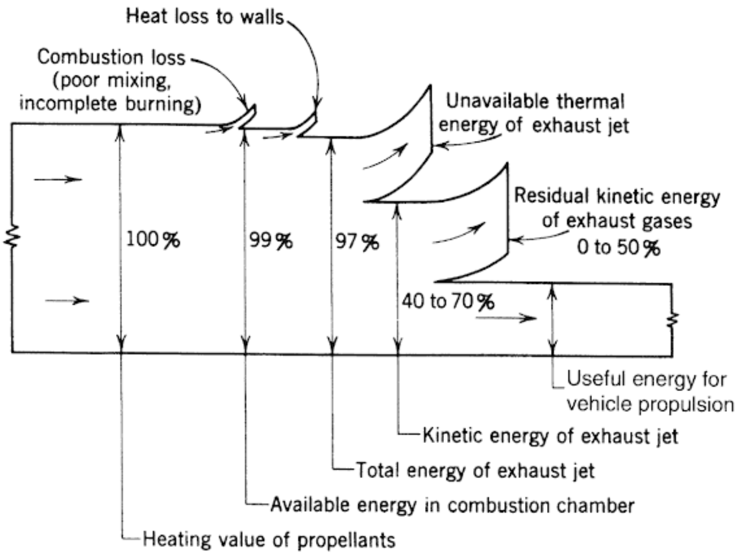

Figure 4: Typical Energy Distribution for Chemical Rocket Propulsion Systems (Sutton and Biblarz 2017: 31-36)

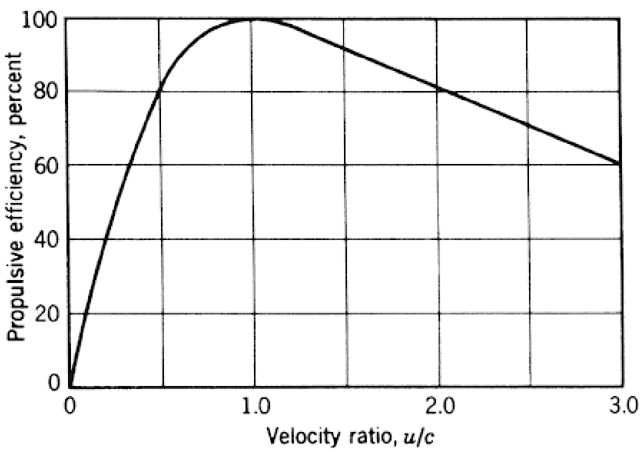

Figure 3: Propulsion Efficiency in Relation to Velocity (Sutton and Biblarz 2017: 37)

The economical use of energy, including high efficiencies with the minimization of waste of mass is desirable. The minimized use of energy is not always the most important goal, as can be shown from the example of nuclear-reactor or radiation energy sources. Hereby while the heat energy available is unlimited, only a fraction of that energy can be carried by the vehicle propellant. The propellant mass economy can be calculated by looking at the proportionality of the thrust to the exhaust velocity, shown by the table below (Sutton and Biblarz 2017: 37).

2.1.4.1. Chemical Power and Propulsion

Chemical propulsion is currently the only truly viable solution for launching a rocket into space, and can be applied as solid, liquid, hybrid or gel (De Luca, et al. 2017: 1).

Chemical power systems use heat gas via an exothermic reaction as a propellant for propulsion systems, considering the heat release, storage, and energy content. In liquid propellant systems, the liquid and fuel are mixed and combusted, as also used in bipropellant systems. This is also similar to the exothermic decomposing of H_2O_2 or N_2H_4. Liquid propellant rockets have superior flexibility over solid propellant rockets, due to start-stop and thrust throttling options. Hybrid rockets using liquid bi-propellant systems supplemented by storable nitrogen tetroxide are used when greater discharge pressures are needed (Moss and Stark 2016).

Solid rocket propulsion systems have a high energy output through the usage of oxidizers such as aluminum peroxide (AP), with low smoke output. The usage of AP results in good rocket stability and density, high O_2 stoichiometry, lack of phase changes in the required temperature range, low moisture absorption, solid-state decomposition, while also having a relatively low-cost range. The only problem with using AP is that it has definite negative effects on the environment, discussed below (De Luca, et al. 2017: 14-17).

Liquid rocket propulsion systems show high potential for rocket launches from earth, due to the fact that sufficiently high temperatures, high combustion chamber pressures, as well as high fuel-density and small molecular mass of the exhaust gases can be attained. Furthermore, liquid propulsion stands out by having a very wide thrust range (De Luca, et al. 2017: 18-21).

Cold gas systems typically feed nitrogen, freon, argon or hydrocarbons stored at high pressures, into thrusters. The driving pressure determines the kinetic energy of the nozzle exhaust due to the lack of combustion heat. The propellants are chosen with regards to storage capability, and exhaust plume impingement of surfaces (Moss and Stark 2016).

2.1.4.2. Electrical Propulsion

Electric propulsion describes the acceleration of a rocket by solar radiation, or nuclear fuel. In recent years electrical propulsion systems have been adopted as regular and viable supplements to chemical propulsion for commercial, military and scientific spaceflight (Moss and Stark 2016).

In earth orbit, satellites of an artificial nature require their own respective source of power, which is often taken from photovoltaic panels, creating electricity from sunlight via substances such as silicon and germanium. This, however, is not a viable power source for artificial satellites operating in larger distances from the earth and the sun. Therefore alternative power and heating sources are found in the use of nuclear power systems (NPS), usually referred to as radioisotope thermoelectric generators (RTS), radioisotope heater units (RHU), as well as thermoelectric generators (TEG), due to their reliance on radioisotopes (IAEA, 2005: 1f).

A Nuclear power system has many advantages over power sources such as photovoltaic or chemical fuels due to its compactness, its resistance to the radiation belts of the earth, its independence of distance and orientation from the sum, its superior mass and size features for unmanned missions, and lastly because of the option of integrating electrical power into the nuclear power system to increase the power and propulsion efficiencies to a maximum, allowing launches up to three times grander than with chemical fuel power sources (IAEA, 2005: 6).

In addition to the provision of electrical and thermal power, nuclear thermal propulsion (NTP) units are developed with the goal of transferring large space systems into orbits (IAEA 2005: 2).

2.1.5. Harmful Environmental Impacts by Rocket Propulsion Emissions

Like any transportation sector, space transport entered a period of continual expansion through privatization, tourism, military and other efforts, simultaneously increasing the concern for the impact of rocket emissions on the environment. Although the impact of rocket emissions on the earth environment is small compared to other transport sectors, and the scientific literature on rocket propulsion emissions is rather scarce, the launch of space privatization and tourism create the need for sustainable and environmentally friendly spaceflight, taking into consideration potential long-term risks to future space operations (Ross and Vedda 2018: 2f).

Due to the fact that the stratosphere is isolated from the troposphere, particles and emissions can easily accumulate. Incorporated within the stratosphere, the ozone layer is strictly regulated by agreements such as the Montreal Protocol on Substances that Deplete the Ozone Layer (UNEP 1987) defining the protection of ozone (Sutton and Biblarz 2017: 3f). The Protocol oversees the production and usage of ozone-depleting substances (ODS), such as chlorofluorocarbons and halogen gases. Following the ratification of the protocol in 1987, The Quadrennial Ozone Assessments are published, to describe the state of the stratosphere and the depletion of the ozone layer. On occasion, the effect on rocket plumes has been addressed, however usually as a rather minor emmittant compared to other industry emissions (Ross, Roohey, et al. 2009).

Solid rocket motors, when launched exhaust the following particles into the stratosphere: carbon monoxide, water vapor, aluminum oxide particles, hydrogen chloride, and molecular nitrogen. A distinction must be made between rocket exhaust and rocket emissions. Rocket emissions can be summarized as the cold plume which is infused into the stratosphere, while the exhaust of rockets comprises of the following elements (Jackman, Considinge and Fleming 1998; and Ross, Roohey, et al. 2009):

- chemical compounds: N_2 , CO_2
- radicals: NO, OH, Cl
- radical sources & accumulation: HCl, H_2O
- intermediate underoxidized compounds: H_2, CO.

Oxygen in the atmosphere is mixed into the hot plume of the rocket exhaust, initiating the modification of soot, CO, H_2, H_2O into carbon dioxide, followed by the production of radicals governing the destruction of stratospheric ozone. These secondary combustion processes vary with altitude but are focused on the core part of the stratosphere (Ross, Roohey, et al. 2009).

Alumina particles foster the reaction of activated chlorine with 0.02 reaction probability. In the case where the particles are not coated with atmospheric sulfuric acid (H_2SO_4), where only the sulfate particles would increase in the stratosphere, the alumina particles as such via the chlorine activation reaction contribute majorly to the stratospheric ozone depletion. The process of H_2SO_4 coating is very unlikely to take place, same as any influence by temperature changes (Jackman, Considinge and Fleming 1998).

All types of rocket propellants emit exhaust gases acting as initiators to chemical reactions in the ozonosphere through the injection of chlorine, while on the other hand water vapor and other particles in the stratosphere result in a changed in net radiative forcing and balancing through increased absorption or reflection of energy from the sun via changes in the total cloud number and mesospheric clouds. Stratospheric heating and surface cooling are a result of these emissions, including continuous ozone depletion (Ross and Vedda 2018: 2f; and Ross, Roohey, et al. 2009: 52f).

The majority of rocket exhaust emissions are CO_2 and H_2O, which are not a concern with regards to environmental risk. Even with realistically high growth scenarios for the space sector, CO_2 emissions will continue to be irrelevant for greenhouse gas developments (Ross, Roohey, et al. 2009: 52f).

The emissions relevant for atmospheric impact are alumina particles and hydrogen chlorine from solid rocket motors as well as black carbon from kerosene-fueled rocket engines, all directly linked to ozone depletion. Black carbon and alumina particles assemble in the stratosphere for a time span of more than four years, leading to a long-term interference with incoming solar radiation through absorption and reflection of the solar flux. This leads to increased temperatures in the stratosphere, amplifying ozone-depleting reactions while decreasing temperatures on the earth surface (Ross and Vedda 2018: 4f).

Accounting for the increase in space launching vehicle flights, a rise of black carbon, alumina and chlorine particles in the stratosphere will soon be one of the major reasons for ozone depletion next to the ozone-depleting substances banned in the Montreal Protocol (UNEP 1987).

The table below describes different rocket launch growth scenarios from 2005 to 2050 and its correlation with global ozone loss. The solid line indicates past ozone depletions from ozone-depleting substances, while the other lines depict a definite increase in the ozone depletion due to emissions from rocket launches (Ross, Roohey, et al. 2009: 70).

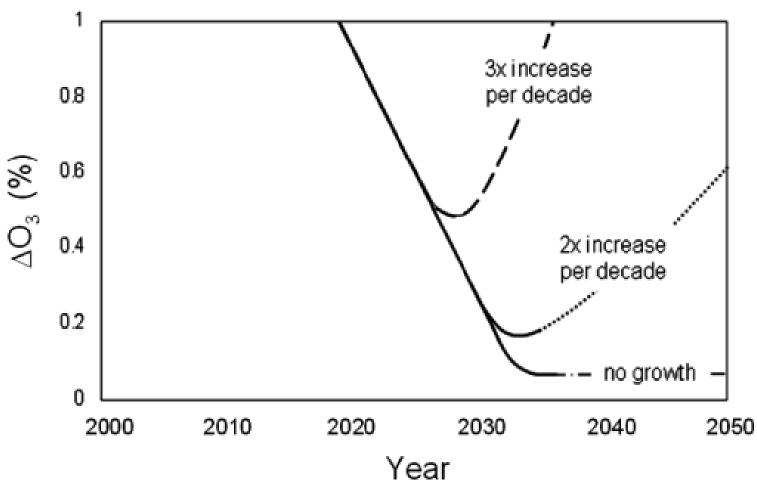

Figure 5: Ozone Depletion & Rocket Launch Growth Scenarios

2.1.6. Green Space Propulsion Efforts

As established above, current spacecraft propulsion commonly uses carcinogenic hydrazine propellants, leading to negative effects on the environment. This includes fuels such as monomethylhydrazine (MMH), hydrazine, unsymmetrical dimethylhydrazine (UDMH), and oxidizers like nitrogen tetroxide (NTO) and mixed oxides of nitrogen (e.g. MON-3). Through privatization and an ever-increasing amount of outer space activities and applications, the significance of protecting the environment while further developing spaceflight has become increasingly important. In the following chapter, promising green space propellants lowering the level of environmental challenges and hazardous conditions will be listed and analyzed for spaceflight actions. Firstly the most important current activities towards a greener space industry will be given, followed by new research efforts regarding environmentally friendly space propulsion.

Current green space propulsion efforts are rather similar to sustainability endeavors of the aviation industry. After for the first time in 2014 the National Aeronautics and Space Administration (NASA) and the Advisory Council for Aviation Research and Innovation in Europe (ACARE) listed aviation challenges, many more reports have been published with regards to green space and space sustainability, including a broad range of methods to implement sustainable space activities (Gohardani, et al. 2014: 129).

As historically, the major concern regarding rocket launches has been air pollution, most research efforts concentrate on propellants which are non-toxic and environmentally friendly. However, even "green" propellants emit products with possible environmental consequences such as water vapor, nitrogen oxides, carbon dioxide, alumina, inorganic chlorine, sulfates, and soot. But even despite those emissions storage, transport, operations and spacecraft development of green propellants have proven to become increasingly safer and cheaper. Generally speaking, most efforts towards green sustainable space propulsion are focused on replacing hazardous propellants or identifying the ones with a decreased environmental impact. Other options are the substitution of ammonium perchlorate and hydrazine in propulsion systems.

2.1.6.1. GRASP – European Commission

One of those initiatives doing research on green sustainable space flight is the green advanced space propulsion (GRASP) initiative of the European Commission, one of the first European projects evaluating green propellants. From 2007 on the project aimed at providing the industry of Europe with alternative propellants as a replacement for the currently used carcinogenic and toxic propellants, reducing potential harm to the environment, and human operators, while ensuring the competitiveness of the European space industry (European Commission 2011).

To reach this result the European Commission`s Community Research and Development Information Service (CORDIS) had established a propellant and catalyst development and analysis methodology which consists of several steps. Firstly, an initial selection of propellants based on reduced toxicity, storability at standard conditions, as well as performance comparability with the toxic alternatives, is undertaken. Secondly, the availability and safety of the selected propellants were evaluated (European Commission 2011).

The GRASP initiative investigated appropriate catalysts and their performances, incorporating two levels: development of currently used catalyst technologies for hydrogen peroxide (H_2O_2) according to factors such as the mass flow rate and the decomposition temperature, and the establishment of new catalyst technologies for ionic liquids (European Commission 2011).

This developed methodology was more detailed than any assessment had been to that point, allowing analyses of the decomposition. First, the models established focused on separate aspects of pressure and thermal conditions in the catalyst bed and the decomposition chamber. Second, verification on the basis of the collected data from the experimental catalyst assessment was undertaken, resulting in improvements to the comprehension of the decomposition process, leading to the understanding that small variations on the thermal mass can have large impacts on decomposition. Third, the manufacturing of catalysts showed a definite improvement, such as that the pre-heating of H_2O_2 leads to decomposition efficiencies of more than 100% and melting of catalyst core at decomposition temperatures under the melting point, and therefore validating the initial methodology (European Commission 2011).

This research and development project finalized its assessment with the selection of several green propellant candidates was conducted, based on performance, toxicity, storability, and technology readiness level (TRL). The following options were selected: two monopropellants (FLP-106, H2O2), one oxidiser (H2O2), three fuels for bipropellant systems (kerosene, turpentine, d-limone) and one fuel for hybrid systems (HDPE), all of which are less toxic, non-carcinogenic, and have shown success in quality assessment testing (European Commission 2011).

Therefore, in conclusion, the developed models had the following results (European Commission 2011; Gohardani, et al. 2014):

- Establish a status-quo of green propellants
- Expanding the comprehension of the H_2O_2 decomposition process
- Redesigning the catalyst process
- Make new investigations and observations on green propellants on system and component level.
- Generate successful predictions, confirmed by experimentation.

This methodology establishes the groundwork for future green rocket propulsion technologies, also usable in environmental impact assessments.

2.1.6.2. GPIM – NASA

Similar to the knowledge generated by the GRASP initiative, the National Aeronautics and Space Administration (NASA) is working together with American companies to develop transformative and innovative fuels with less adverse effects on the environment. NASA`s most recent project is the Green Propellant Infusion Mission (GPIM), focusing on developing a greener alternative to conventional chemical rocket propulsion systems powered by the toxic fuel hydrazine (N_2H_4) for future spacecraft and space vehicles. Furthermore. the GPIM strives to enhance the performance of hardware and power solution systems while taking into account cost efficiency and safe conduct in outer space. This green propellant shall ensure faster, safer, and less costly launching and fuel loading of space vehicles, while simplifying the production and operation of satellites (Gohardani, et al. 2014: 130; NASA 2018a).

The GIMP project will launch in 2018, illustrating the practical application of a blend of oxidizer and the fuel Hydroxyl Ammonium Nitrate, also known as AF-M315E, a high-performance, cutting-edge, and low toxic propellant created by the U.S. Air Force Research Laboratory, constituting a green alternative to hydrazine which is easier to store and handle, while delivering higher specific impulse thrust with a lower freezing point (NASA 2018a).

The GPIM project will launch *smallsats* (small satellites) during test flights where orbital maneuvering will be performed to test the propellant performance. After positive testing, the GPIM will be presented as a new and viable propulsion option for commercial and non-commercial spaceflight, as well as a valid green solution for propellant engine space applications (NASA 2018a).

2.1.6.3. HPGP - Sweden

The Swedish National Space Board (SNSB) has proven very active in conducting research on green and sustainable space programs. It does this by distributing grants on research, technology development, and remote sensing activities for spaceflight, as well as by initiating research and development and international cooperation on sustainable spaceflight (Gohardani, et al. 2014: 131).

The SNSB has worked on possible substitutes for hydrazine, just as NASA or the European Commission have. However the Swedish are focusing on monopropellant systems with only one liquid phase rather than bipropellant systems, consisting of two separate liquid, mostly fuel and oxidizer, phases. To generate thrust the monopropellant releases chemical energy from a combustion chamber as accelerated and emitted hot gas via a nozzle. Stored chemical energy can either be released via combustion or via decomposition, while latter can be described as high enthalpy molecules splitting from each other to form molecular species with a low weight and lowered enthalpy. This decomposition process is applied for chemical energy production via the highly reactive N_2H_4 and H_2O_2 with the help of fraction ammonia, which enables an optimal thrust. The two most relevant factors to consider in the assessment of N_2H_4 substitutes are detonability and thermal stability. This is important as a propellant unable to hold thermal stability, cannot be considered safe to handle. Chemical stability must be guaranteed in monopropellants in storage, while a strong reaction is needed within the combustion chamber. While a replacement for N_2H_4 would facilitate handling and a reduced cost, any change in chemical composition might increase explosive hazards and a reinstatement of chemical stability through substitution is a challenge. Several less toxic options have been considered as replacements for hydrazine: Hydrogen peroxide, Nitrous oxide fuel blends, and Ionic liquids (Gohardani, et al. 2014: 131f).

Hydrogen peroxide (H_2O_2) is the most studied monopropellant next to hydrazine (N_2H_4), therefore establishing data security for future projects. On the other hand, the storage of N_2H_4 must be displaced from the Reaction Control System (RCS) of the space vehicle due to its high reactivity and the problem with safe usage (Gohardani, et al. 2014: 132f).

The second option, nitrous oxide fuel blends have been considered for hybrid rockets or as monopropellants in the form of green oxidizers. This would be a viable high-performance option as it easily ignitable, low toxic and cheap. However, scientific research is far behind when it comes to knowledge on the explosiveness of the fuel blend (Gohardani, et al. 2014: 133).

Thirdly, ionic liquid is a salt used in the liquid state due to a low melting point. Monopropellants with ionic liquid are mostly blends of water, fuel and oxidized salt which are highly soluble. However, research is still ongoing to decide if this is a viable option (Gohardani, et al. 2014: 133f).

To sum up this chapter on launching and flight stage environmental impacts by space rockets and space launch vehicles, it is apparent that the main impacts of space missions at the launching and flight stage on the earth environment are propulsion emissions from chemical solid rocket motors. Those motors directly inject CO, HCl and alumina particles into the stratosphere, where they support an acceleration of the stratospheric ozone depletion. The impairment of the ozone protection layer results in an alteration of the thermal budget on earth due to the change in incoming solar radiation. Furthermore, the injection of water vapor and other particles into the stratosphere result in the increase of cloud albedo and therefore influencing the inflow and outflow of radiation on earth.

Some Green Space Propulsion initiatives were discussed which might in the future present an option to toxic chemical propulsion systems. However, research is not nearly as far as it must be to consider the above-listed options viable for public and private spaceflight. The European Commission has developed a methodology for testing existing propulsion technologies and developing new technologies for more environmentally friendly propulsion.

With regards to the pollution on the environment surrounding the launching area, short-term air and water quality impairment are probable. Furthermore, the handling of hazardous materials such as the fuel for liquid propellants, hydrazine, create safety and health hazards for the operating personnel, and the soil, air and water environment in close proximity of the operating pad. These hazards can be minimized by adding additional safety measures. The description of any launching and flight stage hazards and their possible impact on the earth environment can be assessed in an Environmental Impact Assessment including a detailed description of measures taken to prevent or mitigate any such negative impacts on the earth environment.

2.2. Space Debris

The second most prominent impact of human activity in space flight is the accumulation of space debris. It’s definitions and possible mitigation strategies will be discussed in the following section.

2.2.1. Definition Space Debris

The term space debris is defined by the International Academy of Astronautics (IAA) as follows (Ad 1993):

> “*any man-made Earth-orbiting object which is non-functional with no reasonable expectation of assuming or resuming its intended function, or any other function for which it is or can be expected to be authorized, including fragments and parts thereof. Orbital debris includes non-operational spacecraft, spent rocket bodies, material released during planned space operations, and fragments generated by satellite and upper stage breakup due to explosions and collisions.*“

Since the beginning of space operations in 1957 more than 5253 space launches (as of 01.2017) were undertaken. The increasing population of spacecraft, satellites, and launch vehicles in outer space has to lead to an increasing debris production due to standard mission operations. In addition, approximately 10 collisions and more than 290 explosions of man-made space objects have been recorded. The space debris population was multiplied by anti-satellite testing by both China and the United States of America. The Chinese test itself, targeting the Feng-Yun-1C weather satellite in 2007 produced more than 3400 fragments. The U.S. test targeted the American reconnaissance satellite NRO launch 21 in 2008 with an RMI-161 Standard Missile to test the anti-satellite capacity of the anti-ballistic missile (Navy 2008). Of the cataloged space debris approximately 24% are satellites and 18% are defunct rockets and other vehicles. Most of the space debris is not cataloged and is mostly smaller than 1mm diameter, created either from the residue of solid propellant propulsion systems or of the ejection of cooling liquid from nuclear reactors from Russian satellites launched in the 80s (ESA 2017: 2).

In general, space debris is created during standard operation of spacecraft, through the ejection of mission-related items as well as by defunct satellites and other spacecraft. The United States Space Surveillance Network currently provides the majority of information on the 23,000 items in Earth orbit with a size larger than 5 cm. Estimations on the total number of current space debris is are undertaken by scientific models estimating that in total more than 29,000 objects with a size larger than 10 cm, 750,000 objects with a size of 1 to 10 cm and more than 165 million space objects ranging from 1 mm to 1 cm can be found in Earth orbit. The graph below shows the development of space debris assimilation over time (ESA 2017: 2f):

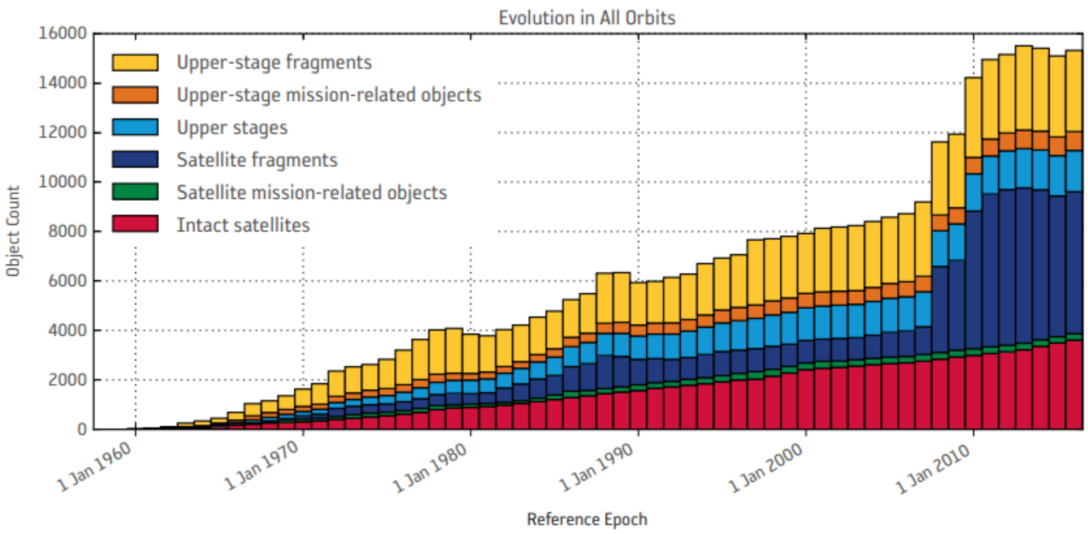

Figure 6: The Evolution of tracked and published space debris population and ist composition by object class (Status January 2017) (ESA 2017: 2f)

In short, space debris is made up of defunct artificial launch vehicles and satellites or parts and materials thereof. The majority of the debris concentrates at an altitude of 800 to 1000 km as well as at 1400km from the earth surface, due to the balance between active debris production and orbital decay. When those materials move in their orbit or in space generally, they travel at tremendous speeds. Debris in the Low Earth Orbits at altitudes of 2000km from earth surface reaches velocities of 14km/s[2]. When the debris collides with each other at those tremendous velocities, more debris is created due to the unavoidable collisions. This chain reaction of ongoing and increasing collisions with a growing accumulation of space debris is called the Kessler syndrome (Adilov, Alexander and Cunningham 2018). The National Academy of Sciences has reported that the amount of accumulated space debris is so high that ill will crash into itself over and over, endangering active satellites, and again creating even more debris. This continuous space debris population growth represents an immense threat to currently active space missions and future space operations (Liou, Johnson and Hill 2010).

The first official damage to an active space mission by space debris was recorded in 1983 when the Space Shuttle Challenger was hit by a piece of thermal paint with a diameter not larger than 0.2 mm at a speed of 3 to 6 km/s and caused major damage to the windshield of the shuttle. Many other incidents have followed since and continue to endanger space missions (Viikari 2011: 268).

The increasing danger of collision for space missions with space debris is depicted in the figure 7 below (NASA 2010).

Space debris not only endangers the space environment but also causes damage to the earth environment through the probability of debris crashing onto the earth surface or the oceans. This can cause major damages not only ecologically but also to human health. Nuclear contamination is one of the possibilities when space particles from nuclear power sources of launch vehicles, satellites or rockets fall onto earth. Due to this threat, most space agencies have started to incorporate design and operational protection measures into their spacecraft. An Environmental Impact Assessment offers a precautionary approach essential to space missions due to the necessity of long foresight since any type of negative consequence is nearly impossible to reverse. (Viikari 2011: 268f).

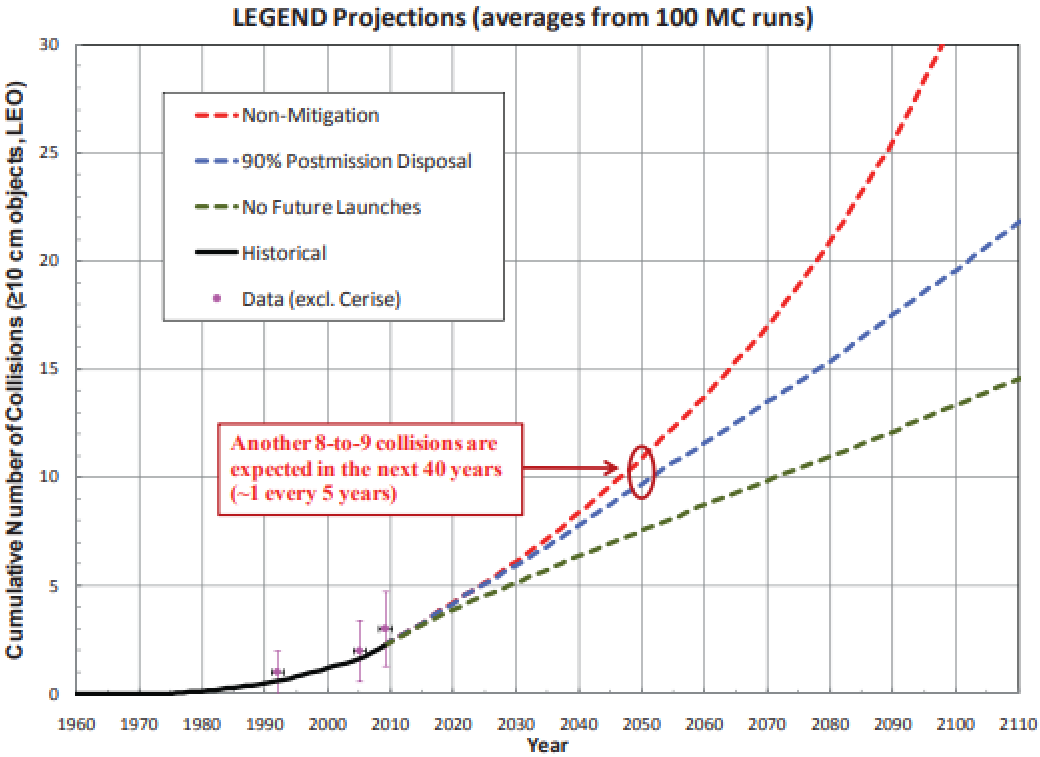

Figure 7: NASA's LEGEND-predicted accidental collisions in LEO (NASA 2010)

The issue of space debris is not addressed in either of the main United Nations space treaties, to be discussed in chapter 4, but mainly in national legislation and procedures, as well as in standards and procedures of a non-binding nature on an international basis. Those national rules ensure that international procedures and standards are applicable for national operations (Steinkogler 2016).

2.2.2. Debris Mitigation

Standards addressing space debris mitigation measures are set up by the Inter-Agency Space Debris Coordination Committee in the Space Debris Mitigation Guidelines, describing best practice experiences applicable for the minimization of new space debris production in the environment. The IADC Guidelines streamline and summarize legal provisions and standards established on a national basis, and lists recommendations to protect the environment from negative consequences based on four fundamental principles (IADC 2007):

"(1) Limitation of debris released during normal operations

(2) Minimisation of the potential for on-orbit break-ups

(3) Post-mission disposal

(4) Prevention of on-orbit collisions".

The IADC Space Debris Mitigation Guidelines are a recommendation for any space mission including its planning, design, and operation phase, of orbital stages or spacecraft in Earth orbit. The Guidelines give definitions for and encourage protection measures for the Low Earth Orbit, the Geosynchronous Region, the Geostationary Earth Orbit, and the Geostationary Transfer Orbit. The IADC defines mitigation terms such as firstly passivation, meaning that all stored energy should be removed from a spacecraft or orbital stage, to minimize the probability of a breakup. Secondly, de-orbiting measures are recommended to ensure the burning up of defunct spacecraft or orbital stages in the atmosphere of the Earth. Thirdly, re-orbiting is defined as the moving of defunct spacecraft or orbital stage to another orbit to reduce the population in the original orbit. And fourthly, different breakup scenarios are defined, including propellant explosions, ruptures due to the internal pressure of a spacecraft of the orbital stage, as well as breakups induced by external energy (IADC 2007).

The Space Debris Mitigation Guidelines recommend the publishing of a Space Debris Mitigation Plan for any space operation to be undertaken, including space debris mitigation activities, risk assessment plans including the applicable regulations and standards, measures to be undertaken to minimize any risk of malfunction of the spacecraft or orbital stage with the probability of creating new space debris, description of possible alternatives and the logic behind choosing the proposed activity, as well as a compliance matrix to the IADC Guidelines (IADC 2007).

The Inter-Agency Space Debris Coordination Committee in the Space Debris Mitigation Guidelines lists several mitigation measures for the production of space debris. Firstly, limiting the amount of debris discharged into the space environment during standard operation is addressed. Secondly, it is recommended that any potential for the on-orbit breakup from stored energy, and during operational phases is minimized through advanced design and operation, and by avoiding any intentional destruction of the spacecraft or orbital stage. Thirdly, a guideline for post-mission disposal in the geosynchronous region, the LEO and other orbits is set up. Forth, it is recommended, that all on-orbit collision should be prevented from happening through an estimation of risk probability, the accumulation, and availability of reliable orbital data and an advanced design of the spacecraft (IADC 2007).

The IADC Space Debris Mitigation Guidelines are supplemented by the United Nations Office for Outer Space Affairs' Committee on the Peaceful Uses of Outer Space (UNOOSA COPUOS), which in 2010 published its own Space Debris Mitigation Guidelines, setting up recommendations for the mitigation of space debris, taking into consideration the IADC Guidelines and the United Nations treaties and principles on space. COPUOS defines two categories of space debris mitigation measures: measures that decrease the amount of debris produced with possible negative consequences on the operation of space mission on a short-term basis and those missions decreasing the generation of debris in the long-term. The first includes the prevention of breakups and the second involves actively removing defunct spacecraft and orbital stages from orbit. The COPUOUS Guidelines do not establish any obligations but recommend measures on a voluntary basis applicable to planning and operation phases of space missions (United, Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space 2010).

COPUOS sets up seven Guidelines that recommend to the Member States of the UNOOSA and other international organizations to voluntarily take measures to (UNOOSA 2010):

"*(1) Limit debris released during normal operations*

(2) Minimize the potential for break-ups during operational phases

(3) Limit the probability of accidental collision in orbit

(4) Avoid intentional destruction and other harmful activities

(5) Minimize the potential for post-mission break-ups resulting from stored energy

(6) Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low-Earth orbit (LEO) region after the end of their mission

(7) Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit (GEO) region after the end of their mission".

In addition to those guidelines set up by the international community, many nations have endorsed the Space Debris Mitigation Guidelines by the COPUOS and the IADC and have set up their own respective space debris mitigation procedures. The United States has in 2012 released the U.S. Government Orbital Debris Mitigation Standard Practices including measures to limit the risk to other space systems from accidental explosions during a mission or after the completion of a mission, as well as to minimize the risk of collisions with large objects and small debris during the space operation. The U.S. Standard Practices include a summary of practices for the disposal of spacecraft or orbital stages in final mission orbits, either via atmospheric reentry, movement, and storage in a storage orbit or direct retrieval after the completion of the space mission (U.S. Government 2001).

In addition, NASA adopted among others the Nuclear Procedural Requirements (NPR) for Limiting Orbital Debris, representing a summary of all practices regarding space debris policy in the United States, and establishing personal and programmatic responsibilities within NASA with respect to managing orbital debris mitigation as well as setting up a reporting structure for proving compliance with the NPR (NASA 2009).

While the guidelines assessed above do set up procedures and best practice scenarios for orbital space debris mitigation, they do not set up an obligation to such measures. One country that has in fact set up legally binding mitigations measures is the Republic of Austria. The Austrian Outer Space Law holds in Article 5 that any operator of a space action must make "*provision for the mitigation of space debris in accordance with the state of the art and in due consideration of the internationally recognized guidelines for the mitigation of space debris. Especially measures limiting debris released during normal operations have to be taken*." (BGBl BMVIT 2011). Austria therefore, sets up an obligation to undertake measures to minimize the production of orbital space debris during any space mission.

In addition to mitigation measures, institutions such as NASA and ESA have begun intense research on possible active space debris removal missions to decrease the population of objects in space and therefore minimize the risk for current and future spaceflight operations (Liou, Johnson and Hill 2010).

Debris removal measures focusing on minimizing the hazards for present and future spaceflight are set up by ESA's Clean Space Initiative incorporating three branches assessing ways of ensuring a safer and more sustainable space conduct with regards to space debris. The first branch ecodesign addresses impacts of orbital debris on the environment and defines which environmental regulation frameworks apply and conducts a life cycle assessment for production and operation processes. This does not imply an Environmental Impact Assessment but focuses more on conducting life cycle assessments. The second branch is cleansat, which focuses on the minimization of debris production in general, while the third branch e.deorbit explores possible technologies with the potential of effectively removing large pieces of debris from the environment (ESA 2016).

While these removal missions are not preventive mitigation measures, they do work on decreasing the orbital space debris population in the long-term. Therefore one could argue that they can be included in an Environmental Impact Assessment as part of the mitigation plans to reduce orbital space debris.

Besides these removal missions, national legislation and international guidelines are in place to prevent orbital space debris production as well as to mitigate any hazards arising from debris collisions with each other or with active spacecraft and satellites.

2.3. Planetary Contamination

The most recent emission source with possible negative impacts on the earth and space environment were addressed in scientific literature in 1976 by George Robinson who discussed the exposure of the earth environment to Martian matter (Robinson 1976).

The strongest legal base addressing contamination from space exploration activities is set up in Article IX of the United Nations Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies of 1967 (UNGA 1967), where it holds that the exploration as well as usage of outer space, the Moon and other celestial bodies shall be supported by international cooperation and assistance. More importantly, the Article IX holds that parties shall:

> "*pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose*" (UNGA 1967).

This wording implies that forward or backward contamination of planetary missions on earth and on the other planet or planets shall be avoided. This will be especially relevant for the case study selected, the Mars 2020 Mission by the NASA. The United Nations General Assembly furthermore establishes that should a Party to the Outer Space Treaty suspect any possible negative impacts on the space operations of other Parties and space activities in general, international consolations on that action must be undertaken previously to the launch of the proposed activity (UNGA 1967).

While Article IX of the Outer Space Treaty addresses contamination in a very general way, issues relating to adverse or harmful changes are mainly formulated either in protocols by NASA or by the United Nations Committee on Space Research (COSPAR). The COSPAR Planetary Protection Policy of 2002, as amended 2011, is concerned with any possible biological and organic-constituent contamination in space exploration and sets up an international standard on procedures as well as a guideline for the compliance with the United Nations Outer Space Treaty. The Planetary Protection Policy establishes that some space missions and target body contamination should be made the subject of controls to ensure the following (COSPAR 2002):

> "*The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized. In addition, the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from an interplanetary mission. Therefore, for certain space mission/target planet combinations, controls on contamination shall be imposed in accordance with issuances implementing this policy*".

COSPAR establishes five contamination categories including the applicable requirements for control. The first Category includes any mission or body not involved in the exploration of chemical evolution and the origin of life in general. No control systems and requirements exist for Category I. The second Category includes all missions that conduct scientific research on chemical evolution and the origin of life with only a low probability of contamination. Category II requires the preparation of a planetary protection plan as well as pre- and post-launch analyses on the impact strategy. The third Category includes all missions that conduct scientific research on chemical evolution and the origin of life with a significant probability of contamination, compromising future scientific research. Category III requires detailed reporting before and after the mission. The forth Category includes again all missions that conduct scientific research on chemical evolution and the origin of life with a highly probable contamination jeopardizing future operations. An inventory list of all constituent organics must be published, including a procedure of cleaning and sterilization. The fifth Category entails all missions returning to Earth. Hereby the concern lays on the protection of the earth a planetary system. Hereby planetary protection requirements only apply to the outbound phase and not for the return to Earth. Regular discussions are ongoing to determine if Category V missions should be prohibited in their entirety or not. In any case, in-depth analyses of the collected sample and the spacecraft transportation body must be done. The COSPAR Policy determines a regular reporting duty for all missions falling under one of the categories above as well as a coordination of the data collected (COSPAR 2002).

Planet Mars is recognized to have similar environments as planet Earth, wherefore the possibility of past or present life exists. The exploration of Mars is one of the main objectives of NASA. In light of those developments, the importance to protect the planetary systems from being contaminated by Earth organisms and vice versa has increased. The United States National Research Council's Space Studies Board's Committee on Preventing the Forward Contamination of Mars seeks conduct scientific research on the Mars and Earth environments' interactions as well as to analyze possible methods to achieve a satisfactory degree of cleanliness and bioload reduction of the spacecraft launched towards the planet to be discovered, in the case of NASA Mars (Committee on Preventing the Forward Contamination of Mars 2006).

In the United States also the U.S. National Environmental Policy Act is applicable for planetary sample return missions in the establishment of a requirement to conduct an Environmental Impact Assessment and to publish an Environmental Impact Statement. It is estimated, that no matter how small the collected sample or the contamination of the spacecraft is, an interaction between the biospheres of Mars and Earth would have large and severe environmental impacts on Earth. This impact is to be analyzed in an EIA (Robinson 2010).

In 1969 NASA established its own Extraterrestrial Contamination regulations within the Federal Register, vouching to protect the earth environment from any harmful contamination or negative consequences as a result from spacecraft, personnel or other property returning to Earth. In 1999 these regulations were inserted into NASA's Biological Contamination Control for Outbound and Inbound Planetary Spacecraft where it is held that (NASA 1999):

“*The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized. In addition, the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from another planet or other extraterrestrial sources. Therefore, for certain space-mission/target-planet combinations, controls on organic and biological contamination carried by spacecraft shall be imposed in accordance with directives implementing this policy*.”

This is applicable to all spaceflight mission that may intentionally or unintentionally transport Earth organic substances to the solar system and to other planets as well as any mission designed to return to the earth environment after mission completion on another planet. NASA establishes that the conduct of research and development must be increased, the monitoring of space missions should meet any guidelines and standards applicable to NASA operations, and regular reviews and assessments procedures should be conducted (NASA 1999).

Critique has recently been voiced opposite NASA, which is said to be violating Article IX of the UN Outer Space Treaty by contaminating the International Space Station, and Mars with bacteria and fungi due to not adequately sterilized space equipment. The future danger is that NASA will, in addition, threaten the contamination of the earth ecosystem when attempting to re-enter the Mars mission spacecraft and equipment (Joseph 2018).

The scientific and regulatory base of this type of spaceflight emissions is quite limited due to a lack of scientific information collected so far. Nevertheless, the contamination of either one planetary ecosystem is one of the largest risks to be considered when assessing the environmental impacts of a space mission.

To summarize this chapter, one can assess three major spaceflight emission sources. Firstly, launch- and flight-stage emissions, secondly orbital space debris production, and thirdly the biological contamination of the planetary environment. The currently most pressing hazard is space debris, which endangers present and future space operations alike as well the earth environment. Prevention and mitigation of the emissions would minimize the negative impact of these spaceflight emissions on the earth, space and planetary environment. This chapter partially verifies the first hypothesis. While it is generally agreed upon that space operations cause environmental harm, the long-term effects cannot always be classified as “irreversible”.

Launch- and flight-stage operations have mainly short-term effects on the earth environment. The production of space debris, on the other hand, has reached a point where its effects are irreversible and are the cause for severe safety hazards for present and future spaceflight operations. The potential forward and backward contamination of bacteriological matter from earth and other celestial bodies poses a possibly irreversible hazard for the respective ecosystems. A priori preventive and mitigation measures can decrease the impact of any such emission on the earth, space or planetary environment.

3. Environmental Impact Assessment

This chapter will define the general concept of an Environmental Impact Assessment (EIA) including its aims, structure, strategy, and included actors. The chapter will also define the legal basis for the conduct of Environmental Impact Assessments, followed by an analysis of the usage of EIAs for space activities.

3.1. Aims, Definitions & Types

With the increase of environmental awareness over the last 40 years environmental management has grown in importance, and consequently the application of the Environmental Impact Assessment (Morgan 2012: 5).

The impact can be defined as the difference between the impact with and without the unplanned, planned or proposed actions. An action can be a plan, project, policy, program, activity, legislation, or operation procedure with a cause-effect relationship of future condition changes of an action. Since the future cannot be predicted, the impact assessment works on the identification and managing of uncertainties and risks, and subsequently the preparation of adaption plans for possible changes. An impact can be current, actual, negative, positive, indirect, direct, cumulative or individual, and the probability is linked to the defined environmental circumstances such as chemical, physical, biological, human health, ecology, society, economy, finance, sustainability, heritage, culture, and so on. Like the term impact, assessment can also defined on a very general basis, limited only to the future impact on a specific basis, focusing on identification, measurement, prediction, interpretation, integration, mitigation and control of the consequences., depending on the depth activity to be assessed (Lawrence 2013: 5).

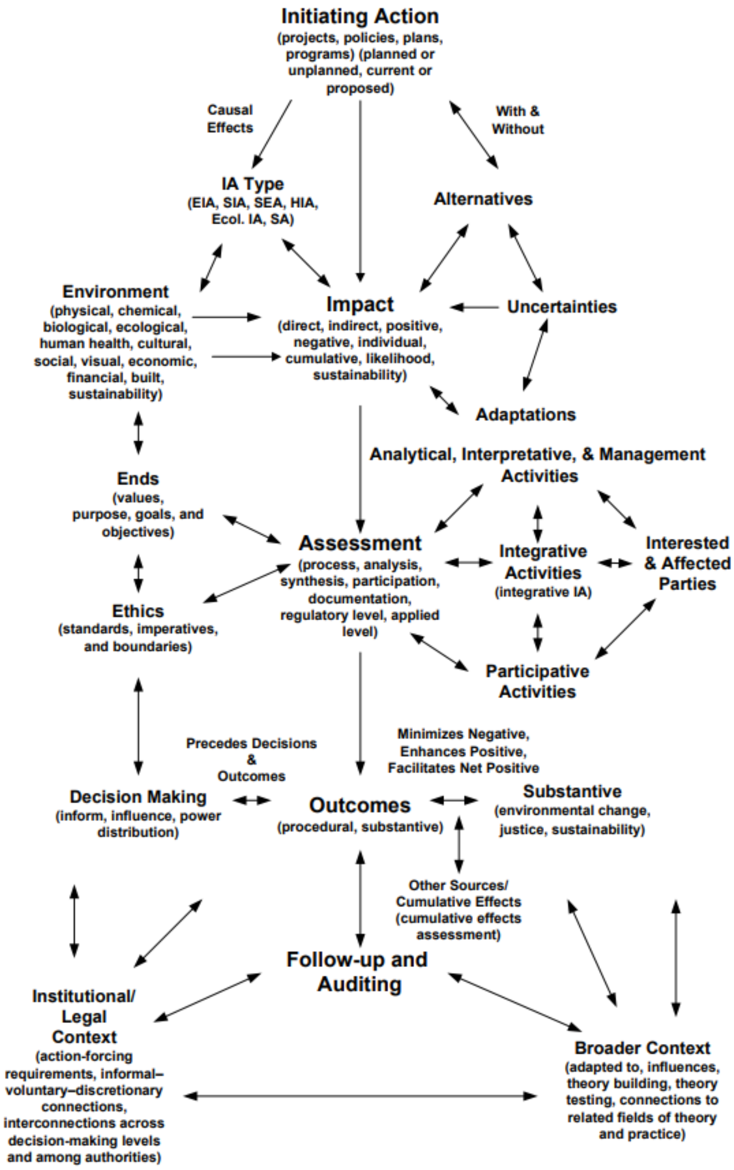

Figure 8: The Structure and Procedure of an Impact Assessment(Lawrence 2013: 5f)

An impact assessment is always conducted prior to the decision making and commitment taking process while tying in decision-making actors into the assessment process. These actors may be parties interested in or affected by the impact of an action and who are able to participate, influence and partially control the outcome of the IA. The process of the impact assessment conduction and the outcome can either passively, through informational documents, or actively, through distribution or reinforcement of power among parties, exert a political decision making role. The definitive elements of an impact assessment are described in figure 8 above (Lawrence 2013: 5f).

The most commonly known and used impact assessment is the Environmental Impact Assessment (EIA), focused mainly on physical activities and projects, dictated by institutional requirements depending on the various physical and ecological impacts which extend to economic, health and social aspects of the environment controlled under numerous jurisdictions. The assessment acts either as a regulatory and applicatory tool, meaning that it is either used to produce requirements, guidelines or review documents or, on the other hand, is applied as a process design and management concept or for review, but is always centered on assessment documents prior to any decision making. In general, it is safe to say that the EIA process generally adopts a passive stance with regards to political influence, and can be seen more as a medium for confirming the accuracy of environmental predictions. However, the main purpose of the EIA remains the facilitation of integrating environmental values and concerns into decision-making processes (Lawrence 2013: 7).

There are several specific relatively new types of impact assessment relating to the EIA, for example, those assessments relating to ecological protection, health implications, or regional effects (Lawrence 2013: 7ff):

One of the noteworthy types of impact assessment related to the Environmental Impact Assessment applying mostly on a national basis is the Health Impact Assessment (HIA). HIA is defined as a "*combination of procedures, methods, and tools that systematically judge the potential, and sometimes unintended, effects of a policy, plan, program, or project on the health of a population and the distribution of those effects within the population. HIA identifies appropriate actions to manage those effects*" (Quigley, et al. 2006). HIA entails a systematic analysis and assessment of a planned political action with regards to a possible positive or negative consequence on human health (Horvath, et al. 2010).

Most of the specific types of Impact Assessments are set up in the European Union, wherefore the following section will focus mainly on EU legislation and procedures governing the conduct of specific Environmental Impact Assessments:

The Transboundary Environmental Impact Assessment (TEIA) is enforced when the probability of emissions crossing territorial borders exists. International organizations such as the United Nations Environment Program (UNEP) or the Organization for

Economic Co-operation and Development (OECD) and the Council of Europe have promoted the establishment of international TEIA legislation based on national Environmental Impact Assessment norms, resulting in the conclusion of normative regulatory bodies and international treaties on TEIA. Examples, therefore, would be the United Nations General Assembly Resolution of 1972 on Cooperation between States in the Field of the Environment (Basmeijer and Koivurova 2011: 8ff).

The Ecological Impact Assessment (EcIA) is defined as "*a process of identifying, quantifying and evaluating potential effects of development-related or other proposed actions on habitats, species, and ecosystems*" (IEEM 2016). The EcIA can be used on its own to assess the compliance of an action with policy and legislation requiring the conduct of an EIA, or as the ecological component of the Environmental Impact Assessment (IEEM 2016: 1). The EcIA can be applied to any project relating to or possibly evoking significant effects on habitats, species and ecosystems. The EcIA is governed by regulation determining the EIA in general, such as the European Council Directive as codified in 2011/92/EU (European Union and Council of the European Union 2011) known as the Environmental Impact Assessment Directive of the European Union which in Annex III sets up the requirement for an EIA for projects with significant environmental effects, including flora and fauna, as well as the interactions with water, air and soil. Most EU Member States set up their own statutory instruments to implement the EIA Directive. In the European Union furthermore requirements to undertake an Ecological Impact Assessment can be derived from the Habitats Directive (Council of the European Communities 1992) and the Water Framework Directive (European Union and Council of the European Union 2000).

The Council Directive 92/43/EEC of May 1992 on the conservation of natural habitats and of wild fauna and flora, short the Habitats Directive of 1992, has the goal of promoting the maintenance of biodiversity while considering economic, regional, social and cultural requirements, and is the main pillar of the European Union's nature conservation policy. Together with the so-called Birds Directive[1], the Habitats Directive creates an ecological network of areas to be protected against potentially damaging actions (European Commission 2016b; Council of the European Communities 1992).

[1] For more see: http://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm

The Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, short the Water Framework Directive, regulates the protection of rivers, lakes, groundwater, coastal beaches from water pollution by urban wastewater, agricultural production, or others (European Union and Council of the European Union 2000).

Another form of impact assessment is the Sustainability Impact Assessment (SIA), a tool specifically designed to analyze and support large trade negotiations conducted by the EU Commissioner for Trade, such as the Transatlantic Trade and Investment Partnership[2]. The SIA was first developed by the European Union for the World Trade Organization Doha Development Agenda negotiations in 1999, and today systematically assess possible human rights and sustainable development consequences of a negotiated trade agreement (European Commission 2016a: 4f).

The last impact assessment type discussed here is the Strategic Environmental Assessment (SEA), as set up in Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the Assessment of the Effects of Certain Plans and Programmes [sic] on the environment. The SEA is in place to ensure that parties utilize an environmental assessment as one of the first steps when conducting a plan or program. The ultimate goal is to mainstream all environmental, economic, social and health topics in decision making to have all actors jointly work towards general sustainable development goals. The SEA is, therefore, a systematic and comprehensive procedure which analyzes the consequences of a policy, plan or program, as well as its alternatives and which uses the findings in publicly accountable decision making processes. The benefit of the SEA is that many different methodological tools of are used and that the process has been internationally acknowledged (European Parliament and Council of the European Union 2001; Lawrence 2013: 8).

Generally one can state that there has been a definite increase not only in the appliance of impact assessments but also in the creation and the diversification of them.

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[2] For more information on SIA, the TTIP and sustainable development objectives of the European Union see: Kraft, Julia. *Sustainable Development, the TTIP and the EU - Three mutually influenced regimes? The Implications of the Transatlantic Trade and Investment Partnership on sustainable development objectives of the European Union.* Vienna: University of Vienna, 2016.

The different types of IA explained above are all linked together in the Environmental Impact Assessment, which can be described as a well-established process, method and framework including a set of best practices addressing questions regarding the environmental, ecological, social, health and economic consequences. However, using the separate impact assessment enables a more individual and integrated analysis with higher sensitivity to the respective issues. In the end, the decision comes down to the specific project to be assessed and the stakeholders involved. All impact assessments strive to make decision making more transparent, democratic and collaborative.

3.2. Structure & Process

Impact assessments operate within frameworks set up by institutional organizations, which determine the requirements and the scope of the IA. The classic structure of an Environmental Impact Assessment is the following and can be seen in detail in the figure below (Lawrence 2013: 12, 15):

- Screening
- Scoping
- Impact prediction
- Significance
- Monitoring and other follow-ups

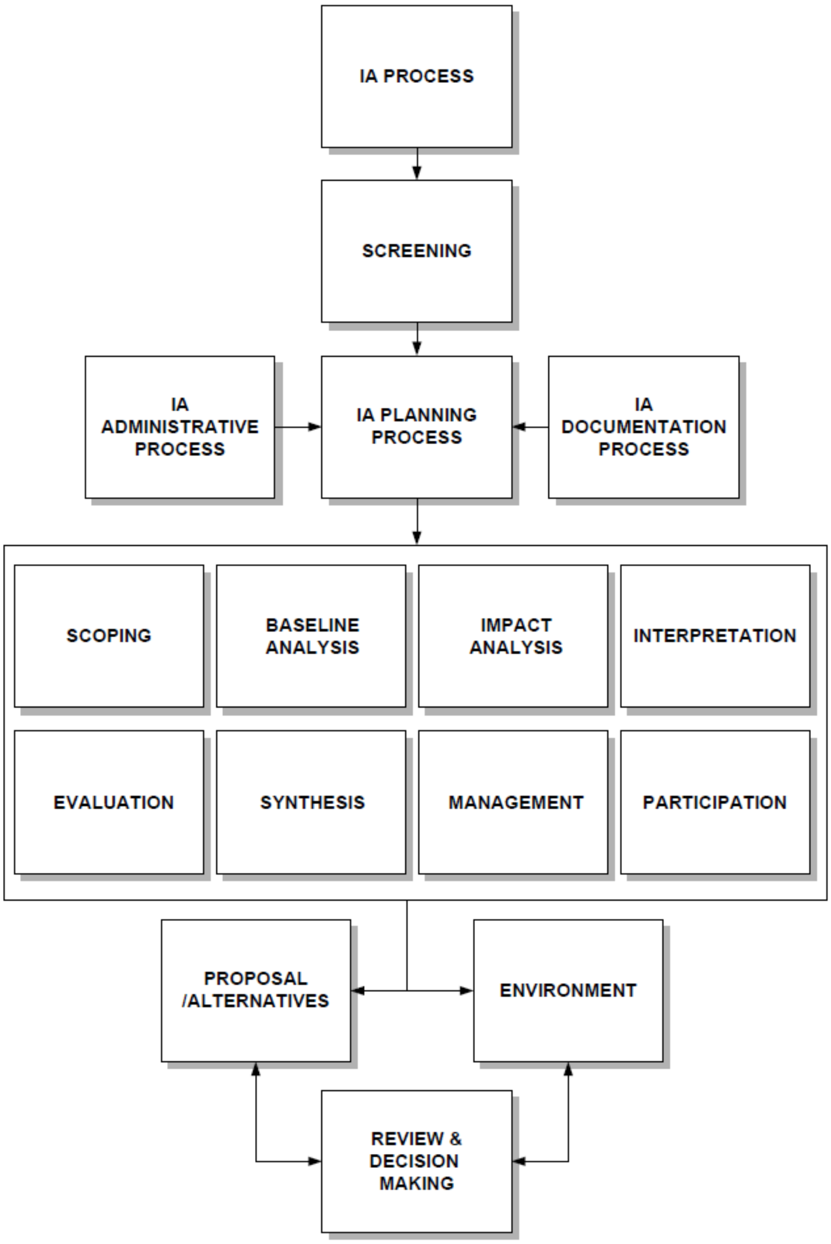


Figure 9: Impact Assessment Process Activities (Lawrence 2013: 12, 15)

Public Participation is seen as a major part of an impact assessment, especially after the European Union incorporated the Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, into the EU Environmental Impact Assessment Directive, further discussed below. Participants may be stakeholders, communities, and individuals with any kind of interest in or affectedness by an action. The purpose of public participation in the EIA process can be classified in a threefold matter. Firstly public participation can be used solely as public input into general decision making, secondly as an allocation of part of the decision making to the public, and thirdly as a complete alteration of the structure of decision making. Depending on the specific process and the action to be assessed these forms may vary dynamically (Morgan 2012: 9f).

The outcome of an Environmental Impact Assessment is normally a formal document, called the Environmental Impact Statement (EIS), which includes the outcome information, the methodology, possible consequences as well as alternative scenarios and is made publicly available (Wathern 2013).

3.3. Legal Basis & Application

An Environmental Impact Assessment is usually initiated and guided by legal, institutional, and action-forcing structures, establishing a formalized procedure to determine any potential environmental effects. Today more than 100 countries apply EIAs due to growing concerns with regards to negative effects on the environment and human health, focused on positive, indirect, and accruing effects, including sustainable decision making (Lawrence 2013: 10). This section will, therefore, address the legal rules and procedures setting up a requirement to assess the possible environmental impacts of a project or an action on the national, international and European level.

3.3.1. National Law

While the United States of America did set up one of the first obligations to conduct an EIA many other countries have pioneered in establishing rules and procedures for the conduct of impact assessment to prevent and minimize environmental hazards.

Historically, the concept of the Environmental Impact Assessment was legally addressed first in the National Environmental Policy Act (NEPA) of the United States of America in 1969 (Senate and House of Representatives of the United States of America 1982) which in Sec. 102 [42 USC § 4332] holds that an Environmental Impact Statement (EIS) is a prerequisite for any Federal activity:

„*[...] to the fullest extent possible: (1) the policies, regulations, and public laws of the United States shall be interpreted and administered in accordance with the policies set forth in this Act, and (2) all agencies of the Federal Government shall –*

(A) utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in

planning and in decisionmaking which may have an impact on man's environment;

(B) *identify and develop methods and procedures, in consultation with the Council on Environmental Quality established by title II of this Act, which will insure that presently unquantified environmental amenities and values may be given appropriate consideration in decisionmaking along with economic and technical considerations;*

(C) *include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on*

(i) *the environmental impact of the proposed action,*

(ii) *any adverse environmental effects which cannot be avoided should the proposal be implemented,*

(iii) *alternatives to the proposed action,*

(iv) *the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and*

(v) *any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.* [...]

(E) *study, develop, and describe appropriate alternatives to recommended courses of action in any proposal which involves unresolved conflicts concerning alternative uses of available resources"* (Senate 1982).

NEPA has set up an environmental policy guide for Federal institutions to control the effect of their actions on the environment, society, and human health, as well as the requirement for the production and publication of a statement paper listing possible environmental impacts of those actions. The publication of the statement was intended to act as a form of checks and balances opposite the American population, as well as to establish a mandatory conduction of factual assessments on possible environmental consequences of a proposed activity, to be used in the decision making the process of Federal agencies (Morgan 2012: 5).

Unfortunately, NEPA was not established as a regulatory authority, but rather for information collection purposes. More importantly, NEPA did not demand new scientific research on environmental impacts, wherefore EIS' have often been criticized for being misleading and inaccurate. Furthermore, NEPA only regulates the national system and therefore leaves international actions and impacts out (Senate and House of Representatives of the United States of America 1982; Ross, Roohey, et al. 2009).

The purpose of NEPA was furthered when in 1979 the President of the United States of America signed Executive Order 12114 on Environmental Effects Abroad of Major Federal Actions, establishing national procedures to identify and process possible environmental impacts of a program or project undertaken by a Federal agency outside of U.S. territory. The Executive Order also suggests that environmental considerations should be a major factor in decision-making processes of Federal agencies (The 1979).

The implementation of NEPA is regulated in 40 CFR of the Council on Environmental Quality, focusing on incorporating NEPA further in decision-making processes. §1500.2 establishes that the basis of an EIA shall be "*concise, clear, and to the point, and shall be supported by evidence that agencies have made the necessary environmental analyses*" including in a detailed list of "*reasonable alternatives to proposed actions that will avoid or minimize adverse effects of these actions upon the quality of the human environment*" (Council on Environmental Quality - Executive Office of the President of the United States 2005: 1).

The Council on Environmental Quality (CEQ) Regulations for Implementing the Procedural Provisions of NEPA focuses on conducting an EIA as early as possible in the operations planning to ensure that environmental values are the basis for planning and operations of the project. Such an Environmental Impact Assessment is in §1502.2 specified to (a) include analytic text, (b) address mainly the for the respective project relevant impacts, (c) be brief and to the point, (d) include an assessment of alternatives to the proposed action more or less stringent with regards to environmental legislation and policy, and (g) focus on the assessment of environmental consequence rather than the justification of a project or program (Council on Environmental Quality - Executive Office of the President of the United States 2005: 8).

Furthermore, environmental law principles set up in the Clean Water Act, the Clean Air Act, the Endangered Species Act and the National Historic Preservation Act can be seen as regulatory drivers of Environmental Impact Assessments (Serafini 2015).

The American example was soon followed by other national legislation in Australia, Canada, Sweden, New Zealand, Austria and others (Petts 1999).

In the European Union, Germany and France were the first countries that introduced legal obligations for Environmental Impact Assessments. France is until today the country in the EU that has produced the most Environmental Impact Statements (Watson 2003). Some of the most stringent regulations on the conduct of an EIA have been set up in the Republic of Austria following the establishment of the EU EIA Directive. The Austrian EIA Guidelines "UVP-Richtlinie 85/337/EWG" were realized as legally binding in the Bundesgesetz über die Prüfung der Umweltverträglichkeit und die Bürgerbeteilung BGBl Nr. 697/93, which was then streamlined in the Umweltverträglichkeitsprüfungsgesetz (UVP-G) of 2000, as amended last in 2017 (UVP-Gesetz 2000). The goals of an EIA are set up as assessing, describing and quantifying any short-term as well as long-term effects on the environment, and to analyze all advantages and disadvantages of the proposed action and its alternatives. The UVP-G includes a strong focus on public participation including the active involvement of non-governmental organizations, and citizen initiatives in the EIA process. The environmental interests are defended by the Federal Ministry of Agriculture and Forestry, Environment and Water Management as well as the Viennese Ombuds office for Environmental Protection. The interesting part of the Austrian EIA law is that it puts special emphasis on actions which have the legal option of applying to expropriate measures or of interfering with private rights to conduct the proposed activity. Such activities have in any case the obligation of administering an Environmental Impact Assessment for the possibly affected locations. From the formulation of the goals of the UVP-G one can assess that the main focus of the national EIA incorporates preventive, coordination, information, and pacification functions (UVP-Gesetz 2000). Austrian law therefore does not solely base environmental assessments on administrative actions, but establishes actual rights by parties to an action or possibly affected by an action, to the conduct of an Environmental Impact Assessment to ensure preventive measures are taken to minimize environmental consequences and maximize the environmental protection (Klaffl, et al. 2006).

Another case important to discuss is the Belgian environmental impact assessment system. The main legal requirements to be addressed by federal actions are Environmental Impact Assessments and Strategic Environmental Assessment for transboundary impacts on (de Mulder 2008):

> "*1. Protection against ionizing radiation from nuclear installations;*
>
> *2. Protection of the marine environment; and*
>
> *3. A limited number of plans and programmes.*".

Interestingly, Belgian federal law establishes a requirement for an EIA and SEA also for foreign plans and programs with possible significant environmental effects on the Belgian Environment. In the case that the Belgian federal service receives a plan or program on a proposed action of a foreign agency, the responsible ministry evaluates if the proposed action has possibly significant environmental consequences, followed by an extensive public consultation process. The recommendation given by the ministry is then transferred to Ministry for the Environment as well as to the Administrative Advisory Committee, who decide on further actions to be undertaken concerning the proposed activity by the foreign actor (de Mulder 2008). Belgian federal law thereby does not wait for possible Environmental Impact Assessments and Strategic Environmental Assessments by a foreign party or the international community but takes matters into national hand and conducts an assessment of any possible risks arising from an activity undertaken by a foreign party. This is interesting, as this system establishes a checks and balances mechanism by any possibly affected party, therefore ensuring that all environmental factors are included to the satisfaction of all parties in an assessment and hopefully also included in a mitigation strategy for environmental impact minimization.

3.3.2. International Law

In 1978 the United States once again pioneered the legal application process for Environmental Impact Assessments, when a proposal was made to set up a convention, this time applying to prospective transboundary emissions. The proposal intended to set up a reporting duty to the United Nations Environmental Program (UNEP) with the goal of preventing and minimizing negative effects on the environment across state lines. Unfortunately, this convention was never set up (Basmeijer and Koivurova 2011: 9f).

The United Nations Conference on Environment and Development of 1992, called the Rio Declaration, is a good example of an international conference establishing national guidelines of conduct, as in Principle 17 establishes for the national conduct of EIAs that (UNGA 1992):

> "*Environmental impact assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment and are subject to a decision of a competent national authority*."

The conference sets up the recommendation for states to notify "*potentially affected States on activities that may have a significant adverse transboundary environmental effect and shall consult with those States at an early stage and in good faith.*" (UNGA 1992).

One of the most important legal guidelines addressing transboundary environmental impacts are the articles on Prevention of Transboundary Harm from Hazardous Activities adopted by the International Law Commission in 2001 (International 2001). The ILC Guidelines deal with the concept of preventing significant damage from a situation planned or carried out in the territory or jurisdiction of a state. Prior to the conduct of any such action that might invoke compensatory measures or liability when impacting the environment, persons or property of another party, an assessment or appreciation of the possible risks of transboundary harm must be undertaken. The transboundary harm must be caused by the physical consequence of an activity. The ILC Guidelines provide in due diligence that all appropriate measures are undertaken to prevent or minimize any significant transboundary impacts. Article 5 of the Guidelines see that states shall take measures necessary to adopt measures to ensure the effectiveness of the articles. Article 7 states that "*Any decision in respect of the authorization of an activity within the scope of the present articles shall, in particular, be based on an assessment of the possible transboundary harm caused by that activity, including any environmental impact assessment.*" (International 2001). The ILC, therefore, sets up an obligation to conduct an a priori assessment of the possible negative impacts on the environment, persons, and property, including a notification of the possibly affected parties. Who is responsible for the actual assessment is not specified, as well as the exact content of such an assessment is left to domestic laws. The main factors to be considered in a consultation between the parties are (International 2001):

> "*(a) the degree of risk of significant transboundary harm and of the availability of means of preventing such harm, or minimizing the risk thereof or repairing the harm;*
>
> *(b) the importance of the activity, taking into account its overall advantages of a social, economic and technical character for the State of origin in relation to the potential harm for the State likely to be affected;*
>
> *(c) the risk of significant harm to the environment and the availability of means of preventing such harm, or minimizing the risk thereof or restoring the environment;*
>
> *(d) the degree to which the State of origin and, as appropriate, the State likely to be affected are prepared to contribute to the costs of prevention;*
>
> *(e) the economic viability of the activity in relation to the costs of prevention and to the possibility of carrying out the activity elsewhere or by other means or replacing it with an alternative activity;*
>
> *(f) the standards of prevention which the State likely to be affected applies to the same or comparable activities and the standards applied in comparable regional or international practice.*"

The ILC Guidelines establish a general notification and information obligation by any state conducting actions with possible transboundary effects. Furthermore, the articles on Prevention of Transboundary Harm from Hazardous Activities adopted by the International Law Commission set up a dispute settlement procedure concerning the interpretation or application of the Guidelines, including "*negotiations, mediation, conciliation, arbitration or judicial settlement*" (International 2001).

3.3.3. European Union Law

Contrary to the rather weak international guidelines and procedures, the European Union institutions have set up very stringent and highly advanced obligations on the conduct of Environmental Impact Assessments for public and private projects and programs with regards to biophysical impact assessments:

In 1985 the Council of the European Communities published the Council Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment and its amendments Directive 2011/92/EU and Directive 2014/52/EU, in short called the EIA Directive, placing a focal point on the harmonization of all Environmental Impact Assessment procedures previously set up by the European nations. Article 1 defines the application of the Directive for all public and private activities which might have an impact on the environment. Article 2 of the Directive establishes that any activity with the likelihood of "*significant effects on the environment by virtue inter alia, of their nature, size or location are made subject to an assessment with regard to their effect*" (Council of the European Communities 1985: 175). This EIA shall "*identify, describe and assess in art appropriate manner*" for each proposed activity individually any direct or indirect consequences on *"— human beings, fauna and flora, — soil, water, air, climate and the landscape, — the inter-action between the factors mentioned in the first and second indents, — material assets and the cultural heritage*" (Council of the European Communities 1985: 175).

Annex I referring to Article 4(1) of the EIA Directive specifies the types of public and private projects automatically subject to an EIA in accordance with Articles 6 to 10, while Annex II referring to Article 4(2) defines projects where EU Member States will assess if an EIA is necessary in accordance with the selection criteria set up in Annex III of the Directive. Examples for Annex I projects would be crude-oil refineries, thermal power stations, or installations operating with nuclear fuels and radioactive waste, while Annex II includes projects of agriculture, the extractive industry, energy projects, infrastructure plans such as airfields, and other projects such as test sites for engines, turbines and reactors (European Parliament and Council of the European Union 2011: 18-24). With regards to outer space operations, one could argue that spacecraft and launch vehicles using nuclear power sources fall under the Annex I projects and need to be assessed, while the testing of rocket engines, reactors, and propulsion systems fall under the definition of Annex II projects, and therefore consultations by the Member States of the European Union need to be undertaken to determine if an EIA must be initiated (Council of the European Communities 1985: 175).

Furthermore, relevant to space operation is the following: Annex III states that should a project be large in size and an accident of that mission could risk major disasters with effects on the environment, climate change and human health in accordance with scientific knowledge, the project is subject to an Environmental Impact Assessment

(European Parliament and Council of the European Union 2011: 27f). As most space missions can be characterized as large projects, and failures in the different mission operation phases can have severe impacts on the earth and space environment, as well as on human health in the short and long term and due to the irreversibility of those impacts, one can analyze that space operation is indeed subject to an EIA in accordance with Articles 6 to 10 of the EIA Directive (European Parliament and Council of the European Union 2011).

Article 5 of the EIA Directive defines that an Environmental Impact Assessment must produce a final report including a detailed description of (a) the "*site, design, size and other relevant features of the project*", (b) any probable impacts on the environment, (c) the technological and operational featured added in the project design "*in order to avoid, prevent or reduce and, if possible, offset likely significant adverse effects on the environment*", (d) an analysis of the alternatives to the project with respect to environmental protection, as well as (e) a "*non-technical summary of the information referred to in points (a) to (d)*" and (f) information in accordance with Annex IV on the character of the operation (European Parliament and Council of the European Union 2011: 9).

The EIA Directive furthermore specifies the aspect of public participation in an Environmental Impact Assessment procedure. Article 6 defines that (1) concerned authorities may give their opinion on the EIA report published, and that (2) the concerned public must be informed as deemed appropriate to ensure that public involvement in the decision making processes is given. The public may (4) communicate opinions and must be given access to the decision making processes relating to environmental issues within a timeframe (6, 7) of more than 30 days (European Parliament and Council of the European Union 2011: 10ff).

As previously stated, Article 6 of Directive is supported by the Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters adopted in 1998 and entered into force in 2001, created to guarantee public participation rights in decision making processes to ensure that the public can contribute to the right to live in an environment suitable for personal well-being and health. The Aarhus Convention is built upon three central pillars and establishes a legal right of the public to (1) Access to environmental information, (2) Participation in environmental decisions, (3) Access to justice in environmental matters (European Parliament and Council of the European Union 2011; UNECE 1998).

In consolidating the Espoo Convention on Environmental Impact Assessment in a Transboundary context set up by the United Nations Economic Commission for Europe, the EIA Directive in Article 7 establishes a right to information and consultations in the case of a potential transboundary implication on the environment by a public or private project to minimize hazardous effects on the environment outside of the territorial boundaries of the operating country (European Parliament and Council of the European Union 2011; UNECE 1991).

With the adoption of Directive 85/377/EEC or Directive 2014/52/EU and the Environmental Action Programs, the European Commission has indicated a policy movement towards using Strategic Environmental Impact Assessments. The usage of, Env,ironmental Impact Assessments for the outer space environment presumes a large level of political assurance on a national and international level. Strategic Environmental Assessments have the potential of being a viable tool for precautionary strategic operations towards managing the use of resources, the pollution load and the analysis of alternative technologies benefitting the environment. A SEA for political space activities could initiate long-term viable outer space targets minimizing environmental costs while supporting innovative production and consumption. SEA could be a direct driver of political and financial incentives and innovation for eco-friendly taxation of space operations. However, it is important to state that while the SEA is a very useful tool for assessing the implications of space policies, projects, and programs, it is not a quantitative measuring instrument. SEA supports decision making processes in analyzing the possible negative impacts of a policy on the environment, and in altering the policy decision to include precautionary principles (European Environment Agency 2008: 6f; Basmeijer and Koivurova 2011).

This chapter has analyzed the general definition and aims of an Environmental Impact Assessment, including its sub-assessments, whereof the Strategic Environmental Assessment is the most practically applied within the European Union and its Member States. The second part of the chapter discussed National, European and International legal norms and guidelines on the conduct of an Environmental Impact Assessment. One can state that nations have established Federal laws and guidelines for the realization of EIAs on a national level. National law in some cases also established obligations and recommendations for transboundary environmental impacts. On an international level, it is apparent that rules of procedures are less concrete and mainly have a non-binding nature. Important guidelines are set up by the IADC inter alia. The

European Union's Environmental Impact Assessment Directive represents the most stringent and advanced obligation for the conduct of EIAs including concrete descriptions of the structure and aims of the assessment, as well as a detailed list of projects and actions directly or indirectly subject to an EIA. Outer Space activities can be interpreted to be part of the EU EIA Directive as they can be described as large projects with possibly severe impacts on the environment in case of an accident. National obligations for space activities might arise from norms such as the Austrian EIA law, with a strong focus on preventive measures. Important to mention is also the large role of the public participation process within the Environmental Impact Assessment procedure and its influence on decision making processes throughout the planning and operation phases of the proposed action.

4. Environmental Impact Assessment in the Space Sector

This chapter will discuss the role of the Environmental Impact Assessment for human activities in the space sector, as well as the applicable legislation.

The outer space environment was accessed by humans only in rather recent history due to technological advancement. The challenges and accessibility arising in human activities in outer space can be compared to remote areas on earth, such as the Antarctic. The management of environmental problematics arising from human activities is also approached from a similar legal perspective, being mainly transboundary effects of an activity. With an increase in threats to the environment from the growing space industry, and with growing awareness towards those environmental consequences, the need for an assessment controlling space activities same as activities on earth has become more pressing every day. The Environmental Impact Assessment has celebrated significant success in many areas but has yet to be properly established as a viable instrument in international space law. The regulatory recommendations to undertake an EIA under international law were originally introduced and are still today governed under the context of possible impacts of certain actions on a national or transboundary basis. As space activities mainly take place outside state territories, obligations under national environmental law do not apply. However, due to growing recognition of international interdependence, international jurisdiction not limited to national borders has started to include obligations for the conduction of Environmental Impact Assessments, such as in United Nations

Convention on the Law of the Sea of 1982 (United Nations 1982) or the Protocol to the Antarctic Treaty on Environmental Protection of 1991 (United Nations Economic Commission for Europe 1991). Similar obligations beyond the limits of national jurisdiction have not been adopted for space activities yet. (Viikari 2011: 265f).

As stated in previous chapters, space propulsion contributes only to a fraction of total emission impacts on the atmospheric environment. Therefore the political focus has not yet fully been put on this subject, but is rather focused on commercialization of outer space and building an economically valuable industry. In addition, EIAs are less applied in space compared to on earth projects, as less information is available on both the natural processes taking place and the highly advanced and challenging technological circumstances required for the acquirement of information, in contrast to a very minimal information gap for earth activities subject to an EIA. Furthermore, currently the space sector is dominated by military and commercial actors, keen on minimizing general information accessible to everyone. All of the above-mentioned factors together with the general hazardous conditions are hindering actors to conduct scientific research in outer space (Viikari 2011: 269f).

The fact that no human settling exists in outer space, facilitates the legal definition of outer space as a province of all mankind, as defined in Article 1 of the Outer Space Treaty (OST) (UNGA 1967). On the other hand, this also implies that outer space, planetary systems, and other celestial bodies are not subject to national legislation claims to sovereignty as set up in Article 2 or the United Nations' OST (UNGA 1967). Space mission operators are furthermore often unwilling to include precautionary measures in the preparation of a space action due to the higher short-term costs. Furthermore, this regulatory development by some, benefitting all evokes the free rider problematic, where many might benefit from the precautious actions of others, a problem often arising in areas of the common (Viikari 2011: 270).

All those factors listed above are recognized barriers to the general acceptance of Environmental Impact Assessments for outer space missions. They also depict the high necessity of a general regulatory framework to enhance the promotion of assessment conduct to minimize the negative impacts of prospective space missions on the earth and space environment. International law is currently in place to regulate impact assessments for general activities on earth, especially with regards to transboundary impacts. National legislative norms regulating transboundary environmental hazards are also steadily increasing. Furthermore, space agents have their own norms and rules of procedure regulating their general conduct, and sometimes also the incorporation of precautionary actions to space missions (Viikari 2011: 270f).

Up to the point where the Space Shuttle was introduced, space flight was generally always considered a national matter, wherefore international political and scientific activities were at a minimum with regards to environmental impacts of rocket propulsions. The Space Shuttle changed that situation in 1981 when it became the largest stratospheric rocket emission source. The Montreal Protocol on Substances that Deplete the Ozone Layer was used to categorize the emissions from solid rocket motor is driven space shuttles and create emission models. This proves that the Montreal Protocol is consistently used as a regulatory basis for new scientific research, and as such determines regulation on ozone depletion as well as radioactive forcing (Ross, Roohey, et al. 2009).

While the Montreal Protocol does not determine aerospace emissions, it does address the ozone depletion potential of emissions. The preamble states that parties (UNEP 1987):

> "*Recognizing that world-wide emissions of certain substances can significantly deplete and otherwise modify the ozone layer in a manner that is likely to result in adverse effects on human health and the environment,*
>
> *Conscious of the potential climatic effects of emissions of these substances, Aware that measures taken to protect the ozone layer from depletion should be based on relevant scientific knowledge, taking into account technical and economic considerations,*
>
> *Determined to protect the ozone layer by taking precautionary measures to control equitably total global emissions of substances that deplete it, with the ultimate objective of their elimination on the basis of developments in scientific knowledge, taking into account technical and economic considerations and bearing in mind the developmental needs of developing countries"* (UNEP 1987)

Already the preamble of the Montreal Protocol addresses "potential climatic effects of emissions" as well as the need of "taking precautionary measures" to avoid environmental damage. The Protocol specifically determines substances with ozone-depleting potential (ODP) in its annexes, to which rocket emissions are often subjectively assigned (Senate and House of Representatives of the United States of America 1982; Ross, Roohey, et al. 2009).

The Montreal Protocol does not directly contradict the findings of the NASA routine payloads of space operations coming to the conclusion ‘No Significant Impact’. While certain substances from chemical combustion engines do show high ozone depleting potential, the amount of injected chemical propellant exhaust is very small compared to other transport sectors. The impact of rocket exhaust must nevertheless be continuously assessed and reviewed to keep consequences for the stratospheric ozone layer at a minimum.

On an international basis, rocket emission regulation was not explicitly established by the Outer Space Treaty of 1967 which regulates the general exploration of outer space. Article IX only defines that harmful contamination and negative effects on the environment should be avoided (UNGA 1967).

With this limited legal basis, space launch providers benefit from unconstrained policy regulation. With an increase in environmental awareness, more political and scientific light might be shed onto space propulsion emissions. Research on alternatives to traditional launching motors is underway and might soon bring new viable options for less environmentally invasive technologies.

4.1. Environmental Impact Assessment and Current Space Law

This section will analyze the existing international, European and national legal norms and regulations governing the use of Environmental Impact Assessments in outer space.

4.1.1. International Law

The main international instruments regulating activities in outer space are five space treaties adopted by the United Nations Organization in the 1960s and 1970s: the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies of 1967, the Agreement on the Rescue of Astronauts, the Return of Astronauts and Return of Objects Launched into Outer Space of 1968, the Convention on International Liability for Damage Caused by Space Objects of 1972, the Convention on Registration of Objects Launched into Outer Space of 1975, as well as the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies of 1979. These treaties were drafted at a time where environmental consciousness was not at the center of outer space activities. Therefore those principle space treaties have a deficiency with regards to environmental protection norms. (UNOOSA 2017).

However, the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies of 1967, called the Outer Space Treaty, in Article IX includes a requirement for consultations prior to an action which might cause possible 'potential harmful interference' with the space missions of any other space actor. Article IX states that:

> *"Parties to the Treaty shall pursue studies of outer space, including the moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.*
> *If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment."* (UNGA 1967).

The wording "*avoid harmful contamination and also adverse changes to the environment*" has in the past been interpreted as an international basis for raising concerns regarding space debris and environmental pollution by space vehicles. Yet, it can also be interpreted as asking for Environmental Impact Assessments for actions with possible impact on orbital debris and environmental rocket emissions. However, Article IX is not backed up by any obligation with regards to the outcome of such consultations (UNGA 1967; Ross and Vedda2018).

Article XI of the Outer Space Treaty goes on to hold that all parties conduction space activities are obliged to "*inform the Secretary-General of the United Nations as well as the public and the international scientific community, to the greatest extent feasible and practicable, of the nature, conduct, locations and results of such activities*." (UNGA 1967). While this text does establish a general reporting obligation on the space mission as such, Article XI does not set up either an obligation to conduct research on potential negative environmental consequences, or any reporting duty with regards to any effect on the earth or space environment thereof.

Furthermore relevant to Environmental Impact Assessments is Article VI of the Outer Space Treaty which sets up international responsibility for national operations in outer space for governmental and non-governmental actors alike. This responsibility is extended to the ensuring the conformity of any action is space with the Treaty. Furthermore, Article VI OST obliges states to "*authorization and continuing supervision*" of the activities of non-governmental actors in outer space, the moon and other space bodies by the applicable State Party to the OST. This Article is a vital tool for implementing environmental obligations (UNGA 1967).

In practice, consultations are mainly undertaken for space missions to the geostationary orbit (GEO) and the placement of satellites therein. This practice is based, beside the Outer Space Treaty, on the Constitution and Convention of the International Telecommunication Union (ITU), Article 1 Paragraph 2b of the Constitution and Convention of the ITU where it is held that the ITU shall (ITU 1992: 332f):

> "*coordinate efforts to eliminate harmful interference between radio stations of different countries and to improve the use made of the radio-frequency spectrum and of the geostationary-satellite orbit for radiocommunication services*"

The ITU regulates firstly international coordination with regards to the installation of satellites in the geostationary orbit and the use of radio communication technologies, and secondly states that any kind of negative obstruction must be eliminated (ITU 1992: 332f).

Additionally, the United Nations General Assembly Resolution on Principles Relevant to the Use of Nuclear Power Sources in Outer Space of 1992, in short, called the NPS Principles, governs the use of nuclear power for outer space missions and the possible negative effects arising from that usage. Principle 4 of the NPS Principles on 'safety assessments' sets up a requirement to an a priori safety assessment of all space activities to assure a safe use of technologies on earth as well as in space. This assessment should be conducted with those who "*have designed, constructed or manufactured the nuclear power sources, or will operate the space object, or from whose territory or facility such an object will be launched*" (UNGA 1992), including all stages of the space mission including the means and technologies used. The outcome of the safety assessment should to be published before the launch of the space rocket or the launching vehicle. Unfortunately, the NPS Principles do not have a legally binding nature and are only recommendations focused on nuclear safety. Environmental principles are not explicitly included in the Principles (UNGA 1992; Viikari 2011: 272f).

In 2001 the United Nations General Assembly adopted a resolution on the international cooperation in the peaceful uses of outer space, where it is established in Paragraph 14 that the Scientific and Technical Subcommittee is responsible for analyzing space debris mitigation measures currently existing on a national and international basis based on submitted reports by nations. The resolution further stated in Paragraph 34 that efforts toward the protection and preservation of the environment of outer space shall be increasingly focused on with the full support of the United Nations General Assembly (UNGA 2000).

Another international body actively participating in the establishment of rules and guidelines for EIA space activities is the European Space Agency. The European Space Agency has established mechanisms to prevent and mitigate the problem of space debris pollution. Software models such as the Debris Risk Assessment and Mitigation Analysis have been applied. This was not established on a legal basis, but on general operation frameworks already addressed previously (ESA 2016).

4.1.2. National Legislation

On a national basis increasingly more legislation regulating Environmental Impact Assessments for outer space operation by states, agencies or private actors exists.

As analyzed in a previous chapter, the first Environmental Impact Assessment procedures were set up on a regulatory basis by the National Environmental Policy Act in the United States in 1969. The NEPA set up the requirement of environmental impact documentation in an early stage of a planned activity including a description of the action, necessity and purpose, alternatives as well as potential environmental and health consequences. The NEPA includes a right to public participation at different planning phases and influence with regards to decision-making processes (Senate and House of Representatives of the United States of America 1982; Viikari 2011: 273f).

The NEPA is also relevant for space activities, as space launches have been qualified as a Federal action for which Environmental Impact Assessments must be undertaken.

While the Act as such does not define impacts across state borders, American courts have historically held that the National Environmental Policy Act also addresses actions with potential impacts abroad. In the case ‘Environmental Defense Fund vs Massey’ the American Court of Appeal has held that U.S. Federal activities with effects on Antarctica also must comply with the NEPA (Court of Appeals, District of Colombia Circuit. 1993; Wirth 1993). In correlation NEPA also applies to activities in the outer space sector. Environmental Impact Assessments are mainly applied for space activities and their immediate consequences from the launch of a space rocket or a space launch vehicle, but have also been conducted for actions with impacts globally or on the outer space environment (Senate and House of Representatives of the United States of America 1982; Viikari 2011: 273f).

For outer space missions using nuclear power systems a specific nuclear safety launch approval procedure is in place in the US which takes approximately five years in addition to the previous NEPA process: The United States Department of Energy (DOE) cooperates with the respective parties planning a space mission when the Environmental Impact Statement entails the analysis of nuclear power systems, preparing specific assessments entailing an analysis of a possible nuclear accident. The risk assessment statement by the DOE is then examined on an ad hoc basis set up Interagency Nuclear Safety Review Panel with experts from each sector putting together their own mission report. Based on this review the mission party decides if to continue with the mission or not. The last step of approval for any space operation including the usage of nuclear power for electricity or heating purposes, official launch authorization must be granted by the President of the United States himself (The White House 1977; Viikari 2011: 275f).

Moreover, NEPA is supplemented by the NASA Policy for Limiting Orbital Debris Generation, which is primarily in place to avoid the assimilation of new orbital debris to decrease the risk for present and future space activities, and establishes the necessity of (National Research Council 2011: 9):

> “*(1) limiting the generation of orbital debris, (2) assessing the risk of collision with existing space debris, (3) assessing the potential of space structures to impact the surface of the Earth, and (4) assessing and limiting the risk associated with the end of mission (EOM) of a space object*”.

This policy sets up the obligation for all NASA projects and programs of assessing the debris generation during standard operation and failure scenarios (explosions, intentional breakups), as well as from collisions during operation and for disposition (reliable disposal of the vehicle in orbit, outside orbit, or on earth). In the two required assessments, one in the preliminary design audit and one 45 days before the critical design audit, mitigation options must be included for all scenarios in correspondingly to the NASA Safety Standards (National Research Council 2011; and U.S. Government 2001).

Furthermore, NASA has itself adopted policy and procedures for implementing the National Environmental Policy Act, where in 14 CFR Subpart 1216.3 the scope, applicability, and responsibilities of NASA with regards to Environmental Impact Assessment standards set up in NEPA. It is written in §1216.303 (NASA 2012):

> "*(a) NEPA requires the systematic examination of the environmental consequences of implementing a proposed Agency action. Full integration of the NEPA process with NASA project and program planning improves Agency decisions and ensures that:*
>
> > *(1) Planning and decision making support NASA's strategic plan commitment to sustainability and environmental stewardship and comply with applicable environmental statutes, regulations, and policies.*
> >
> > *(2) The public is appropriately engaged in the decision-making process.*
> >
> > *(3) Procedural risks and delays are minimized.*
>
> *(b) Determining the appropriate level of NEPA review and documentation for a proposed NASA action will depend upon the scope of the action and the context and intensity of the reasonably foreseeable environmental impacts.*
>
> *(c) The environmental impacts of a proposed Agency action must be considered, along with technical, economic, and other factors that are reasonably foreseeable, beginning in the early planning stage of a proposed action. NASA will take no action which would have an adverse environmental impact or limit the choice of reasonable alternatives prior to completion of its NEPA review.*"

The conduct of an Environmental Impact Assessment in the United States will be further analyzed in the case study in the last chapter.

Another example for national legislation regulating EIA processes is the Russian Statute on Licensing Space Operations Number 104 of 1996, which in Art. 5 (h) requires documents affirming the safe conduct of a planned space mission including ecological safety in order to receive an official license for an outer space operation (UNOOSA 1996). Similar requirements are set up by other space-faring nations such as Australia as well (Viikari 2011: 276).

The Austrian Federal Law on the Authorization of Space Activities and the Establishment of a National Registry (Austrian Outer Space Act) has previously been mentioned in this thesis as a role model with regards to establishing obligations for nations. Article 4 of the Austrian Outer Space Act established conditions for the authorization of space operations. Prerequisite for the authorization is a guarantee that no negative consequences will arise for (Art. 4(1.3.)) the safety of persons, property and public health, as well as (Art. 4(1.5.)) for the earth and space environment. Furthermore, Article 4 (1.4.) addresses mitigation measures for space debris creation. Article 4 OST furthermore establishes liability for damages caused (BGBl BMVIT 2011).

The Austrian Outer Space Act furthermore establishes in Article 5 an obligation for space mission operators to prevent the creation of space debris as well as for setting up orbital space debris mitigation measures (BGBl BMVIT 2011). The Austrian Outer Space Act, therefore, serves as a role model establishing legally binding norms for the requirement of a detailed assessment of all possible risks on the environment, persons, and property, including a sanctioning mechanism to ensure that this process is in fact followed. This obligation sets a precedent for other nations to follow (BGBl BMVIT 2011).

The United Nations Office for Outer Space Activities set up a Compendium on all Space Debris Mitigation Standards Adopted by States and International Organizations in January of 2018. To give an example, Canada establishes a legal obligation to a disposal plan of all sensing space systems (UNOOSA 2018: 14).

While nowadays impact assessments are conducted regularly and on a precautious basis, environmental deliberations still do not rank as one of the most significant. A lack of binding legislation including liability as well as the relatively small influence of Environmental Impact Assessments on decision-making processes lead to the continuing low realization rate (Viikari 2011: 276f).

Next, to legally binding obligations non-binding soft law has found increasing support in international fora and can be assessed as the most practically realized Environmental Impact Assessment provisions. Soft law is often exerted by guidelines and recommendations of national space agencies, such as the United States National Aeronautics and Space Agency or the French Centre National d'Etudes Spatiales (CNES) (Viikari 2011: 277).

The Inter-Agency Space Debris Coordination Committee (IADC) brings together all space agencies globally to facilitate information sharing and cooperation on space debris activities, to review programs and projects as well as to find mitigation measures. The IADC Space Debris Mitigation Guidelines have previously recommended the establishment of a Space Debris Mitigation Plan a priori to the launch of any space mission including a detailed assessment and analysis of mitigation measures of space debris in the space environment (IADC 2014). The Guidelines express that (IADC 2007: 4):

> "*the implementation of some debris mitigation measures today is a prudent and necessary step towards preserving the space environment for future generations.*"
>
> And (IADC 2007: 7): "*During an organisation's planning for and operation of a spacecraft and/or orbital stage, it should take systematic actions to reduce adverse effects on the orbital environment by introducing space debris mitigation measures into the spacecraft or orbital stage's lifecycle, from the mission requirement analysis and definition phases."*

The space debris protection manual published by the French CNES has initiated the establishment of the European Code of Conduct Outer Space Activities as a Contribution to Transparency and Confidence-Building Measures in Outer-Space Activities. The Code of Conduct requires regular reporting and assessment on the implementation of space projects to the High Representative of the European Union for Foreign Affairs and Security Policy as well as to the European Commission (Council of the European Union 2015). Other Space Debris Mitigation Guidelines already mentioned in the previous chapter are the UN COPUOS Guidelines and the IADC Guidelines on the Mitigation of Orbital Space Debris.

To summarize this chapter on the legal framework of Environmental Impact Assessments for Outer Space Activities again the national, international and European norms and procedures were addressed. On a national level, Austria acts as a role model for establishing legally binding obligations to conduct a priori assessments of possible environmental impacts of an action and also to actively conduct orbital space debris mitigation to reduce the risk of collision with space debris for present and future space missions. The United States has also set up detailed guidelines and rules of procedures to govern the conduct of EIAs as part of the planning phase of a proposed action. International guidelines are set up by the United Nations Outer Space Treaty, addressing the necessary environmental protection standards for space missions, as well as the authorization principles for spaceflight with an a priori Environmental Impact Assessment. The United Nations has set up Principles Relevant to the Use of Nuclear Power Sources in Outer Space and has established many other recommendations as such on the a priori assessment of potential environmental impacts of a proposed space operation. The Inter-Agency Space Debris Coordination Committee has additionally published a summary of all existing best practice scenarios with regards to orbital space debris mitigation by member states to streamline the information sharing and cooperation between states. Generally, national rules and guidelines have stronger language and establish strict reporting duties. International law on the other hand still has a large gap with regards to legally-binding legislation. International guidelines exist which are generally followed but cannot be supported by sanctions or liability measures.

5. Case Study – Environmental Impact Statement Mars 2020 Mission - NASA

Due to the fact that the state of the art regarding Environmental Impact Assessments in the space sector is very fragmented, and binding norms in international instruments are also limited, a case study based on international environmental space norms is unfortunately impossible. Therefore the case study selected in this thesis deals with a currently ongoing space mission of the United States National Aeronautics and Space Administration (NASA) where a disproportionately high number of documents relating to an Environmental Impact Assessment is available. While this is a nationally conducted EIA, based mainly on national legal norms, NASA is a viable and strong influence in the international space community. Therefore it can be assumed that an EIA conducted by NASA will be used as a role model for space missions of other national and international actors and might trigger negotiations on new international obligations regulating environmental assessments of space activities.

NASA conducts Environmental Impact Assessments on the basis of Executive Order 12114, the National Environmental Policy Act, and NASA's NEPA policy procedures, as well as international legislation, discussed previously.

As set up in the CEQ Regulations for Implementing the Procedural Provisions of NEPA, an Environmental Impact Statement shall include (Council 2005: 10):

> " *(a) Cover sheet, (b) Summary, (c) Table of contents, (d) Purpose of and need for action, (e) Alternatives including proposed action. (f) Affected environment, (g) Environmental consequences, (h) List of preparers, (i) List of agencies, organizations, and persons to whom copies of the statement are sent, (j) Index, (k) Appendices (if any).* "

The case study will be structured based on this procedural prerequisite.

5.1. Executive Mission Summary

§1502.12 of the CEQ regulation sets up that the EIS should be initiated with a summary of the statement in general (Council 2005: 11).

The National Aeronautics and Space Administration (NASA) has set out to launch the Mars 2020 spacecraft on a launch vehicle in the year 2020 to transport a Mars rover to a specific location one year later. The Environmental Impact Statement reporting on the findings of an in-depth Environmental Impact Assessment of the Mars 2020 Mission was published in November of 2014 by the National Aeronautics and Space Administration Headquarters in Washington, DC, in cooperation with the United States Department of Energy and the NASA Planetary Science Division Science Mission Directorate (NASA 2014: iii).

This final EIS for the Mars 2020 Mission is based on principles set up by the following legal frameworks (NASA 2014: iii; and Serafini 2015):

(1) National Environmental Policy Act of 1969, as amended;

(2) Executive Order 12114 on *Environmental Effects Abroad of Major Federal Actions*;

(3) The Council on Environmental Quality (CEQ) Regulations for Implementing the Procedural Provisions of NEPA;

(3) 14 CFR 1216.3 and NPR 8580.1A on NASA policy and procedures for implementing the National Environmental Policy Act.

The impact assessment conducted hat its focal point on analyzing possible alternatives for the Mars 2020 operation and the probable environmental consequences resulting thereof. The Environmental Impact Statement sets out to deliver viable input in decision making processes with regards to environmental standards and possible implications NASA 2014: iii).

The Mars rover to be used is more specifically a large laboratory operated by a Radioisotope Thermoelectric Generator enabling the exploration of the planet Mars. The operation in general was initiated by the Science Definition Team Report of the Mars 2020 Mission, suggesting the project including the possible technology to be used, such as technological instruments to sample environmental pieces to be returned to Earth by another mission for further analysis, and other robotic and human missions (NASA 2014: iii).

The final Environmental Impact Statement includes explanations on the mission as such, the launch vehicle, the spacecraft, the potential environmental impacts on site and globally, caused either by the proposed operation or possible alternative scenarios counting in the No Action Alternative (NASA 2014: iv).

The purpose and need for action of the proposed space operation is the conduct of astrobiological and geological research as well as the display of technological progress, establishing a pioneering first human exploration of Mars, and therefore decreasing the risks and information gap for future space missions to Mars (NASA 2014: iii f; and NASA 2013).

The results of the conducted EIA proposes four separate alternatives. Alternative 1 is the proposed mission and is also labeled as the Preferred Alternative. Alternatives 2 and 3 propose the usage of different power sources from the preferred power system, while the fourth alternative is the No Action Alternative proposing that no Mars mission is undertaken (NASA 2014: iv).

The scientific capabilities and risks of the four alternative scenarios are the following. All alternatives have identical mission science objective as the use of scientific instruments are exactly alike. There is, however, a difference in capability between the alternatives, as NASA's Preferred Alternative guarantees power supply over a longer time span and in all latitudes, compared to Alternatives 2 and 3 which are limited in time and capability. As a result, Alternatives 2 and 3 would increase technical risks and therefore also the operating budget. Under the No Action Alternative, no science capability can be achieved as the planning would be stopped before operation (NASA 2014: v).

The environmental consequences of the proposed missions and the alternatives can interfere with both the launch site environment and the global earth environment. Impact evaluations are based on previous experiences with other NASA space missions such as Falcon Heavy or Atlas V. The environmental consequences of normal mission operation would center on emissions from launch vehicle exhaust, primarily impacting air quality, as well as water bodies and their ecosystem due to short-term acid deposition loads close to the launch site. In 2011 NASA has in its Routine Payload on Expendable Launch Vehicles Impact Assessment determined that no long-term or aggregate damage is caused by spacecraft launches. With regards to the flight path, solid chemical propulsion emissions result in ozone depletion in the stratosphere (NASA 2014: vi; and NASA 2011).

This part of the EIS also assesses non-radiological and radiological environmental impacts from possible launch accidents. Non-radiological impacts from launch accidents could be liquid propellant spills during fueling or a launch vehicle accident with increased propellant combustion exhaust together with surface debris production. Radiological impacts of launch accidents could lead to the discharge of nuclear radiation at all stages of the launch into the earth environment or into orbit, possible under Alternative 1 and 3. To calculate the impact of such risks, in 2014 the U.S. Department of Energy has conducted a Nuclear Risk Assessment for the Mars 2020 Mission to be incorporated into the Mars 2020 EIS, and has analyzed potential accident scenarios as well as the immediate responses required to minimize the environmental damage of that accident, and thirdly assessed general risks and consequences on the environment and human health as well as on the budget of the mission. The probability of such a launch accident occurring under Alternative 1 or 3 was estimated at below 2,5% (NASA 2014: vii f; and Sandia, et al. 2014).

The table below summarizes the alternative scenarios (NASA 2014: xv):

Table 4: Summary Comparison of the NASA Mars 2020 Mission Alternative Scenarios (NASA 2014: xv)

	Proposed Action (Alternative 1)	Alternative 22	Alternative 3	No Action Alternative
Rover Power Alternative	MMRTG	Solar Array no LWRHUs	Solar Array with LWRHUs	Not applicable
Functional Capacity	Capable of operating for at least one Mars year at landing sites between 30 north and 30° south latitudes on Mars	Unable to operate for a gull Mars year at any latitude	Limited operational capability for a full Mars year for landing sites between 20° south and 5° south latitudes on Mars	Not applicable
Science Capacity	Capable of accomplishing all science objectives at any scientifically desirable landing site between 30° north and 30° south latitudes.	Capable of accomplishing of the 33% of science objectives during partial year operation at limited latitudes.	Capable of accomplishing 70% of science objectives at limited latitudes due to constrained operations during northern winter.	No science achieved
Anticipated Environmental Impacts (Normal Launch Operation)	Short-term impacts associated with exhaust emissions from launch vehicle during a normal launch.	Short-term impacts associated with exhaust emissions from the launch vehicle during a normal launch.	Short-term impacts associated with exhaust emissions from the launch vehicle during a normal launch.	No impacts
Potential Environmental Impacts in the Event of a Launch Accident	Potential impacts associated with combustion of released propellants and falling debris. Potential radiological impacts associated with the release of some of the plutonium dioxide from the MMRTG.	Potential impacts associated with combustion of released propellants and falling debris.	Potential impacts associated with combustion of released propellants and falling debris. Potential radiological impacts associated with the release of some of the plutonium dioxide from LWRHUs.	No potential impacts

5.2. Purpose and need for action

§1502.13 of the CEQ regulation states that section two of the EIS must "*specify the underlying purpose and need to which the agency is responding in proposing the alternatives including the proposed action*" (Council 2005: 11).

5.2.1. Background

The Mars Exploration Program (MEP) was established by NASA as a long-term exploratory scientific strategy with the goal of comprehending geologic and climate conditions on planet Mars as such and as a potential habitat for microbial life including the existence of water, energy sources and sedimentary soils. The scientific objective of the Mars 2020 Mission can, therefore, be summarized as a quest to comprehend the planet in order to smooth the path for future exploration of Mars by humans. Within this MEP came the requirement of technological advancement to enable safe transport from Earth to Mars, precise scientific investigations including access to atmosphere, surface, and subsurface of the planet to be discovered (NASA 2014: 1-1ff).

5.2.2. Purpose of action

The underlying purpose of NASA's Mission 2020 to Mars is firstly the conduct of extensive scientific research on planet Mars, and secondly publicly display highly advanced technologies for prospective explorations of the planet. The scientific objective of the Mars 2020 mission can be divided up into four goals (NASA 2014: 1-4f):

> (1) Comprehend geological and astrobiology changes within a defined area on the Mars surface, with the underlying hope of discovering environmental and geologic variety.
>
> (2) Investigate collected geologic matter with astrobiology relevance and the potential of preserving biosignature in order to assess the habitability of the Mars surroundings.
>
> (3) Build a storage container with the prospective option of returning it filled with Mars samples to Earth in a later mission. This shall be undertaken while taking into account planetary protection standards and engineering principles to guarantee a safe return at any point in the future.
>
> (4) Prepare for prospective intense human exploration programs of the planet by increasing the knowledge available on Mars, including In-Situ Resource Utilization, assessment of morphology and weather conditions technologies.

5.2.3. Need for action

The Mars Exploration Program described Mars as an optimal case for exploration of questions such as possible habitability and life as a reference for the solar system in general, as transportation to Mars has been made possible due to technical advancements, and also because it is assumed that Mars holds astrobiological evidence for past life. Several studies and proposed research projects such as the National Research Council's Vision and Voyages for Planetary Science in the Decade 2013-2022 established the national need for an increase in the scientific exploration of outer space outside the current state of the art, towards a scientific assessment of planetary exploration. NASA's Mars 2020 mission aims at narrowing that scientific research and knowledge gap in order to enable future advanced human exploration programs of the planetary solar system (NASA 2014: 1-5f).

The means of conducting the mission via a mobile rover transporting scientific instruments on a large area is proof of the will to retrieve maximum scientific knowledge from this mission. Only through mobile instruments can the necessary information for conclusions on habitability under the title “Seek Signs of Life” be retrieved (NASA 2014: 1-6f).

5.2.4. NEPA procedure, public participation

Following the rules of procedures set up by the National Environmental Policy Act, NASA initiated the Environmental Impact Assessment procedure with the publishing of a report Final Programmatic Environmental Impact Statement for the Mars Exploration Program in 2005. The Final Programmatic was signed later in 2005, incorporating the prospective launch of at least one spacecraft to Mars (NASA 2005; and NASA 2014: 1-7f).

The official Notice of Intent (NOI) to set up an Environmental Impact Statement for the Mars 2020 mission was published in the Federal Register in 2013. This notice opened the EIA process up to public participation on environmental consequences and possible alternatives to be concluded until October of 2013, Informative and dialogue meetings were held with the public and formal public input was collected. Most of the input focused on including assessments of possible effects on the local environment, including radioactive accidents and waste. After receiving approximately 200 inquiries by Federal, state and regional agencies and individuals, the results of the public participation process were summarized in a Notice of Availability (NOA) for the draft Environmental Impact Statement in the Federal Register in June of 2014, initiating the 45 day timeframe for public review of the draft EIS for the mission. All received comments submitted during the public participation procedure including some of NASA’s statements are included in Appendix D of the final EIS on the Mars 2020 mission (NASA 2015; and NASA 2014: 1-7 - 1-10).

A competitive selection process of the most highly advanced and best practicable scientific tools was analyzed and selected for the specific use of Alternatives 1, 2, and 3. In the Draft EIS previous to the public participation process instruments powered by radioisotopes were addressed, while after the public review and comment process the use of radioisotope instruments for the Mars 2020 operation was completely eliminated from the Final EIS. This shows that the public was indeed successful in altering the decision making process in the planning phase of the Mars 2020 mission (NASA 2015; and NASA 2014: 1-10).

5.3. Alternatives – Description & Comparison

Segment three is the core of the EIS and defines the basic findings of the Environmental Impact Assessment and the general environmental impacts of the proposed action. Furthermore, this section describes the alternatives analyzed in the assessment and the environmental implications thereof. One or more preferred alternative scenarios may be described in addition to listing all relevant alternatives including their evaluation. Should no mitigation measures have been included in segment two on purpose and need for action, this third segment may describe appropriate mitigation procedures (Council 2005: 11).

The Science Definition Team report published in 2013 set up basic competencies required for a successful mission. The capability baselines are outlined in the table below (Mustard, et al. 2013):

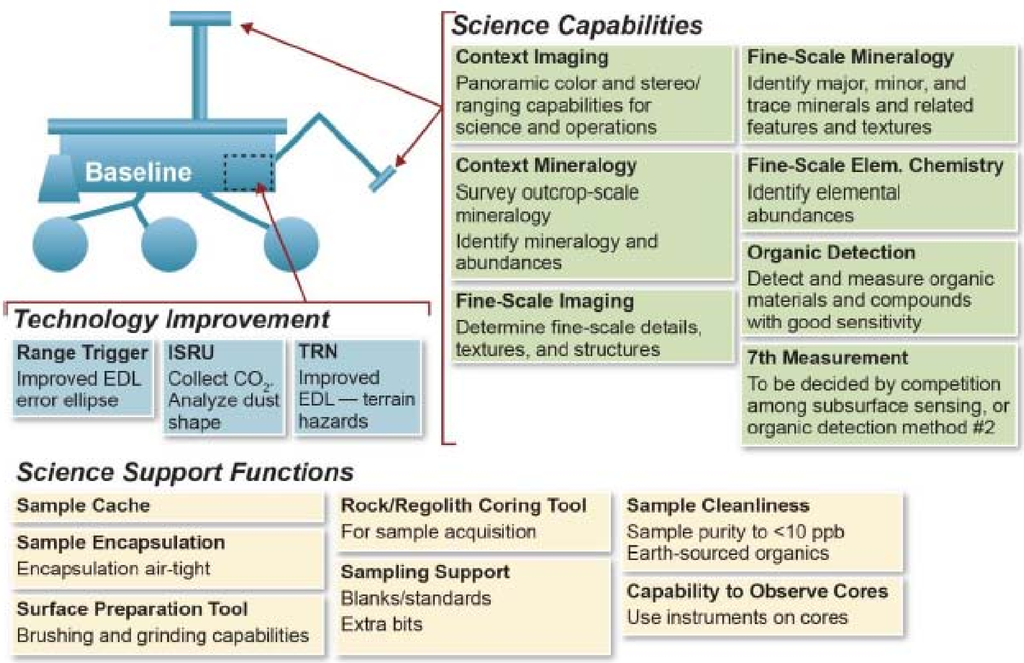


Figure 10: Summary of Science Capabilities for the Mars 2020 Mission (Mustard, et al. 2013)

5.3.1. Alternative 1 / Proposed Action – Description

The proposed action, Alternative 1, being NASA's Preferred Alternative proposes to fully implement the planned operation which would be launched between July and August of 2020 either from the Cape Canaveral Air Force Station or the Kennedy

Space Center in Florida via an expandable launch spacecraft. The next possible launch time would not be until 2022 (NASA 2014: 2-1).

The mission phases would be divided up as follows: Firstly, the spacecraft is disconnected from the expendable launch vehicle before entering into the atmosphere. Secondly, the spacecraft travels for about seven months to reach the Mars atmosphere. Thirdly, the entry vehicle is detached from the spacecraft and enters the Martian atmosphere to land in the destined area on the Mars surface, while the remaining spacecraft burns up in the Mars atmosphere. At this phase the mobile Mars rover would start its work in first testing its systems, second analyzing the environmental of the selected area and third start collecting samples from the Mars surface (NASA 2014: 2-2 – 2-6).

Alternative 1 proposes to use a Mars rover powered by radioisotope heat and electricity battery system. The Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) would power the mobility systems including all testing instruments and the robotic arm, the communication system and technologies powering remote sensing with imaging, navigation, and etcetera. The MMRTG transforms thermal energy from the radioactive decay of the 4.8 kg plutonium-238 into electrical energy. This heating and electricity system includes extensive safety measures to prevent nuclear contamination of the earth, space and Mars environment during all conditions. The advantage of Alternative scenario 1 is that the Mars rover powered by MMRTG can work during a full cycle of the Mars year under all conditions independently from external energy sources and provides for 100% capability (NASA 2014: 2-16 – 2-23).

5.3.2. Alternative 2 – Description

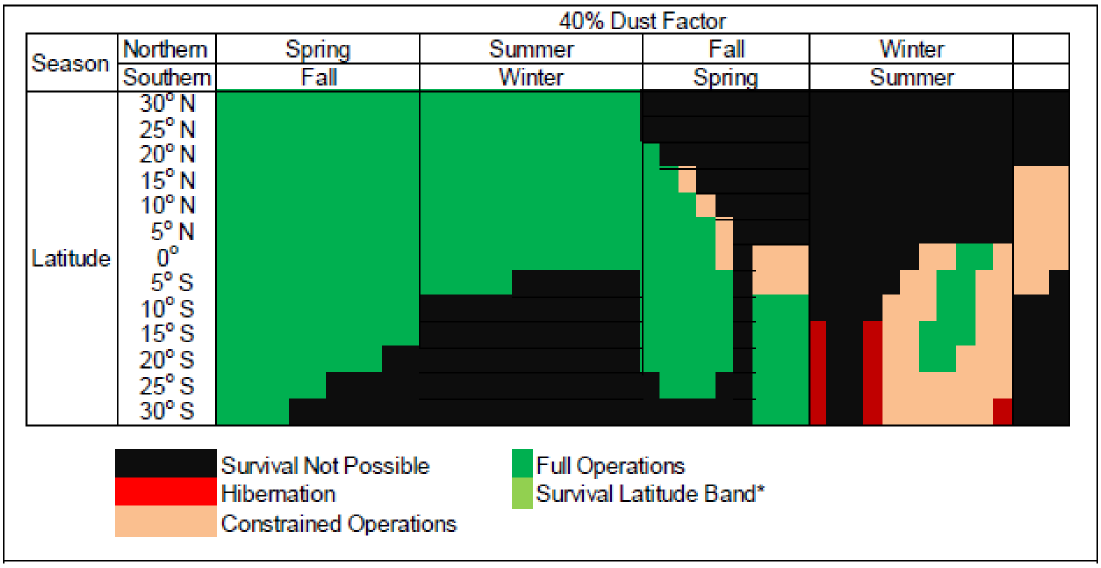
Alternative 2 suggests putting a halt on the NASA Preferred Alternative and developing a Mars rover powered solely by a solar radiation system. The launching time would be identical to the one proposed in Alternative 1 (NASA 2014: 2-1).

Alternative 2 uses instead of nuclear decay power extraction, a solar power supply system for the Mars rover as a power source for electrical and thermal energy. Solar radiation would be converted to electrical power via a Mars Optimized Solar Cell Technology including two separate solar panels with 35% efficiency. The problematic of such a system is that it is dependent on solar radiation. Since the surface conditions of the planet Mars and the Mars cycle are not fully understood yet, it is possible that at some times no solar radiation would be available for electricity conversion, bringing the rover to a halt. In comparison to the MMRTG powered rover of alternative 1, guaranteeing full operation ability during the Mars year, this is not given for the solar-powered rover due to dependence on high solar radiation and low dust factors. This is depicted in the table and figures below, showing the outcome of a solar feasibility assessment (NASA 2014: 2-38 – 2-40):

Table 5: Mars 2020 Mission Alternative 2. Operation Lifetime of a Solar Powered Rover within the Martian Year (NASA 2014: 2-38 – 2-40)

Option		Operational Lifetime	
		Solar	MMRTG
Latitude	30° N	50%	100%
	25° N	50%	100%
	20° N	50%	100%
	15° N	55%	100%
	10° N	60%	100%
	5° N	60%	100%
	0°	60%	100%
	5° S	35%	100%
	10° S	25%	100%
	15° S	25%	100%
	20° S	20%	100%
	25° S	15%	100%
	30° S	10%	100%

Table 6: Mars 2020 Mission Alternative 2. Solar Feasibility Assessment (NASA 2014: 2-38 – 2-40)



5.3.3. Alternative 3 – Description

Alternative 3 also proposes stopping preparations on Alternative 1 and instead developing a rover whose electricity source is solar radiation and heat source are Light-Weight Radioisotope Heater Units (LWRHU). Again, the timeframe of the launch would stay the same (NASA 2014: 2-1f).

Efficiency and capacity of the solar-powered electricity system are identical to those assessed in Alternative 2. The heating source is comprised of a combination of 71 LWRHUs utilizing plutonium-238 decay and electric heaters. Similar to Alternative 2, this scenario is restricted in operation, capacity, and performance at a lifetime of just 40% of the total Martian year. Alternative 3 is therefore also not competitive in comparison with the proposed action (NASA 2014: 2-42 – 2-47).

5.3.4. No Action Alternative – Description

Fourthly, the No Action Alternative entirely discontinues developments of any operation scenario for the Mars 2020 mission in its entirety (NASA 2014: 2-2).

The table below summarizes the scientific capability of the Alternatives 1, 2, and 3 (NASA 2014: 2-49):

Table 7: Estimated Science Capability Comparison of the Mars 2020 Mission Alternatives (NASA 2014: 2-49)

Rover Power Alternative	Landing Site Latitude Range	Operational Capability	Percentage of Science Achieved at Landing site Latitude
MMRTG (Alternative 1)	30°S to 30°N	100%	100%
Solar Array (Alternative 2) 40% dust factor	0° to 30°N	Unable to Operate for Full Year. Maximum Operational Lifetime 60%.	20-30%
	30°S to 0°	Unable to Operate for Full Year. Maximum Operational Lifetime 35%.	A few percents
Solar Array with LWRHUs (Alternative 3) 40% dust factor	30°S to 20°S	Unable to Operate for Full Year. Maximum Operational Lifetime 25%.	A few percents
	20°S to 5°S	Unable to Operate for Full Year. Maximum Operational Lifetime 28%.	60-70%
	5°S to 30°N	Unable to Operate for Full Year. Maximum Operational Lifetime 70%.	20-40%

5.3.5. Environment Impacts of Alternatives 1, 2, and 3

The table below depicts a summary of the probable impacts on the environment for the Alternatives 1, 2, and 3. The main environmental consequences would stem from propulsion exhaust during launch, injecting aluminum oxide, nitrogen, water vapor, carbon monoxide and hydrogen chloride into the atmosphere, producing carbon dioxide and nitrogen oxides, resulting in stratospheric ozone depletion, and short-term water acidification. Noise pollution is another unavoidable emission (NASA 2014: 2-51ff):

Table 8: Summary of Anticipated Environmental Impacts of the Mars 2020 Mission Alternatives: Impact Category – Normal Implementation Alternatives 1, 2 and 4 – No Action Alternative (NASA 2014: 2-51ff)

Land Use	Consistent with designated land uses at KSC and CCAFS; no adverse impacts on non-launch-related land uses at KSC and CCAFS would be expected.	No change in baseline condition.
Air Quality	High levels of solid propellant combustion products occur within the exhaust cloud for a launch vehicle using solid rocket boosters (e.g., the Atlas V). The exhaust cloud would rise and begin to disperse near the launch complex. Some short-term local ozone impacts. No long-term adverse air quality impacts would be expected in the region.	No change in baseline condition.
Noise and Sonic Boom	Sound exposure levels during launch are estimated to be within OSHA and EPA regulations/guidelines for affected workers and the public.	No change in baseline condition.
Geology and Soils	Some deposition of Al_2O_3 particulates and HCl near the launch complex for a launch vehicle using solid rocket boosters. No long-term adverse impacts would be expected.	No change in baseline condition.
Water Quality	Water used for pre-launch fire protection, heat suppression, acoustic damping, and post-launch wash down is recovered and treated, if necessary. No long-term adverse impacts to groundwater or surface water would be expected; short-term increase in the acidity of nearby surface waters would be expected.	No change in baseline condition.
Offshore Environment	The offshore environments at KSC or CCAFS would be impacted by the jettisoned launch vehicle sections in pre-approved drop zones. Small amounts of residual propellants would be released to the surrounding water. Toxic concentrations would not be likely because of the slow rate of the corrosion process and the large volume of ocean water available for dilution.	No change in baseline condition.
Biological Resources	Biota near the launch complex could be damaged or killed during launch, although no animal mortality has been observed that could be attributed to previous Delta and Atlas launches. Possible acidification of nearby surface waters from solid propellant exhaust products is not expected to cause any mortality of aquatic biota. No long-term adverse effects would be expected. No short-term or long-term impacts would be expected to threatened or endangered species. No long-term impacts would be expected to critical habitat.	No change in baseline condition.
Socioeconomics	No adverse impacts to socioeconomic factors such as demography, employment, transportation, and public or emergency services.	No change in baseline condition.
Environmental Justice	No disproportionately high and adverse impacts would be expected.	No change in baseline condition.
Cultural/Historical/ Archaeological Resources	No impacts would be expected.	No change in baseline condition.
Global Environment	Not anticipated to adversely affect global climate change. Temporary localized decrease in stratospheric ozone with rapid recovery would be anticipated along the launch vehicle's flight path.	No change in baseline condition.

Potential Non-radiological Environmental Impacts of Launch Accidents were assessed to have no relevant long-term consequences on the environment. Such accidents would be either a launch vehicle accident creating noise, debris, and releasing air emissions generally present during launches or a spill of liquid propellants such as hydrazine or LOX during the fuelling procedure. For possibly created debris in the earth or space environment, NASA standards, national and international legislation is in place with regards to mitigation measures to avoid a negative effect on human health. The Mars 2020 mission has conducted a detailed orbital debris assessment for its proposed action and alternative scenarios (NASA 2014: 2-53ff).

Potential Radiological Environmental Impacts of Launch Accidents were assessed by the US Department of Energy in form of a Nuclear Risk Assessment for all alternative scenarios. It was found that the likelihood of a launch accident is at 2.5%, therefore also minimizing radiological impacts on the environment and human health in all operations phases and alternative scenarios (NASA 2014: 2-55ff).

Should nevertheless radiological substances be released, the Nuclear Impact Assessment in the final EIS of the Mars 2020 mission, has produced precise calculations of the release probability and the area of land contaminated for Alternative

1 using MMRTG and Alternative 3 using LWRHUs, showing that contamination under Alternative scenario 3 would be smaller than under Alternative scenario 1(NASA 2014: 2-63).

The cost of mitigating the radiological contamination ranges from USD 110 million to USD 611 million per km^2. Complete responsibility and liability in the case of such contamination lie with the US Department of Energy. This was established in the Price-Anderson Act of 1957 as amended, which set up a financial system for operations by or conducted on behalf of the Department of Energy. This regulation also entails transboundary nuclear pollution consequences (DOE 1952; and NASA 2014: 2-63).

5.4. Affected Environment

§1502.15 of the CEQ regulation establishes that this section must include a brief description of "*the area(s) to be affected or created by the alternatives under consideration*" (Council 2005:11). This section will, therefore, describe the launch site locations and the consequences on the local and global environment.

5.4.1. Launch Site

The Cape Canaveral Air Force Station (CCAFS) and the Kennedy Space Center (KSC) are located on the Canaveral Peninsula, and Merritt Island, surrounded by the Atlantic Ocean and the Indian River on the east coast of Florida (NASA 2014: 3-1f).

5.4.1.1. Land Use

For the launch of a space mission like the Mars 2020 mission, many different activities are administered on the ground such as "*Launch, Launch Support, Airfield Operations, Spaceport Management, Research and Development, Public Outreach, Seaport, Recreation, Conservation, Agriculture, and Open Space.*" (NASA 2014: 3-3).

The Mars 2020 mission under assessment can be launched either from the CCAFS via a Delta IV, or Atlas V launch vehicle or from the KSC via a Falcon Heavy launch vehicle. Those launch operations are governed by strict national land use legislation such as the United States Fish and Wildlife Service Agreement with NASA, and national public law focused on the protection of the environment and its wildlife (NASA 2014: 3-3).

5.4.1.2. Air Quality

The Mars 2020 mission EIS includes a description of launch site climatic conditions. The launch sites must comply with American State and Federal ambient air quality standards (NASA 2014: 3-3). The U.S. Clean Air Act of 1970, as amended in 1990 regulates the production of Ozone Depleting Substances, and enforces the phasing out of the production of chlorofluorocarbons, halons, and carbon tetrachloride by 2000, of methyl chloroform by 2002, and in a third step hydrochlorofluorocarbon (HCFC) by 2030. NASA has established a policy to actively work on the minimization of the usage of such HCFCs in order to comply with the Clean Air Act (NASA 2014: 3-5).

5.4.1.3. Noise Pollution

Short term noise pollution results from launching maneuvers, aircraft transport, industrial processes, traffic, and construction. Therefrom affected are several cities close to the CCAFS and the KSC. Historically, the highest degrees of noise emission was exerted by Space Shuttle operations which could reach up to 160 dBA. Today emissions are not excessive and sonic booms are mainly caused over the Atlantic Ocean, not impacting land areas populated by humans. Therefore human health is not impacted by sonic booms, however, the ocean environment is (NASA 2014: 3-6).

5.4.1.4. Soil and Geology

Emissions from space launch operations implicate changes in nutrient levels and the pH of soil surrounding the space launch locations. The land used can have large impacts on soil changes and increased salinity. It is assessed that the soil at the CCAFS and KSC are absorbent with a large buffering capability (NASA 2014: 3-6).

5.4.1.5. Water Quality

The main water bodies surrounding the Air Force Station and the Kennedy Space Center are the Atlantic Ocean, the Mosquito Lagoon, the Banana Richer and the Indian River, which partially are classified as aquatic preserves and waters of high national significance. Freshwater is injected into the local water bodies through precipitation, groundwater water leakage, water runoff, and discharge from impoundments (NASA 2014: 3-7).

The launch locations are located outside the 100 and 500-year floodplains and any other protected water bodies, to ensure that no harm is done to the large water bodies from launch emissions. This is also a safety feature for space operations in case of extreme flooding (NASA 2014: 3-6).

The surface water quality at the Space Station and Center is assessed as generally good. However, the quality of adjacent water bodies has been decreasing, due to algal blooming, and a general increase of mercury in fish populations (NASA 2014: 3-8).

Groundwater is protected at both the CCAFS and the KSC via the surface, intermediate and Florida aquifer systems, while coastal zone management is usually conducted by NASA itself. Any actions undertaken at the Cape Canaveral Air Force Station and the Kennedy Space Center Location with possible effects on the coastal zone must be evaluated as consistent with the Florida Coastal Zone Management Program according to the NEPA procedures (NASA 2014: 3-8).

5.4.1.6. Biological and Natural Resources

Biological resources are any flora and fauna within the possibly negatively affected zone from a space operation. In detail, this definition can be split up into wildlife, vegetation, sensitive habitats including wetlands and flora which is rare and vital for wildlife, and threatened or endangered species. Due to the close proximity of the two space launch stations compliance with the Marine Mammal Protection Act, and the Magnuson-Stevens Fishery Conservation and Management Act, as well as Florida regulations must be upheld, therefore any actions with a possible negative impact on any of the sensitive biological and natural resources located close to the launch stations must not be avoided (NASA 2014: 3-9ff).

5.4.1.7. Human Health and Safety

As there are populated regions in proximity to the CCAFS and the KSC, the EU 13045, Protection of Children from Environmental Health Risks and Safety Risks of 1997, applies. Therefore the Mars 2020 mission should consider any socioeconomic impacts that might take place, including those on tourism, employment, transport, public services and general living standards. The Cape Canaveral Air Force Station and Kennedy Space Center Location, as well as the Kennedy Space Center Location, add immense economic benefits to the state of Florida and the populations living close by (NASA 2014: 3-13ff).

5.4.1.8. Cultural and Historic Resources

Cultural resources are defined as any historic and prehistoric location or landscape, or archaeological area, structures, objects, cemeteries, districts, artifacts, cultural or religious properties and sites, memorials, monuments and any further human evidence which can be considered relevant to a community or culture in the present, past, and future. On site of the CCAFS, many archaeological sites and historic properties are located. Furthermore, some of the KFC's and CCAFS' launch pads and other facilities have been added to the list of National Historic Landmarks (NASA 2014: 3-16ff).

5.4.1.9. Hazardous Materials and Wastes

To support space missions such as the Mars 2020 mission, many hazardous materials are utilized on site of the CCAFS and KSC. The operation and control over those, and therefore also the minimization of possible negative effects thereof is the responsibility of the utilizing corporation. Liquid propellants used for space mission launches are usually handled by a separate Launch Service Provider. All hazardous waste programs aim at minimizing effects on groundwater, air, and soil and therefore preventing negative consequences on human health (NASA 2014: 3-16f).

Hazardous wastes produced during space mission operations at the CCAFS can be fuels, oils, paint, chemicals, and solutions which are accumulated by specific contractors in specific areas with a maximum capacity of 208 liters, or in 90-day accumulation areas for hazardous wastes. Under the current permit issued by the Florida Department of Environmental Protection hazardous wastes can be stored in special facilities for up to one year. The materials exempted from storage are the most environmentally damaging such as hydrazine, nitrogen tetroxide, and MMH. The Space Wing OPlan defines management plans of those wastes as well as mitigation measures to minimize any potential impacts on human health and the environment (NASA 2014: 3-17f).

Waste Management at the Kennedy Space Center Location has a specific Hazardous Waste Storage Facility processing any types of solid and liquid types of hazardous waste materials. The amount of waste generated in the KSC depends on the ongoing space operations. Waste prevention and reduction measures are continuously being assessed at the Space Center Location (NASA 2014: 3-18).

5.4.2. Global Environment

The Executive Order 12114 on Environmental Effects Abroad of Major Federal Actions establishes that a general assessment of the global environment and impacts from the space mission thereon should be included in this section (The 1979).

As the effects of solid and liquid space rocket propulsion systems in the troposphere and stratosphere, as well as the production and accumulation of space debris, have been analyzed in the second chapter, this will not be repeated here.

5.5. Environmental Consequences

Segment five is the most scientific and analytic summary of the Environmental Impact Assessment in the EIS and will incorporate an analysis of the environmental consequences of the proposed activity and its discussed alternatives. Furthermore, any kind of irreversible consequences on resources and the environment must be incorporated, as well as the balance between long-term productivity of the operation and the short term environmental effects, while including any direct and indirect effects and conflicts caused by policy and legislation (Council 2005: 11f).

This segment will analyze the environmental effects of Alternatives 1, 2, and 3 at the following stages: (1) vehicle launch preparation, (2) successful launch conduct, as well as (3) radiological, and (4) and non-radiological launch accidents.

5.5.1. Alternative 1 / Proposed Action – Environmental Impact

As previously analyzed, the Alternative 1 would utilize a mobile Mars rover powered by MMRTG. The launch operator must implement federal, state, and local environmental legislation and regulations, as well as NASA and the United States Air Force regulations and requirements such as the following (NASA 2014: 4-3):

(1) Final Environmental Assessment for Launch of NASA Routine Payloads on Expendable Launch Vehicles (Routine Payloads EA) (NASA 2011a)

(2) PEIS MEP (NASA 2005)

(3) *Environmental Assessment for Falcon 9 and Falcon 9 Heavy Launch Vehicle Programs from Space Launch Complex 4 East Vandenberg Air Force Base California (*USAF 2011)

(4) *Final Supplemental Environmental Assessment to the November 2007 Environmental Assessment for the Operation and Launch of the Falcon 1 and Falcon 9 Space Vehicles At Cape Canaveral Air Force Station Florida (SpaceX 2013)*

5.5.1.1. Environmental Impact - Launch Preparation

Both the CCAFS and the KSC launch pads are implementing the relevant legal regulations to add environmental risk prevention and mitigation plans to their daily business. Preparing for the launch of a space launch vehicle implies the practice of industrial activities including hazardous materials such as inks, oils, alcohol, and others. Should a cooling system be added to the rover power sources, cooling liquids such as trichlorofluoromethane can be added to this list of hazardous materials. Spills or exhaust from the transport of fuels during launch preparation must be avoided and the human resources used in the process need to be adequately protected through special clothing from possible contact with such hazards. Hazardous waste generation would come from the usage of fuel and oxidizer transport possibilities. Launch vehicle and base contractors are in charge of firstly keeping the waste generation to a minimum while secondly processing the wastes according to Federal, state and regional legislation (NASA 2014: 4-4; and NASA 2011a).

5.5.1.2. Environmental Impact - Successful Launch

The environmental impact of a normal launching scenario for Alternative 1 would have standard emissions output of any space launch operation. Land use would not change to the state of the art at CCAFS and KSC when controlling the transport and transfer of liquid propellant fuels (NASA 2014: 4-5; and NASA 2011a).

Air quality emissions could possibly arise already during the fueling process and the transfer or application of hazardous materials or from the handling of ozone-depleting substances (ODS). Fortunately, prevention and mitigation standards are in place at both launching stations to ensure minimal emissions and management including the usage of safe basins in conformity with Spill Prevention, Control, and Countermeasures (SPCC) programs already set up and with ODS regulatory frameworks. ODS emissions at the preparatory stage are not realistic (NASA 2014: 4-5f; and NASA 2011a).

The actual launch of the space vehicle including ignition, liftoff, and further ascent can cause the exhaust of air polluting propulsion emissions such as water vapor, LOX, CO, CO_2 should a liquid propellant system be implemented or AL_2O_3, CO, HCl, and N_2 should a solid propellant rocket system be chosen for the launch operation. Most of these emissions into the atmosphere would not have any long-term impacts but would be dissolved after maximum seven days. Previous impact assessments conducted have shown neither long nor short-term environmental consequences (NASA 2014: 4-5f; and NASA 2011a).

Noise pollution at the ignition to the proximate environment is generally unavoidable for space launches, but are short-term and are kept to a minimum and confined to the launching facilities. To avoid implications on health security of the on-sight workers, those not essential to the ignition and launch are removed from the direct pollution. Furthermore, residents in proximity to the launching pad are not exposed to noise emissions above official maximum levels. While sonic booms will indeed be one of the largest noise emissions, they will take place offshore, far from any residents to avoid human health consequences. The only effect of those emissions would be on some birds breeding on the coast, while mammals and other marine animals will be entire unaffected (NASA 2014: 4-5; and NASA 2005).

Large amounts of water will be used for the launch for the purposes of cooling, washing, suppression of noise and fire hazards. After proper treatment in the onsite wastewater treatment plant and the capture of water resources utilized for industrial launch operations no implications on the natural water bodies will occur. On the other hand, rocket propulsion emissions could lead to surface water acidification and wet deposition of hydrogen chloride on a short-term basis without long-term consequences. Soils will not be affected by these changes at all (NASA 2014: 4-7f; and NASA 2011a).

Significant consequences from the Mars 2020 mission on biological diversity can also be ruled out, as despite short-term propulsion emissions and acidic deposition will occur close on the launch site, precautionary measures of protecting sensible flora and fauna will effectively prevent any larger harm (NASA 2014: 4-10f).

Socioeconomic and health effects are estimated to be low to nonexistent, except for some low-level noise pollution close to the launching pad. Detailed preventive testing will be conducted to predict possible health effects. Only the direct contact with HCl by on-site workers from solid propellant exhausts will cause long-term health effects. To prevent these high safety features are in place to protect workers. Furthermore, extensive warning would be conducted of any marine or airborne commercial or military activity to prevent consequences form noise pollution. (NASA 2014: 4-11ff).

No implications exist for cultural and historic resources as no new facilities will need to be built for the Mars 2020 mission (NASA 2014: 4-12).

Hazardous materials and waste management will minimize the effects of the largely used hazardous substances, and therefore no negative consequences on water, soil or air are to be expected (NASA 2014: 4-12f).

With regards to the global environment, most of the propulsion exhaust emission would not have major implications on the atmosphere and the stratospheric ozone.

Exceptions to this are for example ammonium perchlorate, aluminum particles and LOX from solid propellant systems, which when directly injected into the stratosphere can lead to ozone depletion. The impact can be categorized as immediate and local or as long-term global. Global atmospheric modeling has been conducted for the release of solid rocket propulsion emissions but not for liquid propulsion system emissions. The greatest amount of emissions is excreted by solid rocket propulsion and therefore affecting stratospheric ozone depletion the most. However, it is not estimated that any long-term effects apart from some low degree of ozone depletion will be caused by the Mars 2020 mission Alternative 1 (NASA 2014: 4-14ff).

It is assessed that a successful launch under Alternative 1 would not create any orbital debris (NASA 2014: 4-16f).

5.5.1.3. Non-radiological Environmental Impact – Launch Accident

The main types of accidents are either the spill of liquid propellants or a launch accident. Accident option one of the two would cause leakage of hydrazine, LOX, and other liquids into the environment. As hydrazine is only used on board of the spacecraft in very small quantities, the consequences on the environment and public health would be nonexistent. The latter option of a launch accident would result in increased air quality pollution resulting in wet deposition of HCl and ammonium particles and acidification of soil and water bodies. A large impact would be made on biological resources in general. Human health would be affected the most by an accident close to the Earth surface due to debris, toxic gases, and other pressures. Extensive safely requirements would be incorporated in the production and launch phases to avoid such situations. One very viable accident scenario would be the collision of the Mars 2020 spacecraft with existing debris in orbit. To reduce the probability of further debris generation NASA has conducted intensive research and set up extensive precautionary and mitigation plans to be followed (NASA 2014: 4-17 – 4-22).

5.5.1.4. Radiological Impact – Launch Accident

Although the probability of a launch accident is less than 2.5%, the radiological impact in case of a launch accident has been incorporated into the assessment. Generally, the most likely accident is one without any plutonium spillage, resulting in no radiological fatal human injuries. Intermediate accidents could result in the plutonium-238 transported in the spacecraft for use within the rover operation stage on the planet, to be emitted into the environment, and therefore possibly contaminating soil, surface waters and causing strong adverse effects on human and animal health. The fine particles emitted could furthermore be transported beyond the launching state area, towards the troposphere, contaminating the global environment (NASA 2014: 4-22ff). Accidents have been assessed with regards to the individual and collective effects, health consequences and land area pollution in the case of one of the eight accident scenarios (NASA 2014: 4-24f): "*(1) Liquid propellant explosions; (2) Solid propellant explosions; (3) Liquid propellant fires; (4) Solid propellant fires; (5) Fragments; (6) Ground impacts; (7) Debris impact; and (8) Reentry conditions (i.e., aerodynamic loads and aerodynamic heating)*". The response by the spacecraft and the operators, the possible emission release values and probabilities would be assessed previously to the accident scenario. To prevent launch accidents from happening and to mitigate any possible radiological emission, emergency response plans would be set up and practiced (NASA 2014: 4-25f).

The extensive risk assessment methodology developed by the U.S. Department of Energy with regards to the implications of plutonium emissions at different launch mission stages on the environment, together with highly advanced computer testing models the evaluation of Alternative 1 and Alternative 3 with regards to emissions and mechanical response are highly accurate (NASA 2014: 4-77).

5.5.2. Alternative 2 – Environmental Impact

Environmental impact scenarios of Alternative 2 would have the exact same non-radiological consequences as in Alternative 1. Ad Alternative 2 would not utilize radioactive power sources in any phase of the Mars 2020 mission, radiological environmental impacts can be rendered impossible (NASA 2014: 4-53f).

5.5.3. Alternative 3 – Environmental Impact

Alternative 3 can be explained as a mixture between Alternative 1 and 2, the possible impacts on the environment are identical. Non-radiological impacts are the same as for the Proposed Action, Alternative 1, while radiological environmental impacts would slightly differ from that scenario as instead of MMRTG, Alternative 3 utilizes LWRHUs smaller and less environmentally invasive in case of an accident.

Compared to Alternative 1, accidents including the use of LWRHU would have very small to no implications for human health. Radiological contingency response planning for any type of Mars 2020 operation including either MMRTG or LWRHU is similar (NASA 2014: 4-73).

5.5.4. No Action Alternative – Environmental Impact

The No Action Alternatives would have no environmental impacts, as any operation and planning of the Mars 2020 mission would be completely stopped (NASA 2014: 4-74).

5.5.5. Cumulative Environmental Impacts

The Council on Environmental Quality of the U.S. Presidential Office has defined in1508.7 that a NEPA analysis included in an Environmental Impact Statement of a program or project should take account of any cumulative environmental impact of that when added to past, present and future activities (Council 2005).

The Environmental Impact Assessment conducted for the Mars 2020 mission has concluded that neither one of the Alternative scenarios would not drastically increase the impact scope approved for launches at the CCAFS (USAF 2000). To minimize any other cumulative effects during the production process, strict Federal, state, and regional frameworks are in place to keep any additional pollution output to the natural environment at a minimum (NASA 2014: 4-74).

As already previously analyzed, some short-term stratospheric ozone depletion and an increase in greenhouse gases might take place, but this impact is marginal compared to environmental consequences from other transportation industries. With an increasing amount of space launches each year and new actors participating in new space tourism industries this accumulation of emissions will likely increase. New calculations will then be necessary (NASA 2014: 4-74f).

5.5.6. Incomplete Impact Information

One factor that has to be considered when analyzing the Environmental Impact Statement for the Mars 2020 mission, is that preparations, production and operations have not been completed. One the one hand this means that those processes can be altered to follow the prevention and mitigation plans set up with regards to possible emissions, on the other hand however unexpected and not planned for effects, and results will probably happen. Any substantial changes to the proposed outcomes would have to be completely re-evaluated by NASA. One example is that Falcon Heavy had not been used as a launch vehicle at the time the impact statement was published, therefore calculations made were based on experiences with other launch vehicles such as Atlas V and Delta IV rockets (NASA 2014: 4-76f).

5.6. Other

In addition to the probable environmental impact scenarios, the EIS also includes the following:

A section shall indicate the people and their occupations in conducting the Environmental Impact Assessment, and any relevant other assessments (Council 2005: 12).

The last segment of the EIS shall include a list of all persons, organizations and agencies to which the finalized statement is sent to (NASA 2014: 6-1).

In the case of the Mars 2020 mission EIS the Appendices also included detailed tables of model outcome predictions (NASA 2014).

6. Findings and Conclusion

This thesis has shed light on the potential of an Environmental Impact Assessment for outer space activities to effectively prevent and mitigate any harmful environmental impact on earth and in outer space. As the space sector has entered a period of continuous expansion through privatization, tourism, military and other efforts, the concern for harmful impacts on the environment as well as the accumulation of space debris have increased. The growing awareness of those environmental consequences, has raised the question about the need for an assessment controlling space activities. The Environmental Impact Assessment turned out to be a success tool in many areas but has yet to be properly established as a viable instrument in international space law.

The present thesis analysis has a strong technical focus, assessing environmental pollution on the earth, space and planetary environments, and a strong legal focus, identifying the legal requirements for procedures assessing possible environmental impacts of space activities in the preparation and authorization stage.

The case study addressed the U.S. National Aeronautics and Space Administration's planned mission to Mars in 2020 which plans on sending a large laboratory via a Mars rover to planet Mars to conduct astrobiological and geological research as well as to display technological progress, establishing a pioneering first human exploration of Mars, and therefore decreasing the risks and information gap for future space missions to Mars. The exploration of questions such as possible habitability and life as a reference for the solar system in general, will be undertaken.

The different alternatives included in the Environmental Impact Statement mainly addressed alternatives with regards to the energy source of the Mars rover. Alternative 1 proposes the use of Multi-Mission Radioisotope Thermoelectric Generator, Alternative 2 proposes the use of photovoltaic panels, and the Alternative 3 proposes a combined usage of solar radiation and Light-Weight Radioisotope Heater Units. Thereby nuclear and solar energy sources were addressed. NASA assessed a 2.5% accident probability with regards to the alternative scenarios using nuclear-powered rover systems, which shows that a nuclear accident during the launch-, flight- and Mars operation-stages is not unlikely and therefore possible negative effects on the environment and human health are probable.

Alternative assessments of scenarios relating to any possible impact on the earth and space environment were not included.

The NASA Mars 2020 Mission mainly follows the rules and procedural guidelines set up within the United States with regard to the conduct of Environmental Impact Assessment, environmental protection, and nuclear safety standards. It is assessed that the launch operator must implement federal, state, and local environmental legislation and regulations, as well as NASA and the United States Air Force regulations and requirements such as the following. International guidelines are not directly addressed.

The hypotheses can be generally verified:

The thesis identifies three major environmental impact sources: (1) space launching and flight stage impact, (2) space debris and (3) planetary contamination, addresses the first hypothesis established in the introduction: "**Outer space operations are the cause for irreversible harm to the earth and space environment**".

This hypothesis could only partially be verified. While potential space launching emissions such as noise, human health impacts, air, water and soil pollution, as well as pollution arising from hazardous materials do exist, it was assessed that only short-term consequences would arise on the environment as well as on human health. Through the establishment of protective barriers around the launching area, such effects can be minimized. Therefore, no irreversible environmental consequences arise from standard launching operations.

With regards to flight stage pollution, environmental consequences are of a short-term and long-term nature in the stratosphere due to the direct injection of propulsion emissions into the stratospheric ozone layer, resulting in increased ozone depletion. This depletion drastically alters the radiation and thermal budget of planet Earth. This can be classified as a severe harm. However, in comparison to other industries on Earth, the emission from spaceflight are minimal and contribute only to a very minimized extend to stratospheric ozone depletion.

The second major environmental impact is space debris, which affects the safe conduct of present and future spaceflight operations. Due to the increasing amount of collisions between the existing orbital debris the population is growing at a rate that is on the verge of becoming uncontrollable. This definitely represents a situation of irreversible harm to the space environment, the safe conduct of manned and unmanned space missions, as well as to the earth environment in cases of atmospheric reentry scenarios.

The third major environmental impact is backward and forward contamination on Earth and celestial bodies, such as the planet Mars. The interaction of different ecological systems and the contamination thereof raises the probability of unforeseeable and uncontrollable impacts. This type of emission also qualifies as having the potential for irreversible consequences on the earth and planetary environment.

The second hypothesis assumes that "**the major emission sources from space operations can be adequately addressed in Environmental Impact Assessments**". In fact, this can be fully verified by the legal standards, guidelines and obligations analyzed in the thesis. The EIA Directive of the European Union lists certain projects to be made the subject of an assessment. Large projects with a potentially significant negative impact on the environment are an example, therefore. As all space missions can be classified as "large projects" the European EIA Directive establishes an obligation to an Environmental Impact Assessment to prevent and mitigate any emissions arising from a proposed space activity.

On an international level, the United Nations treaties on outer space set up requirements to avoid harmful contamination and adverse changes to the Earth environment as well as to undertake international consultations, therefore. An information duty is also established including nature, conduct, location and impacts of proposed actions. Furthermore, the UN Outer Space Treaty also establishes the obligation to authorize and supervise any space activities.

Potential nuclear contamination of the environment is specifically addressed in the NPS Principles of the United Nations General Assembly and the UNCOPUOS/IAEA Safety Framework for Nuclear Power Source Applications in Outer Space, including the establishment of safety assessment procedures paired with reporting duties

Guidelines established to mitigate space debris production as well as any negative consequences arising from space debris were set up on an international as well as a national level. Austria has established legally binding obligations to assess possible impacts on space debris production and demands the setting up of mitigation measures to avoid negative consequences by a proposed space activity.

At the national level, laws and regulations often require the a priori assessment of any space activity with potential harm on the environment.

Generally, no relevant international legal obligations do not specifically regulate launching and flight stage pollutions but address the general avoidance of environmental damages. However, there is an increasing focus on the problem of space debris and possible mitigation measures. Requirements and guidelines have been set up to oversee mitigation of forwarding and backward chemical contamination. Therefore the second hypothesis is validated.

The third hypothesis assumes that "**the conduct of an Environmental Impact Assessment and the publishing of an Environmental Impact Statement are ideal tools to incorporate environmental values and scientific analyses into decision-making processes**".

This third hypothesis can be analyzed on the basis of the case study. The Environmental Impact Assessment procedure for the NASA Mars 2020 mission was subject to a strong influence by public participation, including private, public and non-governmental actors of the scientific and non-scientific community. The Environmental Impact Statement published generally describes the assessment of all potential consequences on the environment including the creation of mitigation measures in the planning and operation stages of the action to minimize any such effects. The EIA assesses risks and scientific capabilities as part of a successful Mars mission and includes detailed analyses on the earth and space environments. This includes an assessment of the launching stage of environmental impacts, the flight stage environmental consequences as well as space debris creation from an unsuccessful operation of the Mars 2020 mission.

The Mars 2020 mission's Environmental Impact Statement does indeed depict a scenario where environmental and scientific analyses, as well as public participation suggestions, are incorporated into the decision-making process with regards to the planning and potential operation of the mission.

It is therefore also possible to conclude that NASA in making the Mars 2020 mission subject to an Environmental Impact Assessment including the publishing of the resulting Environmental Impact Statement is in compliance with the reporting requirements set up by the NPS Guidelines, the IADC Guidelines as well as the UNOOSA Compendium on Space Debris Mitigation Standards.

NASA was publicly accused of violating Article IX of the 1967 Outer Space Treaty of the United Nations by enabling a contamination of Mars with fungi and bacteria originating from planet Earth, and on the other hand, contaminating the Earth environment with Martian organisms.

The NASA Mars 2020 mission's Environmental Impact Statement does not address this issue and therefore does not include mitigation measures as set up by the COSPAR Planetary Protection Guidelines for such scenarios.

Another problematic arising is that it is unclear who can verify or falsify the compliance of NASA with the standards set up in the EIS. As NASA is conducting the first Mars rover mission ever, no other organization or regulatory body is able to assess the direct environmental impacts on the Martian environment and the Earth environment. While the EIA sets up a detailed analysis of the potential environmental consequence and assesses possible mitigation measures, they can hardly be enforced. The overseeing of any enforcement or non-enforcement is practically impossible.

Therefore while Environmental Impact Assessments and Statements are viable tools to incorporate environmental values and scientific analyses into decision-making processes, a compliance with the suggestions set up in the EIS is difficult to verify and to enforce.

With respect to the two research questions addressed in the present thesis, following this analysis it can be assessed that an obligation to the conduct of an EIA for outer space activities does exist under some national legal norms as well as partially under international and European Union law.

The three major emissions sources discussed in this thesis appear in most of the EIS. The Mars 2020 mission includes detailed analyses of the launching- and flight-stage emissions as well as an assessment on possible space debris production. In the EIS NASA included prevention and mitigation guidelines to avoid major environmental consequences. While NASA has set up guidelines for planetary protection from backward and forward contamination, the NASA Mars 2020 mission does not address the third emission type, planetary bacterial contamination.

To conclude this thesis with an outlook towards the future one can assess that environmental protection mechanisms will play an increasing role in the planning and authorization of space activities. Making space operations subject to an Environmental

Impact Assessment is a viable tool to assess problematic and provide mitigation measures. In particular, the obligation to mitigate space debris has been established in some national legislation for example by Austria. Other national legislation following that example ahs followed and will come into existence in the near future.

The international regulatory framework supports a rather unconstrained space-faring industry, but does not adequately addressing emission limit values and emission prevention rules. With predictions of a continuously growing spaceflight industry, this lacuna should continue to close soon following the example of national regulations.

Furthermore, scientific research will continue to find more advanced and greener alternatives to current space rocket propellant engines, to decrease the effect of rocket emissions and exhausts on ozone depletion. An initiative worth mentioning again is the project of the European Commission which has developed a methodology to determine the efficiency and environmental friendliness of rocket propulsion engines. This model can be used as a basis for future Environmental Impact Statements as well as for green space initiatives in general.

In addition, this thesis highlights the need for stringent oversight over the compliance with prevention and mitigation measures focused on the minimization of negative consequences on the environment set up in an EIS. International, European and national rules and guidelines should focus not only on the assessment of potential environmental impacts by a proposed action but also on the verification and falsification of complying with the assessed mitigation methods.

Due to the fact that the space sector is a rapidly evolving industry, legislative bodies must react similarly fast to ensure the safe conduct of current and future space activities, in order to avoid leaving environmental protection standards behind in this race to discover the borders of the universe.

References

(UNEP), United Nations Environmental Program. "The Montreal Protocol on Substances that Deplete the Ozone Layer." 1987.

Ad hoc Expert Group of the International Academy of Astronautics' Committee on Safety, Rescue, and Quality (IAA). "Orbital Debris - Status and Possibilities for Control." *Space Policy 9*, 1993: 185ff.

Adilov, Nodir, Peter J. Alexander, and Brendan M. Cunningham. "An economic ‘‘Kessler Syndrome’’: A dynamic model of earth orbit." *Economic Letters 166*, 2018: 79-82.

Basmeijer, Kees, and Timo Koivurova. *Theory and Practice of Transboundary Environmental Impact Assessment. Volume 1.* Leiden, Boston: Martinus Nijhoff Publishers, 2011.

Bastmejer, Kees, and Timo Koivurova. "Introduction." In *Theory and Practice of Transboundary Environmental Impact Assessment. Volume 1*, by Kees Basmejer and Timo Koivurova, 1-25. Leiden, Boston: Martinus Nijhoff Publishers, 2011.

Bonnal, Christophe, and Darren S. McKnight. *IAA Situation Report on Space Debris - 2016.* Paris: International Academy of Astronautics, 2017.

Braun, Vitali, et al. "Drama 2.0. - ESA's Space Debris Risk Assessment and Mitigtion Analysis Tool Suite." 2013.

Bundesgesetzblatt Bundesministerium fuer Verkehr, Innovation und Technologie (BGBl BMVIT). *BGBl. I Nr. 132/2011 Bundesgesetz über die Genehmigung von Weltraumaktivitäten und die Einrichtung eines Weltraumregisters (Weltraumgesetz).* 2011.

Committee on Preventing the Forward Contamination of Mars. Space Studies Board. *Preventing the Forward Contamination of Mars.* Washington, D.C.: The National Academies Press, 2006.

Committee on Space Research (COSPAR). *COSPAR Planetary Protection Policy, 20 October 2002, as amended 24 March 2011.* Houston, USA: World Space Council, 2002.

Council of the European Communities. "Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora." *Official Journal of the European Commission* (Official Journal of the European Communities), 1992: 206/7-206/50.

Council of the European Communities. "Council Directive of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment." *Official Journal of the European Communities* (Off), 1985: 175-184.

Council of the European Union. "COUNCIL DECISION (CFSP) 2015/203 in support of the Union proposal for an international Code of Conduct for outer-space activities as a contribution to transparency and confidence-building measures in outer-space activities." *Official Journal of the European Union*, 2015: 38-44.

Council of the Institute of Ecology and Environmental Management (IEEM). *Guidelines for Ecological Impact Assessment in the UK and Ireland: Terrestrial, Freshwater and Coastal, 2nd edition.* Vol. 2nd edition. Winchester: Chartered Institute of Ecology and Environmental Management, 2016.

Council on Environmental Quality - Executive Office of the President of the United States. *Regulations for Implementing the Procedural Provision of the National Environmental Policy Act. Reprint 40 CFR 1500-1508.* Council on Environmental Quality - Executive Office of the President of the United States, 2005.

Court of Appeals, District of Colombia Circuit. "Environmental Defense Fund, Inc. v. Massey, 986 F. 2nd 528." 1993. https://coast.noaa.gov/data/Documents/OceanLawSearch/Envtl.%20Def.%20Fund%20v.%20Massey,%20986%20F.2d%20528%20(D.C.%20Cir.%201993).pdf (accessed 06 03, 2018).

De Luca, Luigi, Toru Shimada, Valery P. Sinditskii, and Max Calabro. *Chemical Rocket Propulsion. A Comprehensive Survey of Energetic Materials.* Springer International Publishing Switzerland, 2017.

de Mulder, Jan. "The institutional context for transboundary environmental impact assessment in Belgium: multi-level setting - a matter of smooth governance?" *Impact Assessment and Project Appraisal, 26(4), December 2008* (Beech Tree Publishing), 2008: 277-288.

Departement of Energy (DOE), United States of America. *Report to Congress on the Price-Anderson Act.* U.S. Department of Energy, 1952.

European Commission. *Handbook for trade sustainability impact assessment, 2nd edition.* Luxembourg: European Union, 2016a.

—. *The Habitats Directive.* 06 10, 2016b. http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm (accessed 05 30, 2018).

European Commission, Community Research and Development Infromation Service. *Final Report Summary - GRASP (Green advanced space propulsion).* Brussels: European Commission, 2011.

European Environment Agency. *Environmental space and environmental policy assessments.* European environment Agency, 2008.

European Parliament, and Council of the European Union. "Directive 2000/62/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy." *Official Journal of the European Communities*, 2000: 327/1-327/72.

—. *Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment.* Brussels: Official Journal of the European Communities, 2001.

—. *Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment.* Official Journal of the European Union, 2011a.

European Parliament, Council of the European Union. "Informal considerations on DIRECTIVE 2011/92/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment." 12 13, 2011b. http://ec.europa.eu/environment/eia/pdf/EIA_Directive_informal.pdf (accessed 06 04, 2018).

European Space Agency (ESA). "clean space. safeguarding earth and space." 2016. https://esamultimedia.esa.int/multimedia/publications/Clean_Space/ (accessed 06 05, 2018).

—. "Space Operations. Space Debris: The ESA Approach." 03 2017. https://download.esa.int/esoc/downloads/BR-336_Space_Debris_WEB.pdf (accessed 06 04, 2018).

Gohardani, Amir S., et al. "Green Space Propulsion: Opportunities and Prospects." *Progress in Aerospace Sciences* 71 (2014): 128-149.

Hanford, A. J. *Advanced Life Support Research and Technology Development Metric – Fiscal Year 2004.* Lockheed Martin Space Operations, Houston: National Aeronautics and Space Administration, 2004.

Hickman, Leo. "It's not rocket science: leaving the planet costs the Earth." *The Guardian*, 05 11, 2009.

Horvath, Ilonka, Sabine Haas, Christine Knaller, Gabriele Sax, and Oesterreichisches bundesinstitut fuer Gesundheitswesen. *Health Impact Assessment. Konzept zur etablierung von HIA in Oesterreich.* Wien: Bundesministerium fuer Gesundheit, 2010.

IADC, Inter-Agency Space Debris Coordination Committee. "IADC Space Debris Mitigation Guidelines. Issued by Steering Group and Working Group 4." 09 2007. http://www.unoosa.org/documents/pdf/spacelaw/sd/IADC-2002-01-IADC-Space_Debris-Guidelines-Revision1.pdf (accessed 06 04, 2018).

Inter-Agency Space Debris Coordination Committee (IADC). "IADC Space Debris Mitigation Guidelines." 2007. http://www.unoosa.org/documents/pdf/spacelaw/sd/IADC_space_debris_mitigation_guidelines.pdf (accessed 06 03, 2018).

—. "Support to the IADC Space Debris Mitigation Guidelines. Working Group 4. Action Item 26.2." 05 2014. https://www.iadc-online.org/index.cgi?item=docs_pub (accessed 06 03, 2018).

International Atomic Energy Agency (IAEA). *The role of nuclear power and nuclear propulsion in the peaceful exploration of space.* Vienna: International Atomic Energy Agency, 2005.

International Law Commission (ILC). "Articles on Prevention of Transboundary Harm from Hazardous Activities with commentaries." *Official Records of the General Assembly, Fifty-sixth Session, Supplement No. 10 (A/56/10)* (United Nations), 2001.

International Telecommunications Union (ITU). *Constitution and Convention of the International Telecommunication Union (with annexes and optional protocol).* Vol. 1825. Geneva: United Nations, 1992.

Jackman, Charles H., David B. Considinge, and Eric L. Fleming. "A global modeling study of solid rocket aluminum oxide emission effects on stratospheric ozone." *Geophysical Research Letters* 25, no. 6 (1998): 907-910.

Joseph, R. Gabriel. *NASA's Violations of Article IX of the 1967 "Outer Space Treaty". Respectfully Submitted to the Members of the United Nations Committee on the Peaceful Uses of Outer Space, A. NASA's Rovers Contaminated Mars with Terrestrial Fungi and Bacteria, etc.* Cosmology.com, 2018.

Klaffl, Ingrid, et al. *UVP-Evaluation. Evaluation der Umweltvertraeglichkeitspruefung in Oesterreich.* Vienna: Umweltbundesamt, 2006.

Kraft, Julia. *Sustainable Development, the TTIP and the EU - Three mutually influenced regimes? The Implications of the Transatlantic Trade and Investment Partnership on sustainable development objectives of the European Union.* Vienna: University of Vienna, 2016.

Lawrence, David P. *Impact Assessment. Practical Solutions to Recurrent Problems and Contemporary Challenges.* New Jersey: John Wiley & Sons, Inc., 2013.

Liou, J.-C., N.L. Johnson, and N.M. Hill. "Controlling the growth of future LEO debris populations with active debris removal." *Acta Astronautica 66*, 2010: 648-653.

Morgan, Richard K. "Environmental impact assessment: the state of the art." *Impact Assessment and Project Appraisal* 30, no. 1 (2012): 5-14.

Moss, J. Barrie, and John P.W. Stark. "Propulsion Systems." In *Spacecraft Systems Engineering*, by Peter Fortescue, Graham Swinerd and John Stark. 2016.

Muetsch, Thomas F., and Matthias B. Kowalski. *Space Technology. A Compendium for Space Engineering.* Berlin: Walter De Gruyter GmbH, 2016.

Mustard, J.F., et al. *Report of the Mars 2020 Science Definition Team.* Mars Exploration Program, 2013.

National Aeronautics and Space Administration (NASA). *Announcement of Opportunity Mars 2020 Investigations.* National Aeronautics and Space Administration, 2013.

—. *Biological Contamination Control for Outbound and Inbound Planetary Spacecraft (Revalidated 05/17/13 w/change 1).* NASA, 1999.

—. *Final Environmental Impact Statement for the Mars 2020 Mission.* Washington, DC: Science Mission Directorate National Aeronautics and Space Administration, 2014.

—. "Final Environmental Assessment for Launch of NASA Routine Payloads on Expendable Launch Vehicles." 11 2011a. https://www.nasa.gov/pdf/603832main_FINAL%20NASA%20Routine%20Payload%20EA%20Resized.pdf (accessed 06 05, 2018).

—. *Final Programmatic Environmental Impact Statement for the Mars Exploration Program.* Washington, DC: Science Mission Directorate, NASA Headquarters, 2005.

—. *Green Propellant Infusion Mission (GPIM) Overview.* 02 23, 2018a. https://www.nasa.gov/mission_pages/tdm/green/overview.html (accessed 05 27, 2018).

National Aeronautics and Space Administration (NASA). "Handbook for Limiting Orbital Debris." *NASA Handbook 8719.14*, 2018b.

—. *NPR 8715.6A NASA Procedural Requirements for Limiting Orbital Debris.* Office of Safety and Mission Assurance, 2009.

—. "Process for Limiting Orbital Debris." 12 08, 2011b. https://standards.nasa.gov/standard/nasa/nasa-std-871914 (accessed 06 03, 2018).

National Aeronautics and Space Administration (NASA). "Shielding Against Micrometeoroid and Orbital Debris Impact with Metallic Foams." *Orbital Debris Quarterly News, Volume 14, Issue 1*, 2010: 4-7.

National Aeronautics and Space Administration. *14 CFR Part 1216. Subpart 1216.3 Procedures for Implementing the National Environmental Policy Act (NEPA).* Washington, DC: National Aeronautics and Space Administration, 2012.

National Aeronautics and Space Administration (NASA). *NASA Issues ROD for Mars 2020 Mission EIS.* 01 28, 2015. https://www.nasa.gov/agency/nepa/mars2020eis/ (accessed 06 05, 2018).

National Research Council. *Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Meteoroid and Orbital Debris Programs.* Washington, D.C.: The National Academies Press, 2011.

Petts, Judith. *Handbook of Environmental Impact Assessment: Volume 2: Impact and Limitations.* Birmingham: Wiley-Blackwell, 1999.

Quigley, R., Den, Broeder, LP Furu, A. Bond, and B. Bos, R. Cave. *Health impact assessment international best practice principles: Special publication series no. 5. Working Paper.* Fargo: International Association for Impact Assessment, 2006.

Robinson, George S. *Article IX of the Outer Space Treaty: Extraterrestrial Back Contamination, the U.S. Constitution, and the "Politics" of U.S. Regulatory Authority.* EILENE Galloway Symposium, Cosmos Club: Washington D.C., 2010.

—. *Earth Exposure to Martian Matter: Back Contamination Procedures and International Quarantine Regulations.* 1976.

Ross, Martin, and James A. Vedda. *The Policy and Science of Rocket Emissions.* Center for Space Policy and Strategy, 2018.

Ross, Martin, Darin Roohey, Manfred Peinemann, and Patrick Ross. "Limits on the Space Launch Market Related to Stratospheric Ozone Depletion." *Astropolitics*, 2009: 50-82.

Sandia National Laboratories, et al. *Nuclear Risk Assessment for the Mars 2020 Mission Environmental Impact Statement. SNL2013-10589.* Albuquerque, New Mexico and Livermore, California : Sandia National Laboratories , 2014.

Senate and House of Representatives of the United States of America. "The National Environmental Policy Act of 1969, as amended." 1982.

Serafini, Samuel, and NASA. *NEPA Proces.* 03 01, 2015. https://www.nasa.gov/feature/nepa-process (accessed 06 05, 2018).

SpaceX. *Final Supplemental Environmental Assessment to the November 2007 Environmental Assessment for the Operation and Launch of the Falcon 1 and Falcon 9 Space Vehicles At Cape Canaveral Air Force Station Florida.* 2013.

Steinkogler, Cordula. "Small Satellites and Space Debris Mitigation." In *Small Satellites. Regulatory Challenges and Chances. Studies in Space Law, Volume II*, by Irmgard Marboe, 211-238. Vienna, 2016.

Sutton, George P., and Oscar Biblarz. *Rocket Propulsion Elements.* New Jersey, USA: John Wiley & Sons, 2017.

The National Archives of the United States (NAUS). "Federal Register. Executive Order 12114." *Federal Register Vol. 44 - No. 62.* 03 29, 1979. https://ceq.doe.gov/docs/ceq-regulations-and-guidance/regs/CEQ_EffectsAbroad_21MAR1979.pdf (accessed 06 05, 2018).

The White House. "Presidential Directive/NSC-25." 12 14, 1977. https://fas.org/irp/offdocs/pd/pd25.pdf (accessed 06 03, 2018).

U.S. Air Force (USAF). *Environmental Assessment for Falcon 9 and Falcon 9 Heavy Launch Vehicle Programs from Space Launch Complex 4 East Vandenberg Air Force Base California.* 2011.

—. *Final Supplemental Environmental Impact Statement (SEIS) for the Evolved Expendable Launch Vehicle Program.* Washington, DC: HQ USAF/ILEVQ 1260 Air Force Pentagon, 2000.

U.S. Government. "Orbital Debris Mitigation Standard Practices." 02 2001. https://www.iadc-online.org/References/Docu/USG_OD_Standard_Practices.pdf (accessed 06 03, 2018).

U.S. Government. "U.S. Government Orbital Debris Mitigation Standard Practices." 2015. https://www.orbitaldebris.jsc.nasa.gov/library/usg_od_standard_practices.pdf (accessed 06 12, 2018).

United Nations Economic Commission for Europe. *Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters.* Aarhus: United Nations Economic Commiccion for Europe (UNECE), 1998.

—. "Convention on Environmental Impact Assessment in a Transboundary Context." 1991. https://www.unece.org/fileadmin/DAM/env/eia/documents/legaltexts/Espoo_Convention_authentic_ENG.pdf (accessed 06 04, 2018).

United Nations General Assembly (UNGA). *Principles Relevant to the Use of Nuclear Power Sources in Outer Space. UNGA A/RES/47/68.* United Nations, 1992.

—. "Report on the United Nations Conference on Environment and Development." 06 14, 1992. http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm (accessed 06 04, 2018).

—. *Resolution A/RES/55/122 adopted by the General Assembly. 55/122. International cooperation in the peaceful uses of outer space.* United Nations General Assembly, 2000.

United Nations General Assembly. "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies." 1967.

United Nations Office for Outer Space Activities (UNOOSA). "European Code of conduct for Space Debris Mitigation." 06 28, 2004. http://www.unoosa.org/documents/pdf/spacelaw/sd/European_code_of_conduct_for_space_debris_mitigation.pdf (accessed 06 03, 2018).

—. *Space Debris Mitigation Standards Adopted by States and International Organizations.* United Nations, 2018.

United Nations Office for Outer Space Affairs (UNOOSA). *International Space Law: United Nations Instruments.* Vienna: United Nations, 2017.

—. *Selected Examples of National Laws Governing Space Activities: Russian Federation: No 104 - Statute on Licensing Space Operations.* 02 02, 1996. http://www.unoosa.org/oosa/en/ourwork/spacelaw/nationalspacelaw/russian_federation/decree_104_1996E.html (accessed 06 03, 2018).

—. *Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space.* Vienna: United Nations, 2010.

United Nations. *Protocol on Environmental Protection to the Antarctic Treaty.* Madrid: , United Nations; 1991.

—. *United Nations Convention on the Law of the Sea.* United Nations, 1982.

United Nations. "United Nations Treaties and Principles on Outer Space, related General Assembly resolutions, and other documents."

United States Navy (Navy). *Navy Succeeds In Intercepting Non-functioning Satellite.* 02 20, 2008. http://www.navy.mil/submit/display.asp?story_id=35114 (accessed 06 12, 2018).

USAF, U.S. Air Force. *Final Supplement Environmental Impact Statement (SEIS) for the Evolved Expendable Launch Vehicle Program.* Washington DC: HQ USAF/ILEVQ, 1260 Air Force Pentagon, 2000.

UVP-Gesetz 2000. *Bundesgesetz ueber die Pruefung der Umweltvertraeglichkeit (Umweltvertraeglichkeitspruefungsgesetz 2000 - UVP-G 2000) Bundesrecht konsolidiert: Gesamte Rechtsvorschrift für Umweltverträglichkeitsprüfungsgesetz 2000. Including amendments until 2017.* 06 14, 2018. https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=10010767 (accessed 06 13, 2018).

Viikari, Lotta. "Environmental Impact Assessment in the Space Sector." In *Theory and Practice of Transboundary Environmental Impact Assessment. Volume 1*, by Kees Basmeijer and Timo Koivurova, 265-288. Leiden, Boston: Martinus Nijhoff Publishers, 2011.

Wathern, Peter. *Environmental Impact Assessment. Theory and Practice.* London: Taylor & Francis Group, 2013.

Watson, M. *Environmental Impact Assessment and European Community Law. Introductory paper at the XIV International Conference "Danube - River of Cooperation".* Beograd, 2003.

Wins, Elmar. *Weltraumhaftung im Voelkerrecht.* Berlin: Duncker und Humblot (Tuebinger Schriften zum internationalen und europaeischen Recht, Band 51), 2000.

Wirth, David A. "International Decisions. environmental Defense fund v. Massey. 986 F.2d 528. U.S.Court of Appeals,." *Boston College Law School Faculty Papers*, 1993: 626-635.

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