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Sustainability, Ethics and Nuclear Energy: Escaping the Dichotomy

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Abstract: In this paper we suggest considering sustainability as a moral framework based on social justice, which can be used to evaluate technological choices. In order to make sustainability applicable to discussions of nuclear energy production and waste management, we focus on three key ethical questions, namely: (i) what should be sustained; (ii) why should we sustain it; and (iii) for whom should we sustain it. This leads us to conceptualize the notion of sustainability as a set of values, including safety, security, environmental benevolence, resource durability, and economic viability of the technology. The practical usefulness of sustainability as a moral framework is highlighted by demonstrating how it is applicable for understanding intergenerational dilemmas—between present and future generations, but also among different future generations—related to nuclear fuel cycles and radioactive waste management.

Keywords: equity; fuel cycle; future generations; radioactive waste; safety; security; sustainability

1. Introduction

There is probably no other energy technology that could give rise to controversy as much and for as long as nuclear technology. The benefits of large scale electricity production with fairly small amounts of fuel are simply undeniable. Especially in the post-World War II era when access to large amounts of energy was the key to progress and prosperity, nuclear energy seemed to have played an important role in many countries—most notably the United States, France, and Japan. However, the risks and problems are unquestionable too. This is a civilian technology with military ancestors; hence there are certain security and non-proliferation concerns associated with different stages of nuclear energy production. The second—but perhaps equally important concern—has to do with the detrimental health impacts that emanate from being exposed to radiation as a result of a nuclear accident. Particularly the Chernobyl disaster in 1986 proved that radiation impact could be both large scale and long term—it was only after 30 years that the dismantling of the damaged reactors could start [1]. Even though much smaller in terms of impact, the Fukushima-Daiichi nuclear disaster had a similar impact on the controversies surrounding nuclear technology.

Sustainability seems to be an important notion that comes back in a lot of these controversies (most notably in the last three decades). Indeed, both central issues of sustainability—i.e., environmental impacts and an acknowledgement that resources will run out—have some bearing on nuclear energy. Sustainability seems to be used by both proponents and opponents as an evaluative notion that could help endorse or reject this technology. For instance, some people have called nuclear

energy sustainable because it gives access to affordable electricity with low carbon emissions, while others believe it is inherently unsustainable because of the short and long-term radiation and security risks involved. Such dichotomous positions are not helpful in furthering the public and academic debate about sustainability. They only reinforce the stalemate and give rise to more controversy.

In this paper, we argue that sustainability could be a helpful notion for understating important dilemmas of nuclear energy production if we manage to escape the dichotomy. Indeed, in both political and public debate, one is eager to answer the question of whether nuclear energy should be deployed or not. However, to answer that question, we must first understand important moral issues that are associated with nuclear energy and the different technological possibilities for nuclear energy production and waste management. In this paper, we argue that sustainability could best be conceived as a moral framework that consists of several moral values. Such a framework will help us escape the yes/no dichotomy and assess the different possibilities of nuclear energy production and waste management, according to the important ethical issues they give rise to—being safety, security, environmental concerns, resource durability, and economic viability of the technology. This could facilitate a more nuanced and sophisticated comparison of different types of nuclear energy, which could in turn serve as the starting point for a comparison of nuclear energy with other energy systems. For instance, it will help us assess the desirability of future nuclear technological possibilities insofar as new technologies are designed to address some of the issues (e.g., reactors that are built with safety as the leading design criterion) but, at the same time, they do have an impact on other important issues, such as security. So, when a certain option is sustainable according to one aspect, it might at the same time be unsustainable according to another aspect; the choice as to which aspect should prevail is (among other things) a moral question. This paper aims at unveiling these complex moral questions of nuclear energy production and waste management by using sustainability as a moral framework.

The paper is structured as follows. First, by discussing the potential sustainability-related features of nuclear energy, we question the relevance of the use of sustainability in a dichotomous mode and highlight the ensuing pitfalls (Section 2). In the next section, we argue that sustainability should rather be conceptualized as a moral framework based on several moral values, which can be used in an ex ante analysis in order to steer the development of new technologies. This framework has to be elaborated in the context of nuclear energy by answering three main questions: what should we sustain, why should we sustain it and for whom should we sustain it (Section 3)? The practical usefulness of sustainability as a moral framework is then highlighted, by applying it to the choice of nuclear fuel cycles and the related question of radioactive waste management (Section 4). Some concluding remarks are presented in the last section (Section 5).

2. Releasing Sustainability from the Yes/No Dichotomy

Let us first remind one of the most influential definitions of sustainable development, which is given in the report *Our Common Future*, better known as the ‘Brundtland report’. The report states that “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of ‘needs’, in particular the essential needs of the world’s poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment’s ability to meet present and future needs” ([2], p. 43).

Sustainable development thus implies social justice insofar as it entails a reflection about distributions, both from a spatial and a temporal perspective. From a spatial standpoint, sustainability is about the fair distribution of well-being among contemporaries, with a special focus on the needs of the least well-off groups. When it comes to nuclear energy, we might for instance think of distribution of well-being among workers or local communities compared to members of society as a whole [3–5]. Intragenerational justice is at stake in that case. From a temporal perspective, sustainable development refers to the fair distribution of well-being between generations, that is, in terms of what we pass on to posterity. Sustainable development is thus also closely linked to the notion of intergenerational

justice. It is striking to note that essentially sustainable development entails the idea that there is a potential conflict of interest between present generations and future generations; hence, the emphasis that what we leave behind should be appropriate so that it will not compromise their abilities to meet their own needs. This generational conflict is also vividly visible in nuclear energy discussions, not only in questions such as whether or not to deploy nuclear energy, but also in choosing a production method among the alternatives [6,7]. Also, in choosing management strategies for the remaining waste, the interests of present and future generations need to be balanced [8,9].

While sustainability encompasses several important ethical questions (that will be elaborately discussed in Section 3), this notion has been mostly used in a dichotomous mode and in an attempt to arrive at a 'yes' or 'no'. This is rather problematic; i.e., using sustainability in the dichotomous mode leads to oversimplifying the characterization of technologies that might entail very complex issues. For instance, calling biofuel sustainable solely because of its renewability might obscure the fact that there are several other sustainability (or otherwise morally relevant) features that one needs to take into account; think of the water scarcity and food versus fuel dilemmas [10]; it also overlooks the fact that different generations of biofuel technology would deal with such issues differently. Such a binary analysis could also be found in the nuclear energy debate of the last decades. On the one hand, nuclear energy is seen as being intrinsically unsustainable, because of the safety issue (associated with nuclear activities) as well as long-term impacts of waste upon people and the environment [11,12]. Moreover, some scholars believe that nuclear energy might burn rather than build a bridge to sustainable energy policy [13]. On the other hand, nuclear energy is advocated as a sustainable energy source and hence as a necessary input in our future energy mixes [14–16]. The affordability of nuclear energy is also often put forward, just as the fact that nuclear energy could be produced based on natural resources that will not be depleted any time soon [17]. On top of the list of the arguments of the proponents who defend nuclear energy as a sustainable energy source are its low carbon emissions. In the Paris Agreement for combatting climate change, for instance, nuclear energy has been considered as one of the options to avoid the climate change. But again, this issue seems to be part of the ongoing controversy. Some scholars argue that when we consider the whole fuel cycle, nuclear energy has far more emissions than the proponents argue; these emissions stem partly from large scale mining of uranium, fuel enrichment, transportation, and in some countries reprocessing [18]; other scholars argue that the answer to climate change should come from renewable and not from nuclear energy [19].

If we leave out the complexity associated with the concept of sustainability, this notion could be easily (mis)used for greenwashing and rhetorical purposes, leading to potential ideological and political manipulation ([20], p. 128). Moreover, when used in a dichotomous mode, sustainability does not stimulate a proactive ethical reflection regarding the development of technologies. Indeed, a binary view of the potential sustainable feature of a technology is likely to lead to hastily dismissing or endorsing a technology. This is rather unsatisfactory because in policy-making, one needs to first be aware of the different technological possibilities, for instance different existing and future production methods for nuclear energy production, and the social and ethical implications of each method. Indeed, such internal comparison of technological possibilities is the first step towards answering the social desirability question or the question as to whether a certain production method of nuclear energy should be considered as a future possibility for energy production [21,22]. Such proactive thinking about the ethical implications of technology lies at the heart of design for values and responsible innovation approaches [23,24]. We expect that a more sophisticated understanding of the notion of sustainability (as it will be explained below) could help facilitate such analysis and, thereby, actively steer the development of new technologies.

To conclude, rather than referring to sustainability in a dichotomous mode, we need to revisit the concept of sustainability in the context of nuclear energy. We argue that it should be conceptualized as a moral framework in order to account for the complexity of ethically relevant issues associated with nuclear energy technologies, and to actively contribute to a proactive ethical reflection.

3. Sustainability as a Moral Framework

In order to revisit sustainability as a moral framework, it is necessary to elaborate on its foundation in spatial and temporal social justice. Our focus is mainly on temporal justice, since the latter gives rise to the most intricate issues, but as we will argue in Section 3.1 (building on Barry [25]), temporal and spatial justice are intertwined. In discussions on what temporal justice exactly entails, two challenges are particularly striking. First, we do not exactly know what will be the needs of people in the future. It is already complex to determine the needs of present generations, but it is even more complex, if not impossible, to determine the needs of people that do not yet exist. This is particularly problematic considering the fact that we do not even know who these future people will be. This challenge can be called ‘the ignorance problem’. The second issue, which can be referred to as ‘the distance problem’, relates to the questions of to which future people we owe obligations, to what extent we owe these obligations, and whether these are the same obligations we owe to our contemporaries or they are diminishing over time. In order to address these problems in the context of nuclear energy, we need to understand and to spell out the aspects of social justice relevant for nuclear energy. Therefore, three morally laden theoretical questions need to be answered: when speaking of sustainability in relation to nuclear energy, what should be sustained, why should we sustain it, and for whom should we sustain it? The first two questions address the ignorance problem. The third question relates to the distance problem.

Before discussing these questions and the associated values elaborately, one remark seems to be in order. We do not claim that the three questions that are posed in this paper cover all morally relevant features of nuclear energy. There is at least a fourth question as to who should decide. This question refers to the nature of the rules and regulations and to the decision-making processes; these have been called the procedural issues and the associated values are therefore procedural values [26]. Those values are then particularly relevant from a spatial justice perspective. Indeed, they relate to transparency, free and informed consent at local levels while respecting democratic choice at national levels, etc. However, we do not consider these procedural issues here, insofar as we focus in on nuclear technologies as such, independently of the way decision-making processes are conducted. Hence, in this paper we focus on substantive values, defined precisely as the values associated with the technology under consideration. Let us now discuss the values that underlie sustainability as a moral framework.

3.1. What Should Be Sustained and Why Should We Sustain It?

For understanding sustainability in terms of social justice, it is helpful to go back to Brian Barry’s conception of sustainability. Barry argues that for understanding our relations with future generations (and the extent of possible duties we have) we should start asking about the relations among the contemporaries and investigate if and how they could be extended into the future. The premise he is starting from is the fundamental equality of human beings, which leads him to define the “core concept of sustainability” as follows: “there is some X whose value should be maintained, in as far as it lies within our power to do so, into the indefinite future” ([25], p. 50). On the basis of the idea that a fundamental characteristic of human beings is “their ability to form their own conception of the good life”, Barry defines X as “the opportunity to live good lives according to *their* conception of what constitutes a good life” ([25], p. 52). Sustainability should then be understood as the requirement for us to provide future generations with such *opportunities*. In other words, as we are not in a position to foresee how future people will conceive the good life, we should not narrow the range of opportunities open for them.

The next step is to develop what sustainability as distributive justice entails for nuclear energy. In the specific case of nuclear energy production, keeping equal opportunities open for future generations is associated with the requirement to preserve (i) the vital interests of future generations; and (ii) their opportunities for well-being (building on [27]). These obligations are respectively referred to as the ‘no harm duty’ and the ‘duty to sustain well-being’.

In order to determine the values that are related to these two duties, let us first briefly review the intergenerational issues associated with nuclear energy. The depletion of natural resources is the first important intergenerational issue; this mainly concerns uranium, but also potentially other resources such as thorium that might be at stake with the development of Generation IV reactors. The second intergenerational issue has to do with potential accidents and malevolent acts leading to radioactive contamination insofar as the resulting damages could possibly extend beyond our current generation. Finally, a third crucial intergenerational issue is related to the type of waste generated by nuclear energy, some of which could be harmful for a period ranging up to several hundreds of thousand years. Having these issues in mind, let us now come back to the duties to sustain vital interests and well-being, so as to identify the values that are associated with these obligations in the context of nuclear energy.

The potential harmful characteristics of nuclear waste lead to associate the no harm duty with specific values, including safety, security, and environmental benevolence. On the other hand, the duty to sustain well-being is about not narrowing the opportunities for well-being for future people—considering that we do not know what they will value and how they will conceive the good life. Therefore, resource durability inevitably associated with well-being is at stake, as well as the economic viability of the technology.

Safety is understood as “the achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards” ([28], p. 133). Safety applies to our contemporaries and is thus relevant from a spatial perspective, but its importance is also stressed from a temporal standpoint. Indeed, safety lies at the heart of the principle of protection of future generations, which is emphasized both by the International Atomic Energy Agency (IAEA), and by the Nuclear Energy Agency (NEA) in arguing that geological disposal places are the best option for the future [29,30]. Regarding radioactive waste, the IAEA states that it “shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today” ([29], p. 6). Whether guaranteeing the same level of protection for future generations is feasible (considering technical and social uncertainties) or even desirable has been widely debated in the literature (e.g., [8,31–33]), but it is beyond contention that safety is among the most fundamental values worth striving for in the broad context of nuclear energy. Let us note that while there is a reference to the environment in many safety definitions, including the one given by the IAEA, in this paper we consider environmental benevolence as a separate value, so that the different issues associated with sustainability would appear more explicitly. Safety, as we refer to it here, refers thus specifically to public health issues.

Whereas safety refers to unintentional adverse effects of ionizing radiation on health, security, on the other hand, refers to intentional effects. Indeed, security designates “the prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances or their associated facilities” ([28], p. 133). Security has thus to do with sabotage, defined as “any deliberate act directed against a nuclear facility or nuclear material in use” which could “endanger the health and safety of personnel, the public or the environment, by exposure to radiation” ([28], p. 137). However, security is also about non-proliferation of nuclear weapons and fissile (weapon useable) materials. Let us note that safety and security clearly have some overlaps, but discussing them separately enriches the analyses provided by our framework.

Environmental benevolence is understood as “preserving the status of nature and leaving it no worse than we found it” ([27], p. 1345)]. In the context of nuclear energy, environmental benevolence is of course associated with the protection of the environment against radiological risks but also to several other key issues such as preserving the climate by limiting greenhouse gases emissions and preserving natural resources of the environment [16]. Since our analysis aims to primarily facilitate a comparison between different technological possibilities within nuclear energy technologies, issues associated with emissions and climate change are less relevant; those issues become relevant when we

want to compare nuclear technology with other energy technologies. As for the preservation of natural resources, we discuss those as a separate dimension, associated with resource durability, which entails a range of complex issues that are addressed here below.

It is worth noting that environmental benevolence could be approached from the point of view of an instrumental or an intrinsic value. On the one hand, granting an instrumental value to the environment means the environment is only valuable insofar as it is useful to human-beings. This is in line with the belief that “values always occur from the viewpoint of a conscious valuer” ([34], p. 251) and it is referred to as anthropocentric or human-based ethics. On the other hand, granting an intrinsic value to the environment means that the environment is believed to have some value in itself, regardless of what it means to human beings; this is called non-anthropocentrism. While the general debate on this issue in the environmental ethics literature is ongoing, some of this debate has reached the applications of this discussion to nuclear energy, and more broadly, to matters associated with radiological impacts [35]. The International Commission on Radiological Protection (ICRP), for instance, gives guidelines and standards for the protection of animals and plants when they are exposed to man-made radiation in their natural environment [36]. Moreover, the IAEA’s safety definition (as mentioned before) includes the environment explicitly. However, neither the IAEA nor the ICRP document say whether it is important to protect the environment (including plants and animals) for their own sake or for the sake of human-beings. Also in presenting our framework, we do not find it necessary to take a position. Regardless of whether one upholds an anthropocentric or non-anthropocentric view, the impact on the environment needs to be discussed as a separate issue because radiation has a different impact on the environment (including plants and animals) than on human health. What moral relevance one attaches to environmental benevolence would again depend on whether one follows the anthropocentric or non-anthropocentric view.

The duty to sustain well-being relates mostly to the crucial issue of the availability of energy resources. In the context of nuclear energy, the availability of energy resources is conditioned by resource durability, which refers to the availability of natural resources—such as uranium or thorium—for future generations or to their substitution in case of depletion. Resource durability entails not only a technical argument (i.e., how much resources are there left) but also an inherent economic component (i.e., are these resources available at an acceptable price). For instance, for the availability of uranium in the future, we need to make assumptions about future consumption but also regarding the prices at which uranium could be extracted. In other words, against which price does it make sense—economically—to extract uranium? Most natural uranium is to be found in sea water, but its separation/extraction proves to be rather expensive. Hence, the value of resource durability is strongly related to the second value associated with the duty to sustain well-being, which is the economic viability of the technology.

Economic viability of the technology refers to the fact that any activity for energy production must be durable for a period of time, if that is to be sustainable. More generally, economic viability refers to the possibility, from an economic perspective, to embark on a technology and to ensure its perpetuation over time. It is worth pointing out that economic viability itself depends on several factors, such as the affordability, the predictability of the costs over the long-term, and the dependence on external parameters—geopolitical parameters for instance as well as the availability of future technologies [16,27]. So far, we have spelled out and defined the values associated with the sustainability framework, namely safety, security, environmental benevolence, resource durability and economic viability of the technology. We do not argue that values are to be determined objectively. Instead, our set of values are presented in an intersubjective fashion [27]. That is a crucial aspect, because if sustainability is a framework for assessing different nuclear fuel cycles and waste management options, it should be a notion that is in principle useable by all individuals, regardless of their preference. In other words, someone who categorically disregards nuclear energy must in principle be able to express his opinion using the same set of values: the strong opponent of nuclear energy would for instance rank environmental benevolence and long-term safety higher

than other values such as availability of energy resources. Moreover, whether one nuclear energy production option (or waste management option) is to be preferred to others is also a matter of how these values are being ranked in terms of their (moral) relevance.

This multidimensional framework is helpful in that it allows us to account for different values and for potential value conflicts. These value conflicts may even be of different types, namely, different values might conflict in that they cannot be realized simultaneously but there could also be an internal conflict in the same value from a spatial or a temporal point of view. Spatial or intragenerational conflicts occur when the interests of different contemporary or temporal groups differ. Temporal or intergenerational conflicts occur when the interests of different temporal groups are divergent—the conflict can occur between our contemporaries and future generations, or among future generations themselves. This brings us to the third important question for conceptualizing sustainability for the assessments of nuclear fuel cycles and waste management options: for whom should we sustain the things that we wish to sustain?

3.2. *For Whom Should We Sustain It?*

We have highlighted that current people have two duties towards future people, namely to sustain (i) their vital interests (i.e., the no harm duty); and (ii) their opportunity for well-being (i.e., the duty to sustain well-being). An ensuing question is to ask for whom we should sustain these vital interests and opportunity for well-being. There is a fundamental distinction between these two duties in terms of their temporal reach. The former (no harm) duty has to do with the safety and security of nuclear reactors that may lead to long-term damage, but also to nuclear waste and the impact it could have on the vital interest of very many generations to come, while the duty to sustain well-being has a much more limited temporal reach. In other words, we can refer to the no harm duty as a negative duty (to refrain from harmful action) and the duty to sustain well-being as a positive duty to benefit future generations. Some scholars argued that we only have a positive intergenerational duty with a limited temporal reach (e.g., [37]), while other scholars defend a temporally extended negative duty to refrain from actions that could be harmful for future generations (e.g., [38]). Again others have defended both a negative and positive duty with varying temporal reaches (e.g., [39]); the morally desirable option should then be formulated when we consider these duties and the extent of their moral stringency [40]. We build on the latter line of reasoning by arguing that for nuclear energy, safety, security, and environmental benevolence—which are the values associated with the no harm duty—should be ensured for both close and remote future generations, while resource durability and economic viability—associated with the duty to sustain well-being—have a shorter temporal reach and should only be warranted for close future generations. This requires some explanation.

Assuming that we have related the well-being argument to resource durability and assuming that it has to do with the availability of uranium (and possibly thorium) in the case of nuclear energy, it seems reasonable to argue that we are in a position to only positively influence the interest of a few generations to come. It is very uncertain how long nuclear fission will continue as an energy source; by building new nuclear reactors we can ensure its continuation, at best, for about 50 to 100 years. Hence, it would make no sense to pretend we are able to sustain well-being by ensuring resource durability for remote future generations. The same reasoning goes for economic viability of the technology. On the contrary, it is relevant to extend the preservation of safety, security, and environmental benevolence to remote future generations, because we are in a position to negatively affect those values up into the very far future. Even though the uncertainties surrounding the confinement of the waste increases over time, the objective of protecting people against radioactive contamination and radioisotopes release remains—in principle—the same.

4. Applying Sustainability as a Moral Framework

In Section 3, we have answered the three theoretical questions—namely what should be sustained, why should we sustain it, and for whom should we sustain it—that serves as a foundation for our

conceptualization of sustainability as a moral framework aiming at assessing nuclear technologies. In this section, we intend to highlight the practical usefulness of sustainability as a moral framework by demonstrating how it is applicable for understanding crucial dilemmas associated with the use of nuclear energy. Therefore, we will apply our framework to two issues that have been identified as being particularly relevant with respect to sustainability, namely the choice of nuclear fuel cycles and of radioactive waste management strategies.

4.1. Fuel Cycles

Generally, there are two methods for producing nuclear energy, the open and the closed cycle. The open cycle—also known as the once-through cycle—would use uranium oxide fuel in a conventional reactor (which is a light water reactor). Spent fuel consists of the non-irradiated uranium, some plutonium, a number of other minor actinides (i.e., americium, curium, and neptunium) and some fission products. In an open or once-through cycle, spent fuel is destined to be disposed of underground in purpose built disposal facilities, better known as repositories; this disposal will only take place after a few decades to up to 100 years of cooling down of the waste in temporary surface storage facilities [41]. However, spent fuel could also be recycled. This recycling could happen in a chemical process called reprocessing, with the aim of removing uranium and plutonium from spent fuel. Reprocessing has two purposes: (i) to reduce the lifetime of the remaining waste—uranium and plutonium are the longest living actinides; and (ii) to reuse this uranium and plutonium in the nuclear cycle. This is why this cycle is called a closed fuel cycle [42].

Reprocessing has the benefit of reducing the waste lifetime and hence serves the value of safety in the (very) long run. However, at the same time, it creates safety concerns for the present generations. So, here we see a temporal conflict within the value of safety in the short and the long run, that is, the open cycle would better serve the safety of present generation while the closed cycle is improving the safety of future generations.

Another type of (temporal) conflict that could happen is between the value of security in the short run and safety in the long run. That requires some explanation. Reprocessing is a technology with military ancestors; the world's first reprocessing plant was built during the WWII with the aim of extracting the produced plutonium from the irradiated fuel in the world's first nuclear reactor. This led to the manufacturing of the Nagasaki bomb that was built based on plutonium. While the civilian produced plutonium (of the type produced in conventional energy reactors) is not very suitable for manufacturing an explosive device, it has some yield and could in principle be used for malicious activities [43]. Almost all reprocessing facilities operational in the world serve either as a military or as both civilian and military facility; Japan is the only non-nuclear weapon country that has a reprocessing plant. Going back to the sustainability framework, we can argue that the closed fuel cycle brings a conflict between the value of long-term safety in the long run and the short-term security risks it brings.

This is just a glimpse of this analysis and it serves to show how such analysis could be made to reflect on the choices for a fuel cycle. Perhaps more importantly, the framework could serve to pro-actively think about future technological choices. Japan would be a good example to illustrate this. Japan is a country with virtually no fossil fuel energy resources. The country has, therefore, every interest in using the existing resources most efficiently. This is why Japan has chosen to deploy the closed fuel cycle. In the last decades, Japan used to ship the spent fuel from its reactors to other countries (mostly the UK) to be reprocessed and shipped back. The Japanese government was set to use the closed cycle, not only the existing cycle that is discussed above, but also an extended cycle based on new reactor technology (so-called breeder reactors) and multiple recycling. Bringing this back to our framework, the main purpose of this decision was to serve resource durability for several decades. But of course, such an extended fuel cycle would compromise a number of short-term values, namely safety (i.e., radiation risks of multiple recycling), environmental benevolence (i.e., almost the same issues as with safety), as well as security (i.e., the associated risks of a so-called dual use facility

that in addition to a civilian use also has a military use). Particularly the latter security concerns have caused some political problems in Japan's neighboring countries. South Korea has also expressed some serious interest in developing reprocessing, also basically using the long-term safety argument (along with the reduction of the waste volume).

The proliferation of a dual use technologies—more specifically uranium enrichment and reprocessing technologies—are of grave international concern. Indeed, there is a rather powerful international agreement already in place to control such development, namely the Treaty on the Non-Proliferation of Nuclear Weapons (commonly referred to as the NPT). This treaty has the aim to accommodate the peaceful use of nuclear energy, while preventing the spread of nuclear weapons [44]. Despite the fact that there have been new proliferators added to the list of nuclear weapons possessing countries since the NPT first entered into force in 1970 (i.e., India, Pakistan, Israel, and North Korea), it is often argued that the NPT prevented worse from happening; i.e., many countries have openly or clandestinely pursued nuclear ambitions, either through a program dedicated to the development of nuclear weapons or as a civil program that opens the door towards a military program (see also [45]). One of the main problems of the NPT is that it leaves the door open for using dual use technologies. The NPT acknowledges each member state's inalienable right to nuclear technology for civil purposes (Article 4, NPT-treaty). This also includes access to dual use technologies, but of course only for peaceful purposes. The difficulty arises from the fact that when a country has access to such technology, it is one step closer to the potential possibility of developing nuclear weapons sometime in the future. To illustrate this with examples, the controversy surrounding Iranian nuclear program arose from Iran's emphasis on uranium enrichment and South Korean concerns have everything to do with Japan's reprocessing plants.

Various countries all around the world are currently considering the introduction of nuclear energy into their electricity grid or to expand (or simply replace) their existing nuclear energy reactors. These countries will be faced with a number of important choices regarding nuclear fuel cycles and the associated benefits and concerns. Our revisited sustainability framework could help these countries to consider the ethically relevant issues associated with these choices and make responsible decisions.

4.2. High-Level Radioactive Waste Management

Nuclear waste management is an essential part of the nuclear fuel cycle. Our focus here is on high-level radioactive waste management (HLRW), which includes spent fuel and the long-lived waste remaining after reprocessing [46]. In this step, there are important choices to be made that would require some consideration. Our revisited sustainability framework could serve to facilitate making these choices both technically and ethically informed. We will consider two options that are currently endorsed by several countries, namely non-retrievable geological disposal and retrievable geological disposal. The basic principle of a non-retrievable geological disposal is to confine the waste into containers, which are then put deep underground—typically a few hundred meters or more—in a stable geological formation. Once the waste is disposed of, all the galleries and the shafts are backfilled and the repository is sealed. In such a case, safety is assured by both engineered and natural barriers, and it does not require the intervention of men. On the contrary, a retrievable disposal implies that provisions have been implemented in order to ease the waste retrievability. Different types of measures can be implemented, such as for instance enhancing the confinement, choosing a specific type of rock, or leaving the shafts and some galleries open for an extended period of time. In this paper, we consider that a retrievable disposal is equivalent to a non-retrievable one, except for the fact that it is kept open for an extended period of time—without predetermining the length of that period. In such a case, safety requires permanent monitoring, and maintenance if necessary. It should be noted that differences between non-retrievable and retrievable geological disposal will only appear after a few decades, when the galleries and shafts are backfilled.

Let us first compare non-retrievable and retrievable geological disposal for close future generations, for whom the no harm duty and the duty to sustain well-being are both relevant.

The management strategies are thus to be compared with respect to safety, security, environmental benevolence, resource durability, and economic viability of the technology. In order to assess safety, two sub-criteria are taken into account. The first is potential exposure. Potential exposure comprises four components: the distance between the radiation source and the local communities, the protection barriers, the potential for harm of the source, and the likelihood of contact of local communities in case of planned exposure. For a full analysis of how non-retrievable disposal and retrievable disposal score with respect to each of these criteria, see [9]. The second sub-criterion is the possibility to monitor the facility and to proceed to its maintenance if necessary. The first sub-criterion favors non-retrievable disposal, whereas the second favors retrievable disposal. Regarding security, a non-retrievable disposal has the advantage. Indeed, by definition, retrievability provisions go against the aim of preventing the access to the waste [47]. Hence, regarding proliferation issues, the situation is strongly favored in the case of a non-retrievable geological disposal because it is more difficult to access the waste in that case—it is worth noting that the IAEA assumes that HLRW could be diverted from a retrievable facility in a few days, whereas it would take several years to divert it from a sealed geological disposal [47]. Furthermore, even sabotage is likely to cause less damage in the case of a non-retrievable geological disposal, because the waste is better confined.

The analysis of the safety criterion can be transposed for environmental benevolence, except that the focus here is on the fauna, the flora, and ecosystems rather than on humans. Resource durability favors retrievable geological disposal insofar as, in that case, it is easier to recover the waste in order to reuse remaining fissile materials. Finally, the economic viability of the technology is better assured in the case of non-retrievable disposal. Indeed, in that case, it is possible to estimate the costs beforehand and to plan the funding of the facility accordingly, whereas this exercise is much more difficult in the case of retrievable disposal—for which, eventually, further actions besides permanent monitoring will be required. These actions may be related to the later sealing of the facility but also possibly to the implementation of another strategy—which impedes the possibility to estimate currently the related costs.

For remote future generations—that is, after 100 years—the picture is completely different as, for them, the no harm duty remains the only relevant obligation. Here, the focus is hence on safety, security, and environmental benevolence, for which the analysis is the same than for close future generations: regarding security and potential exposure—with respect to humans and to the environment—a non-retrievable geological disposal is favored, whereas regarding the possibility of monitoring and maintenance, a retrievable disposal is advantaged.

Some differences do also occur within remote future generations, notably between future generations who still have the memory of the waste, its location and how to handle it, and future generations who have lost that memory [5]. Of course, it is impossible to foresee when the memory of the waste will be lost, but we may reasonably assume that it will not be before 500 years [48], p. 30). Hence the problem will arise for remote future generations rather than for close future generations. For remote future generations who will have lost the memory of the waste, some of these values become irrelevant. Indeed, when the memory of the waste is lost, the issue of monitoring and maintenance becomes obsolete. The same goes for security—with respect to both sabotage and proliferation issues—which implies malevolent intentions that cannot be at stake anymore when there is no knowledge about the waste. The only remaining relevant criterion is thus potential exposure—both for humans and for the environment—which favors non-retrievable geological disposal. Hence, when the memory of the waste is lost, the value conflicts at stake for close future generations and for remote future generations with the memory of the waste vanish.

The analysis of HLRW management options through the lens of sustainability as a moral framework shows here again—just as for the nuclear fuel cycle analysis—that our framework is able to grasp complexities associated with the notion of sustainability, which are completely neglected when sustainability is considered in the dichotomous mode.

5. Discussion and Conclusions

In this paper, we have argued against the use of sustainability in a dichotomous sense. We have revisited the notion of sustainability in terms of what is morally relevant to be sustained, how that could be sustained, and for whom it should be sustained. This operationalization of sustainability within the nuclear energy context implies keeping opportunities open for future generations. More specifically, it implies a no harm duty—relevant both for close and remote future generations—and a duty to sustain their well-being only at stake for close future generations. These obligations lead to the conceptualization of the notion of sustainability as a set of values which comprises safety, security, environmental benevolence, resource durability, and economic viability.

Such a framework, directed towards current generations but also towards different future generations, can be used in order to provide an in-depth analysis of values associated with different options for nuclear energy production and for nuclear waste management. More specifically, our framework allows to account for intragenerational conflicts as well as for intergenerational ones, insofar as the framework is able to highlight the fact that a technology might be sustainable with respect to some values or to some groups, whereas it might be unsustainable with respect to other values or to other groups that are spatially or temporally distant. However, even though the framework is helpful for highlighting value conflicts, it does not solve these conflicts. Indeed, the question of which value should take precedence if two or more values cannot be accomplished at the same time is a political question to be answered in a public and political discourse. Still, by making these value conflicts explicit, the framework can help us escape the dichotomy, appreciate the complexities of the choices associated with different options for nuclear energy production and waste management, and facilitate a technologically and societally informed decision-making. Moreover, it can help provide ex ante analyses of technologies and steer their development, which is important for policy-making, as sometime choices made once cannot be undone easily afterwards. Pro-active thinking—along with current thinking on responsible innovations—is therefore recommended.

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41. This period depends of the type of spent fuel storage, for instance, dry cask storage of spent fuel can be done for 100 years. Also, the period of temporary surface storage could be extended after several technical measures have been undertaken. However, dry cask storage or extended surface storage of spent fuel are not present in all countries and thus long-term disposal may need to be done much sooner in many cases.
42. Whether the lifetime of remaining waste after reprocessing would indeed substantially decrease rests on several assumptions that are sometimes rather unsubstantiated. It is beyond the scope of this paper to review those assumptions; for a review of these assumptions please see Taebi, B. Moral dilemmas of uranium and thorium fuel cycles. In *Social and Ethical Aspects of Radiation Risk Management*; Oughton, D., Hansson, S.O., Eds.; Elsevier: Amsterdam, The Netherlands, 2013; pp. 259–280.
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46. Two remarks are in order here: first, reprocessing of spent fuel generates two streams of waste, i.e., (i) a new stream of short-lived waste that—in principle—does not require geological disposal; and (ii) long-lived waste that does require geological disposal. Our focus on this paper is on the latter. Second, there is also another category of waste, called ‘military waste’, which requires geological disposal. We leave out that category from our analysis because it has nothing to do with nuclear energy production but also because this waste is typically dealt with differently. In the US, for instance, this waste has already been partly disposed of underground in a facility only built for military waste in New Mexico.
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