Trabajo fin de Máster

Global Environmental Scenarios – a Global South perspective

(Escenarios ambientales mundiales – una perspectiva del Sur Global)

Autor/a: Arthur Haoyu Lauer

Universidad de Valladolid

Tutor/a: Óscar Carpintero Redondo; Carlos de Castro Carranza

Departamento de Economía Aplicada; Departamento de Física Aplicada

Universidad de Valladolid

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Resumen/Abstract:

Ante el desarrollo de la crisis socioecológica, los escenarios medioambientales mundiales han atraído la atención tanto del mundo académico como de la gobernanza medioambiental. Sin embargo, en la actualidad falta una perspectiva crítica del Sur Global sobre estos escenarios. En este trabajo, me baso en la teoría decolonial y en los estudios de los Conflictos Ecológico-Distributivos para analizar críticamente cinco escenarios medioambientales globales importantes, denominados SSP1-19, SSP5-19, SSP5-Baseline, NZE (Net Zero Emissions) y Adv E[R] (Advanced Energy [R]evolution). Demuestro que estos escenarios están sesgados en su argumento y sus cuantificaciones hacia el Norte Global, que tienen una comprensión abstracta y economicista del "desarrollo" y que implican un aumento significativo de los Conflictos Ecológico-Distributivos en el Sur Global causados por impactos ecológicos y sociales adversos ocultos en los escenarios. Estos resultados son relevantes para la práctica de la cooperación al desarrollo porque apuntan a la necesidad de tener en cuenta los cambios medioambientales adversos en la futura cooperación al desarrollo y porque vinculan las cuestiones de "desarrollo" con las desigualdades sistémicas globales, la destrucción ecológica y la necesidad de un cambio de paradigma.

In the face of an unfolding socio-ecological crisis, global environmental scenarios have gained attention in academia and environmental governance alike. However, critical Global South perspectives on these scenarios are currently missing. In this work, I draw on decolonial theory and the studies of Ecological distribution conflicts in order to critically analyze five important global environmental scenarios called SSP1-19, SSP5-19, SSP5-Baseline, NZE (Net Zero Emissions), and Adv E[R] (Advanced Energy [R]evolution). I show that these scenarios are biased in their storyline, and their quantifications, toward the Global North, that they have an abstract and economistic understanding of ‘development’, and that they imply a significant increase of Environmental Distribution Conflicts in the Global South caused by adverse ecological and social impacts hidden in the scenarios. These results are of relevance for the practice of development cooperation because they stress the importance that future development cooperation takes into account adverse environmental change, and because they link questions of ‘development’ to global systemic inequalities, ecological destruction and the need of paradigm changes.

Palabras clave/Keywords:

Escenarios ambientales mundiales; cambio climático; Sur Global; Desarrollo Sostenible; estudios del futuro / Global environmental scenarios; climate change; Global South; Sustainable Development; future studies.

Length: 14937 words (excluding Annex but including Abstract and Bibliography)

Dedication

This work is dedicated to the living Earth and those fighting against the suffocating pressure of an unjust socio-economic system.

Who said: "Everything was burned down,

Never again will you throw crops in the earth?"

Who said, that the earth has died?

No, she has concealed for a time being.

Motherhood can't be taken from the earth,

Can't be taken away, like the water from sea.

Who believed, that the earth was burned down?

No, she's gotten black from grief and sorrow.

[…].

She will endure anything, she will wait,

Don't write her up as a cripple!..

Who said, that the earth doesn't sing,

That she got silent forever?!

No, she rings, deafening the moans everywhere,

From all her wounds and her vents,

Because the earth - it is our very soul,

A soul can't be trampled with boots.

[…]

Excerpt of Vladimir Vysotsky's 'Song about the Earth'. Translated by Nathan Mer, 1991

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LIST OF ABBREVIATIONS

GDP	Gross Domestic Product
Adv E[R]	Advanced Energy [R]evolution
APS	Announced Pledges Scenario
CCS	Carbon Capture and Storage
DAC	Direct air capture
EDC	Ecological Distribution Conflict
EKC	Environmental Kuznet Curve
EROI	Energy Return on Energy Invested
EUE	Ecologically Unequal Exchange
GDP	Gross Domestic Product
GEC Model	Global Energy and Climate Model
GES	Global Environmental Scenarios
IAM	Integrated Assessment Model
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IMF	International Monetary Fund
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
LAM	Latin America
MAF	Middle East and Africa
NGOs	Non-Governmental Organizations
NZE	Net Zero Emissions
OECD	Organisation for Economic Co-operation and Development
PIK	Potsdam Institute for Climate Impact Research
ppm	parts per million
STEPS	Stated Policies Scenario
RCP	Representative Concentration Pathway
REF	Reforming Economies
RES	Renewable Energy Sources
SDG	Sustainable Development Goal
SPA	Shared Policy Assumption
SSP	Shared Socio-Economic Pathway
TFP	Total Factor Productivity
UNEP	United Nations Environment Programme
WEO	World Energy Outlook
WWF	World Wide Fund For Nature

1. INTRODUCTION

With growing awareness about the unfolding socio-ecological crisis which manifests through climate change, biodiversity and ecosystem functions loss, as well as through growing inequality, the interest for global environmental scenarios (GES) has grown in the academic world, the general population and among decision-makers.

GES are 'boundary objects' at the intersection between science, politics and society (Garb et al., 2008). As such, they produce certain imaginaries of the future which are far from neutral and which, already today, influence the socio-environmental policies adopted by decision-makers (Beck & Mahony, 2018).[1] Although they are widely used and cited in academic work, critical analysis of these scenarios from the Global South are still underrepresented in the scientific literature. However, Global South perspectives on GES are of special importance and interest for development cooperation because only by critically examining which future and which kind of development those scenarios envision for countries and communities of the Global South, organizations and individuals in this sector can decide if they can take these scenarios as orientation when thinking about their future activities, or if they rather need to turn to alternative visions of the future.

Analyzing GES also offers the opportunity to apply some of the skills acquired through the master: On the one hand the capacity to establish links between the environment and development, to critically reflect about the very term 'development' and to recognize the differences in power, realities and modes of life between the Global North and South. On the other hand, the complexity of GES as object of study also enable profound scientific analysis, including the application of different methods of scientific research and a science-informed reflection on their implications for the Global South.

This work aims to critically analyze existing GES from a Global South perspective. Concretely, I want to answer two questions: First, which conception of 'development' is prevalent in important GES? And second, if those imagined futures were to become true, what would be the impacts on vulnerable populations of the Global South?

In order to reach these objectives, I draw on different methodologies. To contextualize the topic and to lay out the theoretical foundation, I conduct a literature review focused on the state of the art in GES development as well as on different critical theoretical schools of thought from the Global South. For the analysis of the scenarios, I apply techniques of content analysis (cf. Kleinheksel et al., 2020) and data analysis. The figures presented in this work are produced with the software R and are informed by original data produced by the scenarios as well as by my own calculations.

[1] This characteristic of scenarios is called *performativity*: the very act of formulating certain imaginaries of the future helps to bring them into being (Beck & Mahony, 2018).

Having highlighted the relevance of the topic, in the following section I will shortly present the most important results of the literature review conducted for this work, and explain the theoretical framework which guides the analysis. Informed by the insights of the theoretical part, I go on to examine the implications of five selected scenarios for the Global South. I conclude by highlighting the most important insights from the analysis, implications for development cooperation, and possibilities for future research.

2. LITRATURE REVIEW AND THEORETICAL FRAMEWORK

2.1. Introduction to the literature

In order to orient the reader, this section starts with the most relevant findings from a literature review conducted on the two defining elements of the topic of this master's thesis: 'Global Environmental Scenarios' and 'Global South perspective'.

The literature on global environmental scenarios is extensive and diverse (Van Vuuren et al., 2012). GES can be defined as consistent stories about how the future, and especially environmental conditions and nature-society relations, could evolve (cf. Aguiar et al., 2020; Van Vuuren et al., 2012). Often, these scenarios consist of a qualitative part, the so-called scenario storyline, and a model which quantifies the storyline. GES have a global scope but they also provide information on a regional scale and can be broken down and quantified with more detail through regional analysis (cf. Rounsevell & Metzger, 2010). Scenario development can have different aims but often they want to facilitate the decision-making processes in environmental governance (Van Vuuren et al., 2012). In the literature, there are general environmental scenarios (e.g. Raskin et al., 2002) but also scenarios which focus on some specific dimension of the environment like climate (O'Neill et al., 2017), energy (Ansari et al., 2020), food (Mora et al., 2020) or biodiversity (Pereira et al., 2020; Raskin, 2005). Scenarios with detailed storylines and/or quantifications are often commissioned by international institutions (IPCC, IPBES, UNEP…) or NGOs (Greenpeace, WWF), and developed by scientists (Lacroix et al., 2019). For this work, I will focus on global climate and/or energy scenarios which have a quantitative part and are connected to international institutions or NGOs.

With regard to the framework for the critical analysis, the following question arises: 'But what *is* a Global South perspective?' The scientific literature has found two answers to this question which often overlap. First, there is a geographic-economic approach which designates those countries with low GDP per capita levels, which in their majority are located in the Southern hemisphere, as 'Global South'. According to this definition, Latin America, Africa and most of Asia, including the Middle East, are the Global South while the rest of the regions constitute the Global North (Roy, 2018). Second, an alternative approach drawing on critical theory holds that those social groups that have historically suffered and still suffer from different kinds of colonial, patriarchal and capitalist oppression as constituting a metaphoric 'Global South' which is united through the experience of oppression, the organization of resistance and the quest for emancipation (cf. Santos, 2016). This approach allows for the parallel existence of 'Global North' in the geographical South – for example local elites, state repression or multinational corporations – and 'Global South' in the geographical North, i.e. refugees, oppressed ethnic and racial minorities, and impoverished and marginalized groups in the rich industrialized countries.

Furthermore, there is a host of works about the inequality between 'developing' and 'developed' countries which would be equated to Global South and North in the geographic-economic approach. Examples are structuralist development theory, dependency theory, world system theory, theory of basic human needs or the theory of endogenous development (Llistar Bosch, 2009). A further prominent theory connecting inequality and trade (or dependency theory) with environmental degradation (studied by ecological economics) is ecologically unequal exchange (EUE) theory (Givens et al., 2019; Hornborg, 2009; Hornborg & Martinez-Alier, 2016; Jorgenson, 2016). EUE states that the structure of international trade permits powerful countries of the Global North to disproportionately access the natural resources and sinks of Global South nations. Thus, the Global North can spatially and temporally shift environmental harm at the expense of the Global South (Givens et al., 2019).

This work focuses on the Global North and South as economic-geographic entities but is sensible to power dynamics and inequality. For the theoretical framework, I draw on decolonial studies and the notion of ecological distribution conflicts. Those strands of thought are especially sensible to various forms of oppression caused by power inequalities based on capitalism, patriarchy and/or coloniality. For the analysis, I focus especially on vulnerable social groups in Latin America, Asia and Africa. Vulnerable groups in the industrialized countries, and elites in the so-called developing countries, could be studied in future works.

2.2. Theoretical framework

Due to the fact that there is a wide range of different theories which have their origin in, or are related to, the Global South[2] (cf. section 2.1), it is impossible to find THE perspective of the Global South on GES. Rather, I will focus on two theoretical strands which constitute a

[2] Understood here as encompassing both the geographic-economic entity as well as the population experiencing colonial, patriarchal and/or capitalist oppression.

possible Global South perspective. In particular, I will explain those facets of decolonial theory and the study of ecological distribution conflicts (EDCs) which are useful for conducting a critical analysis of GES. I choose these currents of thought because compared with other theories from and about the Global South they have a clear focus on emancipation from oppression, justice and the well-being of the under-privileged, marginalized social groups, topics which should be of great relevance in the realm of development cooperation.

2.2.1. Decolonial thought and development

Decolonial theory is a critical theory from the Global South (Adams & Estrada-Villalta, 2017; Mignolo, 2013), concretely from Latin America. There is a slight difference between decolonial and post-colonial thought which is worth pointing out: Post-colonial studies draw on post-structuralist critical thinkers mostly from the West like Foucault, Gramsci or Derrida, and have their regional focus on Asia (including India and Palestine) and Africa. In contrast, decolonial studies arise from debates among mostly Latin American thinkers and are influenced by Latin American critical thought, dependency theory and the philosophy of liberation. Also, the Zapatistas movements as well as indigenous movements across the world serve as sources of inspiration for this theory (Mignolo, 2013; Santos, 2022).

Decolonial theorists highlight that the progress and achievements of modernity in the West are deeply linked to, and in fact inseparable from, the simultaneous colonial and imperial exploitation of the people of the South (Mignolo, 2013). Thus, they speak of the 'darker side of modernity' (Mignolo, 2013) and point to the 'myth of modernity' (Dussel et al., 2000) which naturalizes the suffering of the oppressed in the name of the civilizing character of modernity. Decolonial theorists demand that the promise of emancipation of modernity is extended to those who were systematically denied the emancipatory achievements of modernity – the 'others', i.e. the non-Europeans, non-male, non-White, non-rich humans (Dussel et al., 2000). This implies that colonial oppression, injustice and social hierarchies are replaced by solidarity and complementary between socially constructed binaries like center/periphery, woman/man, mankind/earth, Western culture/post-colonial cultures (cf. Dussel et al., 2000).

Thus, decolonial theory claims that the West enjoys the comfort and privileges of the modern civilization while it maintains global political and economic structures which impede the Global South from enjoying the same privileges. They point to the fact that, although colonialism ended in the past century, the South until today faces three different forms of coloniality: the coloniality of power, the coloniality of being and the coloniality of knowledge (Restrepo, 2018).

First, the coloniality of power has been studied by the Peruvian sociologist Quijano who developed the concept of a colonial matrix of power consisting of four interrelated domains of control: the control of the *economy* which includes land appropriation, exploitation of labor and the control of natural resources; the control of *authority* through institutions and an army; the control of *gender* and sexuality; and the control of *subjectivity* and knowledge. The last domain of the colonial matrix of power clearly intersects with the coloniality of being and the coloniality of knowledge as it deals with education, the formation of subjectivity and epistemology (Mignolo, 2013).

Second, the coloniality of being refers to the experience of certain populations of being rendered inferior or less human and to the construction of subjectivities such as the colonizer and the colonized, which legitimize oppression and injustice between humans (cf. Ndlovu-Gatsheni, 2013; Restrepo, 2018).

Last, the coloniality of knowledge criticizes the claim of Western epistemology to be neutral and universal (Mignolo, 2013). It states that there is no 'zero point of observation', which is disembodied and neglects that knowledge is produced by people with different 'race' and gender. The coloniality of knowledge denounces the fact that non-Western, non-scientific knowledge is constructed as inferior and considers the existing hierarchies between 'objective scientific knowledge' from the Global North and 'subjective experiences' of the Global South an expression of coloniality (Quijano, 2007; Restrepo, 2018; Santos, 2018).

From these pillars of decolonial theory one can infer the decolonial stance on the notion of 'development': Overcoming the coloniality of power would mean to conceptualize development as a process whose objective is to eliminate the control of the Global South's economy through the Global North. This would include ending the land appropriation through actors of the Global North, ending the exploitation of laborers from the Global South and increasing the control that marginalized social groups such as indigenous people, ethnic minorities or peasants have over the natural resources of their territories which would probably imply more egalitarian access to resources and more equilibrated material flows between the Global South and the Global North. Also, a decolonial approach to 'development' inspired by the coloniality of being would question the social construction of subjectivities such as 'underdeveloped' or 'developed'. Drawing on the coloniality of knowledge, one could question the concept of 'development' itself because it presents itself as universal, neutral objective, and pathway to be followed by the whole world although in reality it implies that the countries of the Global South and their populations adopt certain ideological premises of organizing their society and their economies, emanating from the Global North, through a process of 'modernization'.

2.2.2. Ecological distribution conflicts

The concept of ecological distribution conflicts was coined by the ecological economist Martinez-Alier (Martinez-Alier, 2003) and is part of the field of Political Ecology. Ecological distribution conflicts (EDCs) are conflicts about the distribution of the benefits and costs of extraction, pollution or resource use, which are expressed as conflicts over valuation. They are linked to increases in social metabolism due to economic and population growth, which requires greater material and energy flows, notably for exosomatic use, i.e. for uses beyond the maintenance of the human body (Martinez-Alier, 2009). EDCs stem from ecologically unequal exchange with the Global South through which the Global North maintains its social metabolism. EDCs unfold if the people affected start to question this cost shifting by claiming their rights. Often, they use languages of valuation which differ from purely monetary reasoning: They might refer to the livelihood value of the environment, to the sacredness of their territories, to human rights or to cultural diversity.

EDCs are related to the concept of 'Environmentalism of the poor' which states that the poor are often the strongest defenders of the environment because they rely on it for their survival and because they lack the financial means to acquire those goods on the market (Martinez-Alier, 2003). Also, EDCs are related to the concept of Environmental Justice as EDCs arise from profoundly unjust systems of exploitation and cost-shifting (cf. Martínez-Alier, 2012). Finally, the theory of EDCs is strongly connected to the theory of ecologically unequal exchange because it is a structurally unjust international trade regime that fuels the growth of the global socio-economic metabolism, and permits unequal resource flows between the South and the North (cf. Hornborg & Martinez-Alier, 2016). At the same time, EDC scholars also argue that EDCs in the Global South could help to minimize or overcome ecologically unequal exchange (Givens et al., 2019).

As resource extraction and struggles for more equitable access to energy and material often takes place in the Global South, the perspective of ecological distribution conflicts can be seen as part of a perspective of the Global South. The study of EDCs focuses on the impacts of an expanding world economy on those populations (primarily of the Global South) whose quality of life, autonomy or even survival is threatened. This type of analysis is, thus, sensitive to the power hierarchies between Global South and North in the current world economic system.

From the key insights of the exposed theoretical strands we can conclude that a perspective from the Global South building on these currents of thought will critically examine the conception of development and the implicit or explicit impacts on vulnerable populations of the Global South if a given discourse would become reality. In the following section, I will apply these criteria to the object of study: existing global environmental scenarios of great relevance in the scientific literature and international environmental and energy governance.

3. ANALYSIS

For this work, I have selected five global environmental scenarios which are used with great frequency in the scientific literature and are of considerable importance in the realm of environmental policy. The scenarios are called "SSP1-19", "SSP5-19", "SSP5-Baseline", "NZE" and "Advanced Energy [R]evolution".

The first three scenarios (SSP-x) were developed by the climate science community for the IPCC and describe possible socio-economic developments until 2100. They are quantified using integrated assessment models and aim to facilitate decision-making in climate governance (O'Neill et al., 2017). The NZE (Net Zero Emissions by 2050) scenario is part of the World Energy Outlook 2022 of the International Energy Agency (IEA) and shows a pathway to decarbonize the economy until 2050 while meeting the 1.5°C goal. Last, the Advanced Energy [R]evolution scenario was presented by Greenpeace in its 'Energy Revolution' report 2015. This scenario can be seen as an alternative to the NZE scenario and aims to achieve an energy system based on 100% renewable energy which is compatible with climate goals (Teske et al., 2015).

Those readers who are not yet familiar with those scenarios can find more explanations in Annex A.

3.1. Conception of 'development'

The conception of development in GES is reflected on the one hand in the storylines of the scenario, and on the other hand in the way this 'development' is quantified in a model.

3.1.1. Qualitative dimension

SSP1-19

In SSP1, 'development' has a great significance: Within the analyzed storyline material of SSP1 (see Annex F.i), comprising 1438 words, the word 'development' is mentioned 14 times. The storyline speaks of 'sustainable development' ("more inclusive development that respects perceived environmental boundaries") and the discourse revolves around the Sustainable Development Goals (SDGs) ("achieving global and national development and sustainability goals").

Also, the idea of sustainable growth, understood as growth that contributes to well-being, equity and sustainability is reflected in this scenario storyline ("shift in emphasis from growth per se to well-being, equity, and sustainability"). In this way, sustainable development is linked to green growth: A kind of economic growth that does not produces the long-term degradation of local environments and is characterized by low material growth and lower resource and energy intensities. In line with the paradigm of sustainable development, in SSP1, improvements in well-being are prioritized over economic growth per se.

The words ‘developing’ and ‘low-income’, as well as ‘developed’ and ‘high-income’ are used as synonyms in the SSP1 narrative, which shows that ‘development’ is primarily associated to GDP p.c. However, in this scenario, development/growth is complemented by adjectives like ‘sustainable’, or ‘inclusive’.

This economic development is tied on the one hand to rapid technological progress (“rapid technological change”) which enables the efficiency gains and new technologies needed to deliver ‘green growth’. On the other hand, it is also tied to an increasing urbanization: In the quantification of SSP1, 92% of the global population lives in cities at the end of the century (Bluwstein & Cavanagh, 2023).

Although the SSP1 storyline mentions cultural and social diversity, implicitly all countries develop toward the same counterfactual state of a ‘green’ consumption society. This imagined world society uniformly adopts a slightly modified Western lifestyle: Consumption ‘light’ in an urbanized environment, enabled by technological progress and growth/development. Thus, although the SSP1 storyline aims to project the future trajectories of both the Global South and the Global North, it mainly reflects realities of life and challenges of the Global North: It could be argued that the ‘lifestyle changes’ which form part of the storyline, are the perspective of the privileged class on the social and environmental problems of the world. For example, only the middle and upper classes of the world population actually *do* have the option to choose public transport instead of cars or to eat less meat, as described in the SSP1 storyline. To sum up, the SSP1 narrative conceptualizes development as a shift from ‘economic growth’ in general to ‘social and green economic growth’ under the paradigm of the SDGs which is supposedly realized by the whole world. It thereby neglects the fact that this kind of shift is first and foremost a task of the Global North, due to its resource consumption and its historically accumulated CO2 emissions (Hickel, 2020), which is projected to the whole world. At the same time, the storyline remains silent on the realities of life and challenges of the Global South with regard to its ‘development’. Also, it does not mention structural inequalities in the global economic order which force the Global South into certain modes of development that harm its people, such as neoliberal ‘development’ or ‘development’ based on extractivism (cf. Andrade, 2022).

SSP5-19/SSP5-Baseline

As in SSP1, for SSP5 which forms the backbone of the SSP5-19 and SSP5-Baseline scenario, the concept of 'development' is central: The word 'development' is mentioned 18 times in the analyzed storyline material (1999 words; cf. Annex F.ii), including the scenario name 'Fossil-fueled *development*'.

The storyline uses 'developing' and 'poorer' [countries] synonymously, as well as 'developed', 'wealthier', and 'industrialized' [countries]. Like in SSP1, this discourse establishes a clear link between development and GDP per capita growth. Furthermore, in SSP5 the focus is on development as industrialization process which is achieved through fossil-fueled, high economic growth.

While in SSP1 the 'world' achieves the SDGs while reducing energy intensities and fossil fuel use, in SSP5 social and economic development is coupled with the exploitation of fossil fuels. Also, instead of sustainable development goals, the SSP5 storyline speaks of 'human development goals' whereby it is unclear what exactly is meant by this concept.

Like in SSP1, in SSP5 there is a clear divide between developed and developing countries, with the latter ones following the pathway of the former group: In the storyline, the developing countries adopt the fossil and resource-intensive development model of the industrialized countries. Also, there is a high level of urbanization, caused by a rapid migration of rural population into cities, with the share of people living in cities reaching the same levels as in SSP1 (cf. Bluwstein & Cavanagh, 2023).

The storyline describes how market-oriented worldviews take over and replace 'traditional' views after a period of significant tension between these different worldviews. Consequently, the narrative describes the convergence of different cosmovisions to a single global one which is 'modern' and market-based. The whole world embraces 'development' as technology-driven and resource-intensive economic growth, coupled to the mode of life of Western societies: an urbanized way of life filled with materialist status consumption.

Thus, in SSP5 there is no room for other concepts of 'development' or modes of living outside the logic of market-based growth. Rather, the storyline envisions global integrated markets and trade liberalization for agricultural products. This strong emphasis on markets and on 'capital' of different kinds (human, natural…) echoes the neoliberal paradigm of the Washington Consensus so fiercely contested in the Global South because of its failure to deliver its promises (Sheppard & Leitner, 2010).

NZE

In comparison to the SSP storylines, the NZE scenario barely has a storyline. Rather, the core qualitative information about the scenario has to be compiled from the Global Energy and Climate Model Documentation (IEA, 2022a) and the IEA World Energy Outlook (WEO) 2022 (IEA, 2022b) (cf. Annex F.iii). 'Development' only appears as 'Sustainable Development

Goals'. Thus, once again, 'development' is equated to a combination of economic growth, combined with social and environmental aims.

As the storyline is very scarce, the entire chapter three of the WEO 2022 is analyzed, which describes the results of the NZE. As in the case of SSP1, the NZE describes a trajectory for the *whole* world but is implicitly centered on the Western reality of life and challenges. Like in SSP1, the NZE scenario highlights that it relies not only on efficiency increases but also on behavior change. As it is acknowledged in the scenario, the proposed measures "target wasteful or excessive energy consumption, predominantly in wealthier parts of the world" (IEA, 2022b, p. 160). Thus, its focus is on the reality of those social groups constituting the metaphorical Global North.

Table B1 in the Annex lists some proposed measures and reflections from a possible 'Global South' perspective.

The Global South is only mentioned with respect to the end of traditional biomass use and the access to 'modern' energy: By 2030, every household in the Global South shall have full access to 'modern forms of energy', concretely through improved biomass cookstoves, liquefied petroleum gas, electricity, biodigesters or ethanol. This transition is mainly motivated by efficiency reasons and has as additional benefit that women are less affected by the health impacts of traditional biomass and can require education in order to access the labor market. This, again reflects an economistic type of reasoning. At the same time, being a purely technical scenario, the storyline ignores systemic social and political factors which in the real world impede this imagined trajectory to zero traditional biomass use in 2030. Like in SSP5, the Global South is linked to something backward or 'traditional' which contrasts with the 'modern' North, using 'modern' energy. As in the SSP storylines, there is a divide between 'advanced economies' and 'developing economies', with the former taking the lead in reaching net zero emissions. Also, it is assumed that there are "different stages of economic development" (IEA, 2022a, p. 7), suggesting that there is an abstract universal development path followed by all countries of the world.

The NZE scenario remains silent on the 'development' trajectory of the South, apart from the already mentioned 'sustainable development' which is assumed to also take place in the South. Once again, there is one single development paradigm – with (energy) technology and (economic) growth at its center - adopted by the whole world (homogenization). For example, the scenario assumes that the whole world uses the same efficient technology based on electricity and digital energy management systems although many regions of the Global South currently lack the basic infrastructural requirements for the adoption of such technologies and it is unclear how within two decades these infrastructures shall be financed and built. The only concrete proposal made in the scenario is that *some* of the funding required for infrastructure building could come from reductions in the funding for airport capacity expansions in 'advanced economies'. Interestingly, the scenario does not propose a radical absolute *reduction* in airport capacity of the Global North which would save the costs of maintaining and replacing existing airport infrastructure.

Also, these future transport, electricity and internet infrastructures entail material and energy costs which will either pose a threat to reaching the 1.5 °C goal or would require further material and energy reductions in the West, which is not reflected in the NZE scenario. Although the NZE scenario describes some moderate behavior change, it does not radically question conventional development and the way of life it entails. For instance, despite discouraging car use, car sales in the NZE scenario are around one quarter above 2021 levels in 2030. After all, economic development is linked to industrialization and global supply chains.

Adv E[R]

As in the case of the NZE storyline, the Adv E[R] storyline is very scarce (cf. Annex F.iv). Thus, I consider the storyline in the context of the whole report.

Unlike the SSPs, for the Adv E[R] scenario 'development' is not of central importance as its focus is the transformation of the energy system to a 100% renewable one. At the same time, as in the other scenarios, there is a binary divide between 'industrialized' and 'developing' countries. Moreover, the scenario assumes that the whole world adopts the same kind of economic development: green growth, understood as the decoupling of energy demand and GDP, which is a "prerequisite for [the] Energy [R]evolution" (Teske et al., 2015, p. 65). Consequently, it is assumed that coal power plants in 'developing' countries will have a shorter operational lifetime (20 instead of 35 years) and technology spreads across the whole world. However, it is at least acknowledged that different assumptions for economic growth and lifestyle consequences are possible especially for countries of the Global South, and would lead to significantly higher energy demand.

With regard to the modes of life that 'development' entails, there are many parallels to the IEA NZE scenario. The focus is on moderate behavior changes which will mainly impact the reality of life of people of the Global North and which focus on the transport sector: It is assumed that people will prefer trains to cars and airplanes if they have the possibility to choose. However, the focus is on gradual reduction, not on radical elimination. Furthermore, it remains unclear who will have the privilege to continue driving and flying. Lastly, fundamental changes in the organization of the global economic system and power hierarchies between the Global North and the South are not part of the Greenpeace scenario discourse.

3.1.2. Quantitative dimension

SSP1-19, SSP5-19, SSP5-Baseline

As has been pointed out in the analysis of the storylines, in the SSPs, 'development' is tightly linked to economic growth with different characteristics: 'green' or 'sustainable' in SSP1, 'fossil-fueled' or 'conventional' in SSP5.

Accordingly, in the quantification of the SSPs, 'development' is modelled through GDP growth. These economic growth rates in the different SSPs are calculated with three economic models although only one set of GDP projections – those of Dellink et al. (2017) - is used in the 'marker' quantifications of the scenario SSP1 and SSP5 ((cf. Kriegler et al., 2017; cf. Van Vuuren et al., 2017).

The authors of Dellink et al. (2017) belong to the OECD Environment Directorate based in Paris and use the OECD ENV-Growth model for their GDP projections.

The model is based on the following aggregate production function (leaving out the region and time dependent subscripts *r* and *t*):

$$Y = [((K)^{\alpha} \cdot (A \cdot h \cdot L)^{1-\alpha})^{\frac{\sigma_E - 1}{\sigma_E}} + a_E \cdot (\lambda^E \cdot E)^{\frac{\sigma_E - 1}{\sigma_E}}]^{\frac{\sigma_E}{\sigma_E - 1}} + VA^{NR} - P^E \cdot E$$

Interpreting this function leads to the following results: GDP is driven by: 1) physical capital K, 2) employment L, 3) human capital h (depends on education levels), 4) energy demand E (depends on energy efficiency and future oil prices), 5) the net value added through fossil fuel extraction (value added of fossil fuel extraction (VA) minus gains through selling the energy, and 6) technological progress (cf. Dellink et al., 2017). Technological progress is reflected in λ^E which is a parameter describing 'autonomous energy efficiency', and in A, which describes 'total factor productivity' (TFP)[3].

The change of A in time depends on various factors but in principle it allows countries to grow forever even if capital, energy and labor are hold constant. Certain features of 'A' are worth mentioning (A is specified in the article of Dellink et al. and not reproduced here): First, countries approach a so-called 'long-term TFP frontier' which shifts over time, enabling endless economic growth. Second, this long-term TFP frontier differs from country to country; this allows inequalities between countries to persist forever. Third, countries which are further away from their 'frontier' converge faster to their frontier, thus, they experience 'technological catch-up'. Fourth, regulatory barriers to market access and

[3] Since the 1970s, aggregate production functions have been exposed as having theoretical and empirical flaws, making their continued use all the more surprising. One weakness which also concerns the function used by Dellink et al. is the correspondence between technological progress and TFP, because TFP is merely a residual of the econometric adjustment to produce the development of GDP which can be *not* explained by the variables considered (in the case of Dellink, labor, capital, and energy demand), as well as measurement errors. For an in-depth discussion of all the problems related to aggregate production functions see Felipe and McCombie (2013).

competition will lower technological growth while trade openness will boost growth. Fifth, it seems that all these parameters can be empirically and scientifically determined.

From a Global South perspective this kind of modelling is problematic because it reproduces and strengthens the power hierarchy between the Global South and North: The model implies that 'developing' countries could be trapped in an endless 'catch up' process while never reaching the same wealth as the developed countries as those themselves follow the way of an exogenous, 'natural' development path whose end will never be reached. The Global South can accelerate its catch-up process by adopting once again a neoliberal development paradigm. This paradigm consists of improving 'human capital' through education, embracing market liberalization, praising competition and increasing free trade. Thus, the myth of some nebulous 'technological progress' serves to naturalize structural inequalities between countries and to reintroduce the neoliberal development tale through the backdoor.

The other two GDP projections for the SSPs are from the PIK (Potsdam Institute for Climate Impact Research) (Leimbach et al., 2017) and from IIASA (International Institute for Applied Systems Analysis) (Cuaresma, 2017).

Leimbach et al. (2017) use a neoclassical approach to economic growth modelling by drawing on the Solow growth model and the Cobb-Douglas-Function while incorporating human capital via a labor productivity factor. Due to the dominance of technological progress in the Solow model, the major part of economic growth is attributed to the growth of TFP. As in the case of Dellink et al., there is a race between advanced countries at the 'frontier' and developing countries trying to catch up.

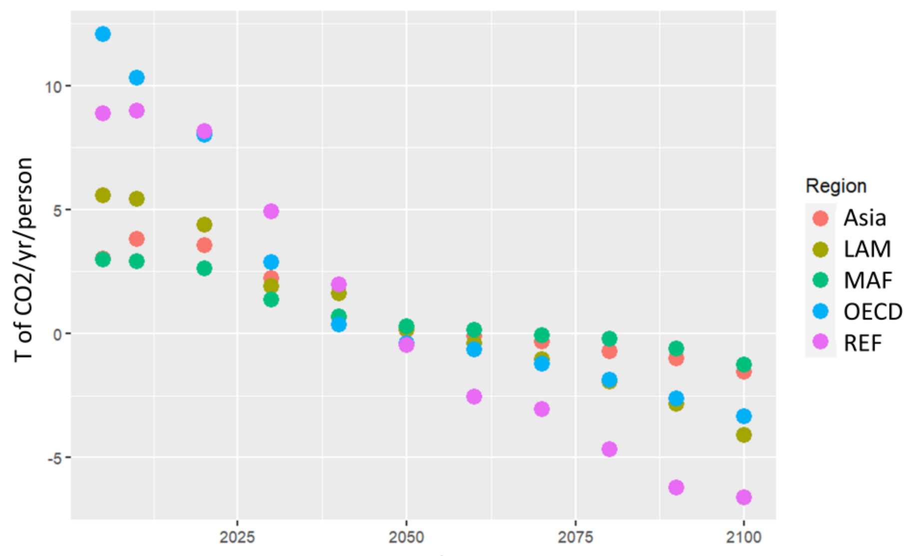
Like Leimbach et al, (2017), Cuaresma (2017) uses an economic growth function which depends on technological growth (TFP), the capital stock K and the labor L a certain population can deliver, which in this model depends on education and age. Technological progress depends on per capita income and can grow infinitely.

For example, in SSP1 the technology frontier growth is 0.35% and in SSP5 0.4% per year (Cuaresma, 2017).

Thus, all three models reduce development to technology driven economic growth. They present the evolution of economies as following a smooth development path which is predictable and explainable by recurring to the powerful discursive concept of technological progress. These models naturalize existing inequalities and neglect the colonial past and present which according to decolonial thinkers is a fundamental driver of inequality (cf. section 2.2.1). Because these models assume that the economy follows the same rules and is based on the same structures in every country, there is no space for economies and ways of life outside the framework of capital accumulation, labor productivity, technological 'progress' and constant growth toward a never reachable horizon.

This peculiar combination of sameness and structural inequality is also reflected in the model output of the SSPs. First, the five modelled regions in SSP1-19 (OECD, Reforming Economies (REF)[4], Middle East and Africa (MAF), Latin America (LAM), and Asia) are so 'same' that the Global South regions (Asia, LAM and MAF) do not even follow the 'Environmental Kuznet Curve' (EKC) which postulates an increase of environmental impacts, such as CO2 emissions, in the industrialization phase, followed by a decrease in CO2 emissions caused by technological progress and a shift to a service economy (Churchill et al., 2018). Instead, from 2010 onwards the Global South regions begin to reduce CO2 emissions (cf. Fig.1) while at the same time it is assumed that they experience high economic growth and an industrialization process.

Figure 1. Per capita CO2 emissions in the SSP1-19 scenario across world regions



Source*: Own elaboration based on data of the SSP Database (Riahi et al., 2017; Rogelj et al., 2018)*

Second, North-South economic inequality persists: Although GDP p.c. is strongly reduced in relative terms (in 2005 the MAF region has 12,2% of the p.c. income of the OECD region; in 2100 its p.c. income is 69,7% of the OECD p.c. income), at the end of the century, the OECD region is still richer than all other regions, and the MAF region is still the poorest. Furthermore, in absolute terms the income gap between the richest and the poorest region actually increases (in 2005 the difference in p.c. income of an OECD individual and a MAF individual is 26.388 $; in 2100 according to this scenario outcome it will be 29.926$) despite

[4] Comprising countries of Central Asia/Eurasia.

strong convergence processes (MAF's p.c. income raising from 12% to almost 70% of OECD's p.c. income).

The degree of GDP convergence and persisting inequality in income is illustrated in Fig.2 for the three SSP scenarios. The interested reader can find analogous analysis of the SSP5-Baseline and SSP5-19 with respect to CO2 emission reductions in Annex C.

Figure 2. GDP p.c. convergence across SSPs

Source*: Own elaboration based on data of the SSP Database (Riahi et al., 2017; Rogelj et al., 2018)*

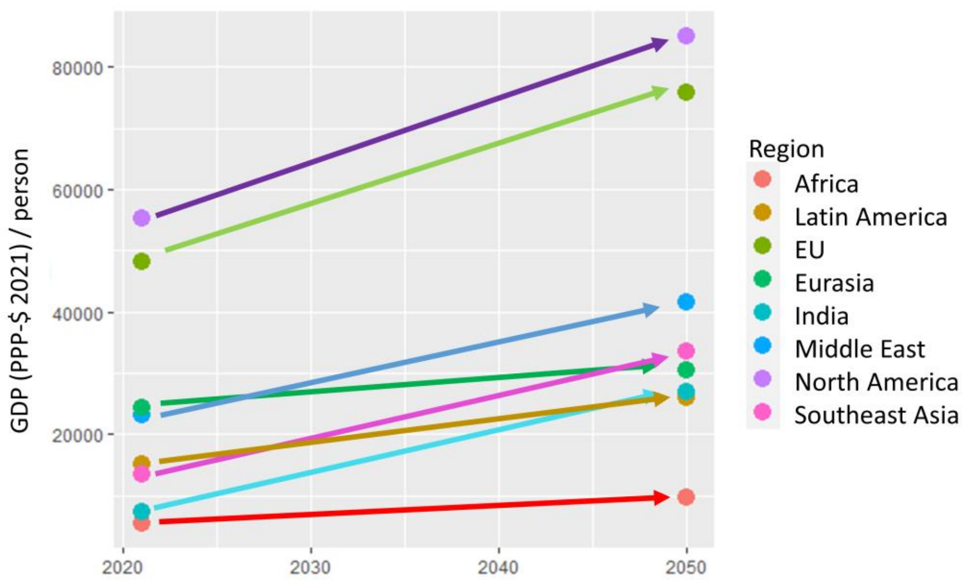
NZE

Like the SSPs, in the quantification of the NZE scenario, 'development' is reflected in GDP growth. In the NZE scenario, there is an exogenous GDP growth assumption for each region for the period between 2021 and 2050. As can be seen from Table B2 in Annex B, the growth rates are positive for all regions in all time periods (except for a negative growth rate of -1.1% for Russia between 2021 and 2030 which probably reflects the economic consequences of the war in Ukraine). The growth rates are generally higher in the Global South than in the Global North, which indicates convergence.

The IEA does not provide an explicit formula which shows how these growth rates are derived. Rather, it refers to the IMF (2022) and Oxford Economics (2022) for short-term and medium growth rates. For the long-term growth rates in each region of the GEC Model (North America, Central and South America, Europe, Africa, Middle East, Eurasia and Asia Pacific) it is assumed that they will converge to a certain long-term value. This value depends on demographic factors, the productivity of the regions, certain 'macroeconomic conditions' and the velocity of 'technological change'. Neither 'macroeconomic conditions' nor 'technological change' are described in more concrete terms (cf. IEA, 2022a). However, from this information we can deduce that the drivers of growth are the same as in the case of the SSPs: the availability of labor (as consequence of demographic developments), physical and human capital (which is reflected in the productivity of a region), trade openness and liberalized markets (which favorably influence macroeconomic conditions), and TFP (technological progress). Also, the discourse employed by the IEA suggests that economic growth has similarities with a natural phenomenon which converges naturally to a hypothetical long-term value.

The logic of 'inequality despite sameness' with regard to 'development' can also applied to the NZE scenario: The countries are the same because they all follow the same unique development path towards higher GDP, lower costs for energy, higher efficiency and bigger markets. At the same time, inequality in p.c. income between Global North and Global South persists, as is also shown in Fig.3: Although all regions grow richer, the richest remain the richest, and the poorest remain the poorest.

Figure 3. GDP p.c. convergence in the NZE scenario

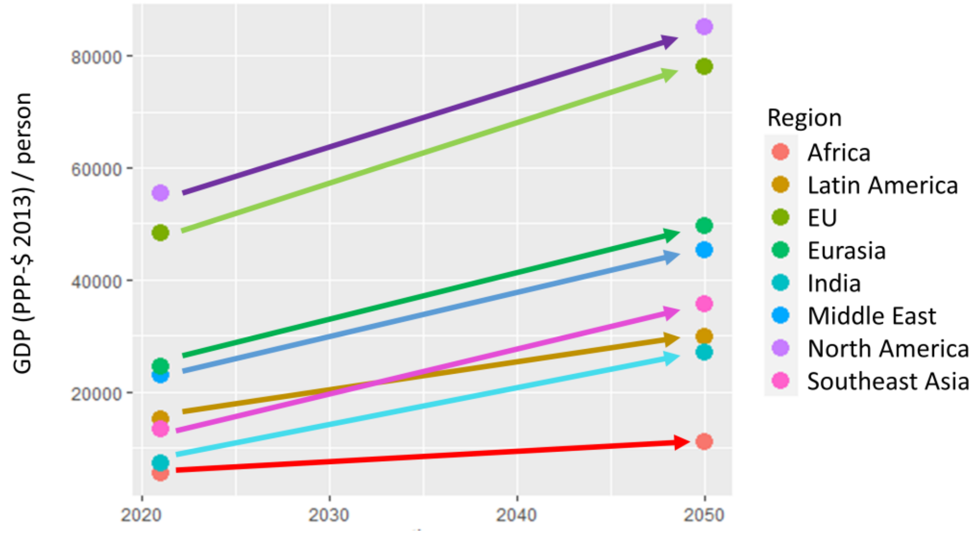


Source*: Own elaboration based on data of the IEA (IEA, 2022b).*

Adv E[R]

For its quantitative analysis, the Adv E[R] scenario draws on the GDP growth assumptions of the IEA. Thus, everything that has been written in the previous paragraphs is equally valid for the Adv E[R] scenario. 'Development' in this scenario is modelled as green growth and is the same everywhere in the world: GDP grows, energy intensity declines. Despite this homogeneous conception of 'development', inequalities in p.c. income persist (Fig.4).

Figure 4. GDP p.c. convergence in the Adv E[R] scenario



Source*: Own elaboration based on data of Greenpeace (Teske et al., 2015)*

If we compare the results of this analysis with the theoretical framework, we see that the conception of development in all five scenarios is barely compatible with a decolonial view on 'development'. First, despite economic growth, the economic hierarchy between Global North and South persists. There is a lack of fundamental changes in the organization of the socio-economic world system in all scenarios, which could address land appropriation by the Global North, equilibrate material and energy flows or end the exploitation of cheap labor in the South. Instead, the scenarios implicitly assume that more 'development', i.e. more growth, consumption and technology, will solve the South-North problems automatically. Second, the scenarios actively construct different subjectivities which have a hierarchical relation, with the 'developed/advanced' nations leading and the 'developing/poorer' nations following. Third, by modernizing, following and assimilating Global North paradigms, the Global South in the scenarios does exactly what would be questioned from the perspective of the coloniality of knowledge.

3.2. Impact analysis

Having analyzed which kind of 'development' the scenarios suggest for the Global South through the discourse embodied in storylines and models, I now turn to the likely impacts on the Global South, should reality unfold in a similar way as these scenarios project. These impacts are ignored in the storylines and quantification because, as has been shown, they focus on the reality of life and challenges of the Global North. Furthermore, the economic models used for the quantification concentrate on monetary flows, regulated through prices, instead of on biophysical material and energy flows. Even when considering the biophysical dimension, the models employ optimistic assumptions based on future energy and material efficiency gains and optimal institutional settings (cf. Bluwstein & Cavanagh, 2023). However, in reality, especially in the Global South, there are no optimal institutions; corruption, for example, can reduce energy efficiency and increase the ecological footprint of states (cf. Yao et al., 2021). Moreover, factors which likely increase energy and material efficiency (such as learning or financial incentives) have to be counterbalanced with factors that tend to decrease these gains (such as decreasing ore grades, thermodynamic limits, inevitable climate change impacts (even with a 1.5°C temperature increase), and rebound effects). As the Global South perspective adopted for this work especially considers the well-being of vulnerable and historically oppressed population groups in the geographical Southern hemisphere, the precautionary principle will be consistently applied when analyzing the impacts of certain scenarios. The reason is that when optimistic assumptions do not become truth, the vulnerable social groups are the ones which have the least possibilities to adapt, and suffer most.

In the following, I will conduct an impact analysis based on the precautionary principle, and with a focus on indigenous people, peasants, local communities and precarious workers, which will consider the following aspects: (i) the climate change impact of the scenario; (ii) the mining impacts of the scenarios; (iii) the impact of the proposed amounts of bioenergy and (iv) the impacts of hydroelectricity. In line with the precautionary principle I will also discuss the consequences of a possible overestimation of the potential of renewable energy sources (RES) in the scenarios for energy poverty in the South. Two further risks (nuclear energy and Carbon Capture and Storage (CCS) assumptions of the scenarios) are explained in Annex D.

3.2.1. Climate change

None of the selected scenarios incorporates the impacts of climate change on societies and economies. Thus, they leave out an important part of the future reality. Furthermore, by only focusing on mean global temperature rise, the scenarios neglect that global warming impacts will be much stronger in the Global South than in the Global North (Gunaratne et al., 2021; Hagen et al., 2022; Kemp et al., 2022).

SSP1-19, SSP5-19 and NZE are scenarios designed to meet the 1.5°C goal. The Adv E[R] does not give an exact temperature increase as its focus is the energy system. However, it states that the scenario is compatible with a global mean temperature increase between 1.5°C and 2 °C. Climate change is already a reality and even meeting the 1.5°C target would entail significant impacts (IPCC, 2022). The 1.5°C goal is crucial to have a chance to avoid triggering 'tipping points' in the climate system: 9 of the 15 known climate tipping elements already have shown signs of instability and there are moderate risks even at an increase of 1.5 to 2.0 °C for some systems such as the Greenland and West Antarctic ice sheets (Wunderling et al., 2022). The peril of tipping points is that they could cause a run-away climate change which shifts the Earth toward another phase state, potentially incompatible with human civilizations or even human life, due to massive biodiversity and ecosystem function loss (Kemp et al., 2022; Lenton et al., 2019; Rockström et al., 2009). Furthermore, there is a significant probability that the emission pathways outlined in the 1.5°C scenarios will lead to warming above 1.5 °C. For example, the IEA states that the probability of reaching 1.5°C in 2100 in the NZE scenario is only 50% (IEA, 2022b). Nevertheless, the impacts and risks of a 1.5°C are generally considered to be manageable (IPCC, 2022).

The 'transition' scenarios contrast starkly with the SSP5-Baseline scenario which leads to a projected increase in global mean temperature of over 5°C in 2100. The CO2 ppm value of SSP5 in 2100 is 1089 which indicates that the temperature could increase well beyond 5°C. For example, already at concentrations of 700 ppm there is a 10% chance of reaching a temperature increase of 6 °C (Jehn et al., 2021). The potentially catastrophic impacts of such drastic temperature rises are underexplored in the scientific literature (Kemp et al., 2022). However, the existing studies which deal with temperature increases of 4°C and beyond draw a dismal picture of the future, especially for vulnerable social groups in the Global South. For example, already at a temperature increase of 2.6 °C, Central and South America will face severe levels of risks regarding food insecurity, water scarcity, epidemics of vector-borne diseases, risks related to sea level rise, storm surges and erosion, floods and landslides, coral bleaching and an Amazon Forest biome shift, as well as the risk of systemic failure due to cascading negative impacts (Hagen et al., 2022). Moreover, the authors highlight that indigenous peoples, Afro-Latin Americans, women, disabled people and migrants are especially threatened (ibid.). Warming of +4°C could cause farming systems in Sub-Saharan Africa to collapse and cause massive migration in South-East Asia due to sea level rise and flooding (New et al., 2011). Also, it could cause heat extremes covering up to 80% of the land surface in North Africa, the Middle East, Latin America and the Caribbean, severely reduce crop yields and increase water scarcity (cf. Busck & Schmidt, 2020; Kemp et al., 2022). A realization of the SSP5-Baseline scenario would make the region around the Arabian Gulf uninhabitable for humans due to extreme temperature that cannot be tolerated by the human body (Pal & Eltahir, 2016).

Thus, although climate change belongs to the realm of deep uncertainty (Kemp et al., 2022), it can be concluded that a scenario like SSP5-Baseline would likely be catastrophic for humanity as a whole but certainly deadly for the poorest and most vulnerable people living in the Global South.

3.2.2. Mining

The energy demanded in the five selected scenarios needs considerable mining activities: In the case of SSP5-Baseline, the continuous extraction of fossil fuels requires a never ending search for fossil sources which will be increasingly more difficult to access and create devastating ecological and social impacts (for example, fracking, unconventional oil, oil explorations in the Arctic or Deep Sea…) (cf. Gulas et al., 2017). The other scenarios require a range of different minerals in order to build the renewable energy infrastructure. Given that the disastrous impacts of fossil fuel extraction on local communities is widely acknowledged (Healy et al., 2019), I will put the focus on the mining issues related to renewable energy technologies.

Mining activities systematically cause EDCs because of their negative social and ecological impacts (Temper et al., 2020). Poor communities, peasants, fishers and indigenous people are most frequently affected (Gukurume & Tombindo, 2023; Saade Hazin, 2013). Fossil fuel projects and mining projects for renewable energy do not significantly differ in their conflict potential: Coal mining, oil and gas extraction, and the mining of 'energy transition minerals' (Owen et al., 2022) cause the same problems, namely, biodiversity loss, loss of land and livelihood, health impacts caused by pollution, human rights violations, displacement and dispossession (Temper et al., 2020). One example is the extraction of Tin, Rare Earths, Lithium and Cobalt, which has fueled child labor, poor working conditions, corruption and violence (Huber & Steininger, 2022). As significant reserves of key minerals for renewables belong to fragile states dealing with corruption issues and located in South America, sub-Saharan Africa and Southeast Asia, growing mineral extraction already have aggravated and likely will further intensify fragility, conflicts and violence in the Global South (Church & Crawford, 2018). Even in more stable environments, resistance to extraction projects are often met with violence, and vulnerable population groups face evictions and displacements (Gukurume & Tombindo, 2023; Saade Hazin, 2013; Temper et al., 2020). Furthermore, mining activities produce 'slow violence', i.e. it poisons and degrades the environment and thereby slowly kills the affected populations (cf. Le Billon & Middeldorp, 2021; Scheidel et al., 2020). The mining of energy transition minerals constitutes a serious threat to biodiversity (Sonter et al., 2020) which directly affects indigenous populations relying on local ecosystems (Diele-Viegas & Rocha, 2020). Also, an analysis of more than 5000 current and likely future mining projects which extract energy transition minerals finds that more than half of these projects are located on or near Indigenous and peasant land (Owen et al., 2022).

Because impacts increase with the scale of mining activities, those scenarios which have the lowest overall energy demand (Adv E[R], NZE and SSP1-19) will produce the least impacts on the Global South while the amounts of final energy proposed by SSP5-19 and SSP5-Baseline will probably cause an explosion of mining-related EDCs (cf. Table 2). However, already realizing the low energy scenarios would imply infringing on biodiversity areas as well as peasant and indigenous land.

3.2.3. Bioenergy

Bioenergy, understood here as electricity from biomass as well as (first, second and third generation) biofuels, is associated to a high number of often violent EDCs (Temper et al., 2020), driven by negative social and ecological impacts for peasants, indigenous people and local communities in the Global South:

Among the ecological impacts are land use change, biodiversity loss (especially in the tropics and in the African Savannas), soil degradation, acidification and eutrophication caused by the massive employment of fertilizers and pesticides (Correa et al., 2019; Creutzig et al., 2021; Gomiero, 2018; Webb & Coates, 2012).

The social dimension of bioenergy includes land use conflicts and the loss of livelihoods as well as food and freshwater scarcity (Gonzalez, 2016; Malkamäki et al., 2018; Overbeek et al., 2012). Bioenergy has increase and will further increase land grabbing, affecting especially marginal indigenous communities or ethnic minorities (Abate & Kronk, 2013; Busck & Schmidt, 2020). This land grabbing is legitimized through the myth of empty or marginal land, which drives dispossession dynamics in many regions of the Global South (Busck & Schmidt, 2020; Corbera et al., 2017; Creutzig et al., 2021). Also, there is a lack of local community involvement in planned bioenergy projects (Overbeek et al., 2012; Temper et al., 2020)

Furthermore, the EROI (Energy Return on Energy Invested) of biofuels and electricity is very low, especially compared to other energy technologies (Chiriboga et al., 2020; Gasparatos et al., 2012; Giampietro et al., 2006; Hall et al., 2014; Ketzer et al., 2018; Raugei & Leccisi, 2016; Wang et al., 2021). Estimates for the global level even suggest that the EROI of biofuels is so low that they are a net energy sink (De Castro et al., 2014; del Castillo-Mussot et al., 2016) and that their ecological footprint is at least a big as that of fossil fuels (De Castro et al., 2014).

Thus, bioenergy might help to avoid crossing dangerous thresholds with regard to one planetary boundary - climate change - but at the same time might push the Earth system beyond dangerous thresholds in the area of biodiversity loss and biogeochemical cycles (Rockström et al., 2009; Steffen et al., 2015).

Taking into account the ecological and social impacts in the Global South and the poor energy performance of bioenergy technologies, it can be argued that electric and liquid bioenergy poses a threat to sustainability and should be avoided. This conclusion starkly contrasts with proposed biomass generated electricity and biofuels quantities in the analyzed scenarios which range from 19 EJ in the Adv E[R] scenario to 137 EJ (+ 50 EJ hydrogen produced by biomass energy) in the SSP5-19 scenario.

3.2.4. Hydroelectricity

Hydroelectricity has been linked to various ecological distribution conflicts in the Global South because of the negative ecological and social impacts of hydropower infrastructure.

Among the negative ecological impacts of hydropower infrastructure in the South the literature frequently finds: losses of agricultural land and forests, impeded fish migration, changes in waterflow, nutrients and sediments, and the degradation of aquatic ecosystems (Begossi et al., 2018; Martínez & Castillo, 2016; Wild et al., 2019).

These ecological impacts might lead to livelihood losses of farmers and fishers (Delang et al., 2013; Morton & Olson, 2018). Furthermore, displacement of people as well as lack of participation and compensation are common problems (Doria et al., 2018; Martínez & Castillo, 2016; Mayer et al., 2022; Suhardiman & Rigg, 2021). Also, hydropower infrastructure has been linked to dispossession of indigenous people (Abate & Kronk, 2013; Kelly, 2021).

The literature finds that even small hydropower projects and run-of-river hydropower plants, which are considered to be more benign compared to big dams, have had negative socio-ecological impacts on local communities and ecosystems, including water quality and habitat deterioration, groundwater depth reduction, river flood alteration and loss of fertile land (Kuriqi et al., 2021; Ullah et al., 2023).

Despite these negative impacts, hydropower is considered to be a relatively environmentally friendly technology. However, as hydropower-related conflicts will spread and intensify in a non-linear way if hydropower is scaled up beyond ecological limits, it is important to consider limits to its expansion. In this work, in order to minimize possible EDCs, one of the more conservative estimates of sustainable hydropower deployment is used which considers a maximum hydropower potential of 30 EJ final energy/year (De Castro, 2023). As a caveat, it has to be mentioned that the study does not directly considers social limits and conflicts. However, constraining hydropower to the most suitable places will reduce ecological impacts and consequently, also social impacts.

Only in the Adv E[R], the SSP1-19 and the NZE scenario the quantity of hydropower electricity use respects this techno-sustainable limit of 30 EJ/year (cf. Table 2). As this quantity is about 2.5 times greater than the current amounts of hydroelectricity even meeting this limits will increase EDCs in the South. However, compared to SSP5-19 (48 EJ) and SSP5-Baseline (36 EJ) the former three scenarios are clearly less problematic for the Global South.

3.2.5. Overestimation of RES potential

The final energy use at the end of the 'transition' scenarios (SSP1-19, SSP5-19, NZE, Adv E[R]) is lower than in baseline scenarios such as SSP5-Baseline. Furthermore, energy use in the models is linked to GDP. Consequently, as the inequalities in p.c. income between Global South and North persist (cf. section 3.1.2), there is also inequality in energy access.

The final energy use in transition scenarios is low because otherwise it would be impossible to meet the 1.5 °C target. Unfortunately, even this low final energy use might be higher than the amount of renewable energy the Earth can sustainably provide without aggravating other environmental issues such as biodiversity loss or biogeochemical cycles (cf. Rockström et al., 2009; Steffen et al., 2015). In the literature, concerns have been raised about the low EROI of the electricity and fuel produced by renewable sources and about inflated estimates of renewable energy potentials (De Castro, 2023; Moriarty & Honnery, 2019). Falling EROIs for fossil fuels, low EROIs for many renewable electricity and fuel technologies, energy storage requirements, mineral and land restraints, biodiversity conservation requirements and climate change impacts are listed as factors that will reduce the amount of final energy available for society (Capellán-Pérez et al., 2020; Moriarty & Honnery, 2016; Pulido-Sánchez et al., 2022). Following the precautionary principle these concerns regarding a possible overestimation of RES potential which can be sustainably achieved in reality should be considered because if they are justified, society will have less energy available than projected by the scenarios. As in the current economic system money decides who gets scarce resources, the richer Global North would secure access to a disproportionate part of the available energy. This would sharpen the inequality in energy access already embodied in the scenarios and increase the risk of energy poverty in the Global South.

Table E1 in Annex E analyzes the proposed energy mix and the quantities of renewable energy in the five selected scenarios. It also shows which quantity of renewable energy would be available in the scenarios, if estimates of sustainable renewable potential based on the precautionary principle were taken into consideration. For the 'correction' of the energy available in a given scenario I use the article of De Castro (De Castro, 2023) which estimates EROI values and the potential of renewable sources considering technical and sustainability limits. Energy technologies with a final EROI of < 2.5:1 are considered to have a potential of 0 EJ because their extended EROI is likely to be <1:1, i.e. they constitute energy sinks instead of sources (cf. Capellán-Pérez et al., 2019; De Castro & Capellán-Pérez, 2018). This 'correction' produces the following results (for details see Table E1).

Table 1. Final energy, taking into account low EROI values and techno-sustainable potentials of RES

Scenario name	Projected Final energy (EJ/y)	Corrected final energy (EJ/y)
SSP1-19	356	243
SSP5-19	809	260
SSP5-Baseline (*)	1167	1115
NZE	337	200
ADV E[R]	279	146

Source: ***Own elaboration.***

(*) As this scenario is mostly fossil fuel based (951 of 1167 EJ are produced by fossil fuels), it is not as affected by overestimation of RES as the others. Possible overestimations of fossil fuel availability are not addressed here.

Table 1 reflects an energy dilemma: On the one hand, the final energy available in RES based scenarios is much lower than the amount of energy currently consumed by the economy. This increases the risk of energy poverty for the poorest as in the current economic system scarcity issues are solved by allocating the good to the person willing to pay most for it. Since in the scenarios there is income inequality between South and North and no specific assumptions about redistribution measures within countries, vulnerable social groups of the South would likely face high risks of energy poverty if any of the transition scenarios would be realized without changing the economic system and the developments described in the scenario storylines. Arguably, the higher the overestimation, the higher are the energy poverty risks if society suddenly faces an energy shortage which was not foreseen by the scenario and for which it provides no adaptation measures.

On the other hand, if the amount of energy available to society would be increased above the techno-sustainable potentials shown in Table 1, this would likely increase even more the negative impacts (climate change, land degradation…) on vulnerable social groups in the Global South described in the previous section.

3.2.6. Summary

Table 2 synthesizes the analysis just conducted. It can be interpreted as an overall evaluation of the degree to which GES consider the livelihoods and well-being of vulnerable people in the Global South. The evaluation is expressed through colors: Green means that the impacts are low and that communities will likely be able to cope with them; yellow means that there is a medium impact which negatively affects the livelihoods and well-being of vulnerable groups; red indicates that the impacts are elevated and potentially catastrophic for the affected groups. In the case of mining, due to the lack of studies which compare the impacts of mining for fossil fuels and for renewables, the fossil fuel-based SSP5-Baseline scenario is ignored (grey color) and only the RES scenarios are compared. Since the RES mix of these scenarios does not differ significantly, scenarios with a greater amount of final energy are assumed to result in more mining activities, and thus, greater damage.[5]

Table 2. Summary of the impact analysis.

Threats	**SSP1-19**	**SSP5-19**	**SSP5-Baseline**	**NZE**	**Adv E[R]**	criterion/ threshold
Climate change	1.345 °C (max:1.558 °C in 2040)	1.374 °C (max: 1.810 °C in 2050	5.052 °C (=max in 2100)	1.4 °C (max: 1.6 °C in 2040)	1.5 - 2 °C (no details)	global mean temp. increase
Mining	Mining required to produce 356 EJ of energy (mainly from RES)	Mining required to produce 809 EJ of energy (mainly from RES)	Mining required to produce 1167 EJ of energy (mainly from fossil fuels)	Mining required to produce 337 EJ of energy (mainly from RES)	Mining required to produce 279 EJ of energy (mainly from RES)	no known threshold; best case: no extrac-tive activities
Modern Bioenergy	18 EJ (biomass-el) + 28 EJ (biofuels)+ 67 EJ hydrogen from biomass	34 EJ (biomass-el) + 103 EJ biofuels+ 50 EJ hydrogen from biomass	12 EJ (biomass-el) + 18 EJ biofuels	74 EJ (solid heat) + 15 EJ (gas) + 12 EJ (fuel)	11 EJ (biomass-el) + 30 EJ (biomass-heat) + 8 EJ (biofuels)	0 EJ
Hydro-electricity	22 EJ	48 EJ	36 EJ	30	18 EJ	30 EJ
Over-estimation	356 EJ/243 EJ = 1.47	809 EJ/ 260 EJ = 3.11	1167 EJ /1115 EJ =1.05	337 EJ / 200 EJ = 1.69	279 EJ / 146 EJ =1.91	projected final energy / corrected Final Energy

Source: ***Own elaboration.***

From this table, the following outcome of the impact analysis can be drawn:

Analyzing the table in a horizontal manner reveals that the scenarios have the least negative impacts for the Global South in the categories 'climate change' and 'hydroelectricity' whereas 'bioenergy' and 'mining' seem to be neglected by all scenarios.

Reading the table in a vertical manner allows comparing the overall performance of the five selected scenarios. It is obvious that each scenario has its weaknesses and problematic impacts on vulnerable Global South populations, should the trajectory of the world's energy system follow what is narrated in the scenarios (cf. also Table D1 in the Annex which shows a summary for the risk of nuclear energy and carbon capture and storage). SSP5-Baseline projects catastrophic climate change which suffices to exclude the viability of this scenario.

[5] This is a simplistic assumption which should be critically examined in future research.

SSP5-19 achieves the 1.5°C with a slight overshoot but at the cost of performing badly in all the other impact categories. The SSP1-19 and the NZE scenario perform somewhat better than the SSP5 scenario variants but the table reveals that also they produce negative impacts for the Global South.

Also, all scenarios except from SSP5-Baseline overestimate considerably the renewable energy potential likely to be available if accounting for mineral, biodiversity and technical constraints and following the precautionary principle. In the case of the Adv E[R], which performs best in the impact analysis, the high degree of overestimation of RES potentials is especially problematic because the original amount of projected energy use in this scenario is already low. Given the unequal distribution of energy, this would likely cause severe energy poverty, should the scenario be realized.

Thus, as all scenarios continue the current pattern of shifting costs to the Global South, EDCs can be expected to rise and to increase in intensity in each of the selected scenarios.

4. CONCLUSION

Having realized an extensive analysis of the five selected global environmental scenarios, it is now possible to answer the two research questions formulated in the introduction of this work: The conception of 'development' in all selected scenarios reflects a Western, neoclassical and neoliberal understandings of development. This kind of development claims to be universal, natural and basically the same for the whole world, and consists of economic growth and technological progress. At the same time, this kind of development reinforces the current politico-economic global order with its North-South hierarchies. Therefore, is incompatible with decolonial theory which contests abstract universals, demands the end of the North-South/developed-developing binary and seeks the liberation and emancipation of marginalized social groups.

Second, if the imagined futures of the selected scenarios would be realized, the impacts on vulnerable population of the Global South would likely be severe in all scenarios, and cause new waves of intensified ecological distribution conflicts.

The analysis has shown that (1) global environmental scenarios systematically neglect future risks and negative impacts for marginalized populations of the Global South, that (2) they are focused on the privileges of the Global North and that (3) they accept social and environmental damage in the Global South to secure a 'sustainability transition'. All this is highly problematic from the perspective of decolonial theory and the study of EDCs.

This work, by combining insights from the natural and critical social sciences, has made a first effort to evaluate GES from a Global South perspective. It has revealed that widely used

GES are biased toward the Global North and harmful for many social groups in the Global South. Nevertheless, this work does not only offer a critique of GES but also wants to inspire readers with a background in development cooperation to ask themselves such uncomfortable questions like: What can be the role of development cooperation in possible futures with increased and intensified EDCs? Which development paradigm does the daily work of development cooperation serve? What does the connection between lack of participation and EDCs in the South mean for development cooperation? And lastly, does development cooperation reproduce or challenge systemic inequalities and injustice between the North and the South?

Despite the detailed analysis, this study has left many issues unaddressed: The impact analysis did not consider all possible and relevant impacts such as for example the toxicity problems generated by different energy technologies. Also, the GDP-energy combinations and resulting energy intensity levels in the different scenarios were not questioned. Last, as this work only focused on five scenarios it is not possible to make generalized statements about GES.

Consequently, future research could build on this work in the following ways: First, researchers could consider a greater number of scenarios and/or include other theories grounded in the Global South. Second, studies could analyze the energy efficiency gains embedded in the scenarios and find out whether they violate concrete thermodynamic limits. In this way, it might be possible to prove the biophysical impossibility of some scenarios. Lastly, research could explore how the institutional context influences scenarios, and what would be needed to integrate Global South perspectives in scenario development.

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6. ANNEX

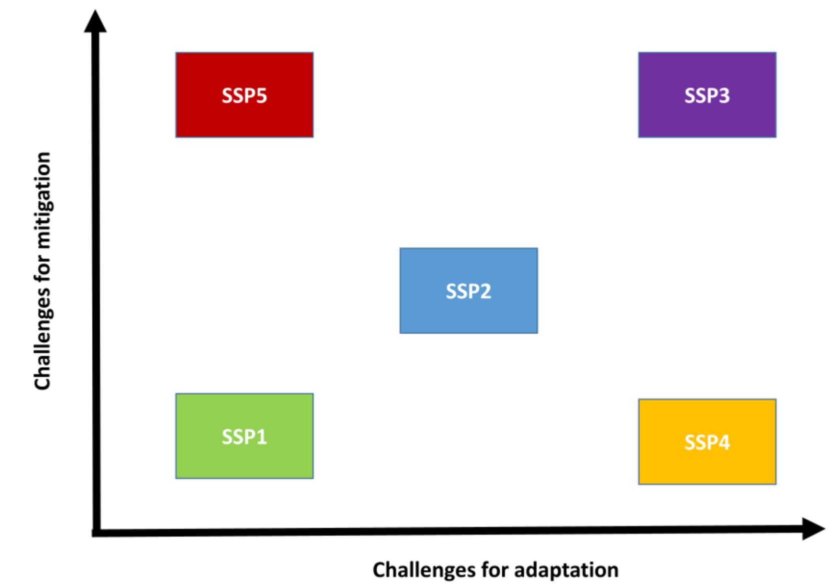
A. Explanatory information for the selected scenarios

The first three scenarios belong to a scenario family called "Shared Socioeconomic Pathways" (SSPs) (O'Neill et al., 2017). They were developed by the climate change research community in order to analyze future climate mitigation and adaptation (Riahi et al., 2017), and are used by the IPCC in its assessment reports (IPCC, 2021).

There are five SSPs which describe different developments of the world throughout the century without considering climate policies. As the name already indicates, the focus is on socio-economic development (O'Neill et al., 2017). Each scenario consists of a narrative (the storyline) and various quantifications of this narrative through integrated assessment models (IAMs). However, for each scenario a certain IAM has been selected to provide the 'marker quantification' of the respective scenario (Calvin et al., 2017; Fricko et al., 2017; Fujimori et al., 2017; Kriegler et al., 2017; Van Vuuren et al., 2017). In this work, for the analysis of the SSP quantifications, these marker quantifications are used. Furthermore, the narratives exist in compact and extended form (cf. the supplementary material in O'Neill et al., 2017). In order to process the greatest amount of information available, for the analysis of the storylines, I draw on the extended versions of the SSPs.

The five narratives describe different 'roads' to the future, and thus, are called "SSP1: Sustainability – Taking the green road", "SSP2: Middle of the road", "SSP3: Regional rivalry – a rocky road", "SSP4: Inequality – a road divided" and "SSP5: Fossil-fueled development – taking the highway". The different SSPs result in different challenges for mitigation and adaptation (see Fig. A1): SSP1 has low challenges for mitigation and adaptation, SSP3 has high challenges for both mitigation and adaptation, SSP4 entails low challenges for mitigation but high challenges for adaptation due to increased inequality, SSP5 means low challenges to adaptation but high challenges to mitigation, and lastly, SSP2 has medium challenges to both mitigation and adaptation.

Figure A1. The five SSPs and their relation to mitigation and adaptation



Source*: Adapted from O'Neill et al.* (2017)

The SSPs are an integral part of the so-called scenario matrix architecture which constitutes the latest development in IPCC climate scenarios: This scenario matrix architecture replaced the scenarios developed for the IPCC Special Report on Emission Scenarios (Nakicenovic et al., 2000) and integrates the Representative Concentration Pathways (RCPs) which were used in previous IPCC reports (IPCC, 2014). RCPs describe emission pathways which result in determined forcing levels (measured in W/m^2) at the end of the century which correspond to a certain increase in the global mean temperature (Kriegler et al., 2014). To form a full-fledged climate scenario, a certain SSP is combined with an RCP goal (2.6, 3.4, 4.5, 6.0, 8.5) and with SPAs (shared policy assumptions) which reflect the climate policies necessary to reach the RCP targets within a certain SSP (ibid.) It is not possible to reach all RCPs in every SSPs, i.e. some SSP-RCP combinations are not possible (ibid.). Furthermore, if no climate policies are applied, there is no RCP goal and no SPAs. In this case, the scenario is called SSP-x-Baseline. In order to reach the 1.5 °C climate target, a further climate forcing category was added: 1.9 W/m^2.

From the different SSP-RCP combinations I chose SSP1-19 as an example of a 'sustainable transition' scenario: SSP1 is a world with high levels of international cooperation, an emphasis on sustainable development and slower population growth. Thus, from the five SSPs it is the one which best fits the 1.9 W/m^2 RCP target. A second SSP-RCP combination which also achieves the 1.5°C degree goal is SSP5-19. As the SSP5 narrative postulates that the world economy will heavily rely on fossil fuels to maintain its metabolism, it requires more aggressive climate mitigation policies to deal with the emissions produced through burning fossil fuels. This scenario, which we could call 'fossil fueled transition' is contrasted with the baseline scenario of SSP5 in which no climate policy is adopted.

The Net Zero Emissions by 2050 (NZE) Scenario was developed by the International Energy Agency (IEA) and is one of three scenarios this agency uses in its World Energy Outlook 2022. While the other two scenarios – the Announced Pledges Scenarios (APS) and the Stated Policies Scenario (STEPS) - are exploratory scenarios, the NZE scenario is a normative, back-casting scenario (IEA, 2022b). This means that in contrast to the APS and STEPS scenario in which the future of the energy system is explored given a set of starting conditions and parameters, in the NZE scenarios a desired end state is defined and the necessary measures to reach this end state are identified (cf. Van Vuuren et al., 2012). The goal of the NZE scenario is to decarbonize the energy sector until 2050 in order to meet the 1.5°C goal.

The last scenario selected is the Advanced Energy [R]evolution (Adv E[R]) scenario presented by Greenpeace in its 'Energy Revolution' report 2015. According to Greenpeace, this report aims to provide an alternative view of the IEA's World Energy Outlooks (Teske et al., 2015). Thus, unsurprisingly, the Adv E[R] scenario has many parallels with the NZE scenario: It is also a back-casting scenario which projects a decarbonized energy system in 2050. However, in contrast to the NZE scenario it is a 100% renewable energy scenario with zero fossil fuel energy inputs.

Thus, I analyze four transition scenarios which propose different strategies to achieve the 1.5°C climate goal, and in contrast, one scenario without climate policies and without changes in the current energy system.

B. IEA related tables

Table B1: A possible Global South perspective on behavior changes suggested in the NZE scenario	
Behavior change measure	**Global South perspective**
consume less, recycle more	for the poorest people, consuming less is not an option; often there are already high recycling rates, due to the reliance on organic material and the scarcity of non-renewable material
drive less or in a more fuel-efficient manner, e.g. more slowly	this measure assumes that people own high-speed vehicles which is not the norm for 'Global South' populations
congestion charging, speed limit reductions, high-speed rail networks; speed limits on motorways to 100 kilometers per hour and eco-driving	this measure assumes that there is an infrastructure supporting high-speed transport, with all the material and energy requirements building and maintaining this infrastructure entails – this infrastructure does not (yet) exist in poor countries of the Global South
behavioral change encouraged by information and awareness campaigns (e.g. product labelling, home energy consumption reports)	what is with people who do not acquire goods through formal markets and who live in states without functioning tax systems and effectively functioning administrations?
home office, 50% reduction in business-related long-haul trips (teleconferencing or high-speed rail for regional flights)	this measure assumes that there is high-tech Internet, electricity, and transport infrastructure, with all the material and energy requirements building and maintaining this infrastructure entails
increased carpooling, discourage car use, discourage ownership of SUVs by banning them from the city centers, frequent flyer levies	the sharing of vehicles is already a reality in the Global South; this kind of measures could increase perceived inequality as only the richest will afford to continue flying and using cars
Source: ***Own elaboration based on IEA, 2022b.***	

Table B2: Projected growth rates across world regions			
Region	**2021-2030**	**2030-2050**	**2021-2050**
North America	2,0%	2,0%	2,0%
US	2,0%	2,0%	2,0%
Central and South America	2,4%	2,4%	2,4%
Brazil	1,8%	2,5%	2,3%
Europe	2,0%	1,4%	1,6%
EU	1,9%	1,2%	1,4%
Africa	4,1%	4,2%	4,1%
Middle East	3,2%	3,2%	3,2%
Eurasia	0,1%	1,4%	1,0%
Russia	-1,1%	0,7%	0,1%
Asia Pacific	4,7%	3,1%	3,6%
China	4,7%	2,8%	3,4%
India	7,2%	4,4%	5,2%
Southeast Asia	5,0%	3,3%	3,8%
World	3,3%	2,6%	2,8%
Source: *Own elaboration. Based on "GECM_2022_Key_inputs.xlsx" downloadable at https://www.iea.org/data-and-statistics/data-product/global-energy-and-climate-model-2022-key-input-data*			

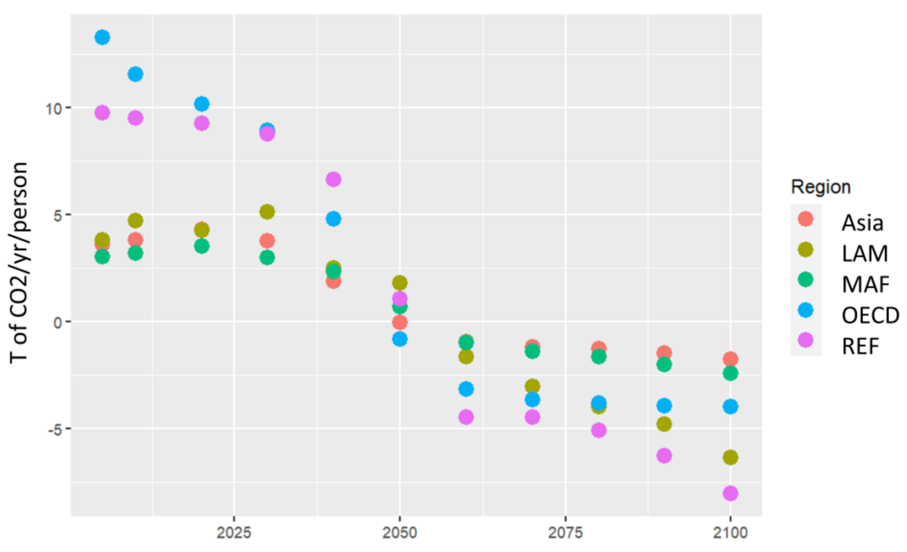
C. Sameness and inequality reflected in the CO2 Emission Reductions for SSP5-19 and SSP5-Baseline

SSP5-19

In the case of SSP5-19 the regions follow broadly an EKC as there are temporal differences regarding the p.c. CO2 emission reductions: The OECD and REF regions reduce their emissions starting in 2005, MAF and ASIA start 15 years later in 2020, and LAM starts in 2030. Nevertheless, the Global South never reaches the p.c. emission levels the Global North produced during its industrialization process nor the emission levels of the currently existing 'service' economies. For example, the highest projected p.c. CO2 emissions of LAM are 5.1 tons of CO2 per year (in 2030), while the OECD in 2005 emitted more than 13 tons of CO2 p.c. The maximum emission levels reached in ASIA and LAM are 4.3 tons of CO2 per year in 2020, while the OECD in 2030 still emits 9 tons of CO2 p.c.

Due to the high economic growth projected for SSP5, in the SSP5-19 scenario, all countries increase their GDP p.c. but as in the other SSP scenarios, at the end of the century the Global North still has a higher GDP p.c. compared to the Global South. In fact, the absolute difference in p.c. between OECD and MAF increases: in 2100 the difference in p.c. income is projected to be 35.320$ per year; in 2005 it was 24.932$ per year. Nevertheless, the convergence processes are assumed to be high: In 2100 MAF's p.c. income is 77% that of OECD's p.c. income while in 2005 it was 13%.

Figure C1. Per capita CO2 emissions in the SSP5-19 scenario across world regions



Source*: Own elaboration based on data of the SSP Database (Riahi et al., 2017; Rogelj et al., 2018)*

SSP5-Baseline

In the case of the SSP5-Baseline scenario, the regions are the 'same' in the sense that they all follow the same fossil-fuel based economic 'development' and experience a considerable convergence in their p.c. CO_2 emissions. Nonetheless, at the end of the century the Global North (mainly OECD) is still emitting more in per capita terms than the Global South (Asia, LAM, MAF) (cf. Fig. C2). Also, the income gap between the Global North and Global South still exists, despite the convergence processes.

Figure C2. Per capita CO2 emissions in the SSP5-Baseline scenario across world regions

Source*: Own elaboration based on data of the SSP Database (Riahi et al., 2017; Rogelj et al., 2018)*

D. Risk analysis for nuclear energy and carbon capture & storage assumptions in the scenarios

Two risks of the proposed energy systems in the different scenarios are analyzed: nuclear energy and carbon capture and storage (CCS).

Nuclear energy

Nuclear energy poses three main risks: Fatal accidents, the disposal of nuclear waste, and proliferation (Diesendorf et al., 2023; Moriarty & Honnery, 2019). The question of where to store nuclear waste remains unsolved (Edwards, 2022; Ramana, 2018). According to the theory of EDCs, the most vulnerable communities face the highest risk of having to deal with nuclear waste and having the lowest capacity to adapt in case of fatal accidents. This was already recognized by indigenous activists in the 1980ies who therefore opposed nuclear energy production in the West (cf. Dunlap, 2021). Because the risks of proliferation and catastrophic accidents are already caused by a small amount of operating power plants, and because the risks of fatal accidents will increase with climate change (Jordaan et al., 2019), it can be argued that any scenario which draws on nuclear energy puts the most vulnerable people at risk. Of the five analyzed scenarios, only the Adv E[R] scenario does not include nuclear energy.

Carbon capture and storage (CCS)

The primary risk associated with CCS from a Global South perspective is the risk that the technology fails to deliver. Unfortunately, there are plenty of factors that point to the unviability of this climate mitigation technology at applied at a large scale:

First, considering the whole life cycle of commercial industrial carbon removal technology, which comprises point source capture and direct air capture (DAC), studies have reached the conclusion that these technologies are net sources of CO2 emissions (Sekera & Lichtenberger, 2020). One reason for this result is that the CCS industry uses the captured CO2 in enhanced oil recovery processes. This entails additional CO2 emissions as the oil has to be extracted, refined and is finally burned by the end user (ibid.). Thus, the concerns that the principal purpose of CCS is to legitimize the continued extraction of unconventional fuels and the social and ecological destruction it entails (Alexander & Stanley, 2022) seem to be justified.

Second, BECCS (Bioenergy with Carbon Capture and Storage) combines the problems related to bioenergy with the problems just illustrated. Thus, it poses a threat to biodiversity, soil health and livelihoods due to its massive land and water requirements (Brack & King, 2021; Creutzig et al., 2021; Fajardy et al., 2019). These threats might lead to human rights violations of the right to food, the right to water, the right to a healthy environment, the right to energy, and peasants rights (Günther & Ekardt, 2022; Wewerinke-

Singh et al., 2022). Furthermore, it is unclear whether the EROI of BECCS actually is >1, i.e. whether it is a net source of energy (Fajardy & Mac Dowell, 2018). Because of the low EROI of electricity and fuels produced with biomass it is very plausible that BECCS at large scale will have an EROI < 1 which undermines the very logic of the concept: Not only would BECCS be a net energy sink but the technology could be a net CO2 source.

Third, although CCS technologies like DAC and BECCS could be net CO2 reductive if powered by renewable energy, they have enormous energy and land requirements (Hanssen et al., 2022; Sekera & Lichtenberger, 2020), which would negatively affect the EROI of the whole energy system, and the amount of energy available to society. Also, scaling up CCS to CO2 removals of 1 Gt/year would produce serious safety issues: Possible risks include groundwater contamination, earthquakes and leakage of CO2 which would not only cause air pollution but also undermine the purpose of CCS. To reduce these risks extensive monitoring and data tracking systems would be required. Moreover, the infrastructure needed by CCS is enormous: To transport 1 Gt of captured CO2 a pipeline capacity greater than the currently existing oil pipeline system would need to be built (Sekera & Lichtenberger, 2020). The long-term storage as well as the transport of CO2 are linked to various technical challenges and potentially fatal risks which are not yet resolved (Sonke et al., 2022). All these factors indicate that large scale CCS of >= 1 Gt CO2/year will be inviable.

If CCS does not work as desired or turns into a net source of CO2 emissions, the climate change in those scenarios relying on CCS will be higher than projected and, once again, vulnerable communities in the Global South will have to deal with the consequences. SSP1-19, SSP5-19 and NZE all rely on CCS and thus create significant risks for vulnerable social groups of the Global South.

As with the impacts, the risks for the different scenarios can be evaluated and compared by using the following table:

Table D1. Summary of risk analysis.

Risks	**SSP1-19**	**SSP5-19**	**SSP5-Baseline**	**NZE**	**Adv E[R]**	criterion/ threshold
Carbon capture and storage	18 Gt CO2/year; 15 of which BECCS	22.5 Gt CO2/year (all of which BECCS)	0 Mt CO2/year	1.5 Gt CO2/year (BECCS+ DAC)	0 Gt CO2/year	0 Gt CO2/year
Nuclear energy	5 EJ	63 EJ	33 EJ	63 EJ	0 EJ	0 EJ

Source: ***Own elaboration.***

E. Final energy and techno-sustainable potential

Table E1. Final energy contrasted with EROI and techno-sustainable potential considerations.

Scenario name	**Final energy (EJ/y)**	**Renewable Energy [final energy] (EJ/y)**	**Corrected final energy: excluding technologies with final EROI <2.5:1 & considering their sustainable potential**
SSP1-19	356 (in the year 2100)	**Electricity:** Hydro: 22 Solar: 103 Wind: 28 Other: - Biomass: 18 Ocean: 0 **Heat** Geothermal: 0 [*this scenario has only 1 EJ heat in final energy*] Hydrogen from Biomass: 67 **Fuels** Biomass: 28	**Electricity**: Hydro: 22 -> no change (below max. potential) Solar: 103 -> no change (below max. potential) Wind: 28 -> no change (below max. potential) Biomass: 18 EJ -> 0 (EROI < 2.5:1) Ocean: 0 **Heat** Geothermal: 0 Hydrogen from biomass: 67 -> 0 (reasoning: EROI for conversion from biomass to hydrogen will very likely be even lower than the conversion to electricity due to low efficiency) **Fuels** Biomass: 28 EJ -> 0 (EROI < 2.5:1) **Energy which potentially will not be available:** (18+28+67 = 113 EJ) 113/356 = 32% of total final energy = 1/3 could not be available 243 EJ final (corrected)
SSP5-19	809 (in the year 2100)	**Electricity** Biomass: 34 Geothermal: 1 Hydro: 48 Ocean: 0 Solar: 370 Wind: 124 **Heat** Geothermal: 45 Hydrogen from biomass: 50 **Fuels** Biomass: 103	**Electricity** Biomass: 34 -> 0 (EROI 2.5:1) Geothermal: 1 -> no change (EROI = 5:1) Hydro: 48 -> 30 (max. potential) Ocean: 0 Solar: 370 -> 133 (max. potential) Wind: 124 -> 47 (max. potential) **Heat** Geothermal: 45 EJ -> 15.2 (max. potential) Hydrogen from biomass: 50 -> 0 (see above) **Fuels** Biomass: 103 EJ -> 0 (EROI <2.5:1) **Energy not available**: = 548,8 68% of the foreseen energy consumption could be not available 260 EJ final (corrected)
SSP5-Baseline	1167 (in the year 2100)	**Electricity** Biomass: 12 Geothermal: 1 Hydro: 36 Ocean: 0 Solar: 81 Wind: 62 **Heat** Geothermal: 6 **Fuels** Biomass: 18	**Electricity** Biomass: 12 -> 0 (EROI < 2.5:1) Geothermal: 1 -> 0 (EROI < 2.5:1) Hydro: 36 -> 30 (max. potential) Ocean: 0 Solar: 81 -> no change (below max. potential) Wind: 62 -> 47 (max. potential) **Heat** Geothermal: 6 -> no change (below max. potential) **Fuels** Biomass: 18 -> 0 (EROI < 2.5:1) Energy not available: 52

			52 / 1167 = 4% 1115 EJ final (corrected)
NZE (*)	337 (in the year 2050)	**Electricity** Solar PV: 97 Wind: 85 Hydro: 30 Other renewables: 42 **Heat** Modern solid bioenergy: 74 Modern gaseous Bioenergy: 15 Other renewables: 2 **Fuels** Modern liquid bioenergy: 12	**Electricity** Solar PV: 97 -> no change (below max. potential) Wind: 85 EJ -> 47 (max. potential) Hydro: 30 -> no change (max. potential) Other renewables: 42 -> 0 (relevant sources already considered) **Heat** Modern solid bioenergy: 74 -> 43.4 (includes waste; max. potential) Modern gaseous bioenergy: 15 -> 0.3 (max. potential) Other renewables: 2 -> no change **Fuels** Modern liquid bioenergy: 12 -> 0 (EROI < 2.5:1) **Total energy not available**: 137,3 41% of final energy might not be available 200 EJ
ADV E[R] (**)	279 (in the year 2050)	**Electricity** Biomass: 11 Hydro: 18 Wind: 78 (of which wind offshore): 23 Solar PV: 49 Geothermal: 16 Solar thermal power Plants: 51 Ocean: 7 **Heat** Solar: 29 Biomass: 30 Geothermal: 18 [hydrogen]: 10 **Fuels** Biofuels: 8 [Synfuels: 5 Hydrogen: 14]	**Electricity** Biomass: 11 -> 0 (EROI < 2:1) Hydro: 18 -> no change (below max. potential) Wind onshore: 55 -> 40 (max. potential) Wind offshore: 23 -> 7 (max. potential) Solar PV: 49 -> no change (below max. potential) Geothermal: 16 -> 0 (all to heat to increase overall energy availability) Solar thermal power plants: 51 -> 0 (EROI <2.5:1) Ocean: 7 -> 0 (EROI < 2:1) **Heat** Solar: 29 -> 22.4 (max. potential) Biomass: 30 -> no change (below max. potential) Geothermal: 18 -> 15.2 (max. potential) **Fuels** Biofuels: 8 -> 0 (EROI <2.5:1) **Total energy not available** = 133,4 48% of energy might be unavailable -> half of energy 146 final energy corrected
Source: *Own elaboration. Data extracted from the SSP Scenario Database, from the WEO 2022 and the Energy [R]evolution Report.*			

(*) With regard to the values for final energy provided in the NZE scenario, it has to be critically remarked that there seems to be an error in the data. The electricity production from renewables is much greater than the final electricity consumption: In 2050, the world consumes 176 EJ of electricity but at the same time in the scenario, solar PV, wind and hydropower produce 212 EJ of electricity; 212 >> 176.

(**) With regard to the data provided by the report for the Adv E[R] scenario, there is a lack of inconsistency regarding the units used. Thus, electricity which is given in TWh is converted into EJ.

F. Storylines

i. SSP1

Source: Supplementary Material of O'Neill et al. (2017), p.1-4)

"*SSP1: Sustainability – Taking the Green Road: The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries. Increasing evidence of and accounting for the social, cultural, and economic costs of environmental degradation and inequality drive this shift. Management of the global commons slowly improves, facilitated by increasingly effective and persistent cooperation and collaboration of local, national, and international organizations and institutions, the private sector, and civil society. Educational and health investments accelerate the demographic transition, leading to a relatively low population. Beginning with current high-income countries,the emphasis on economic growth shifts toward a broader emphasis on human well-being, even at the expense of somewhat slower economic growth over the longer term. Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries. Investment in environmental technology and changes in tax structures lead to improved resource efficiency, reducing overall energy and resource use and improving environmental conditions over the longer term. Increased investment, financial incentives and changing perceptions make renewable energy more attractive. Consumption is oriented toward low material growth and lower resource and energy intensity. The combination of directed development of environmentally friendly technologies, a favorable outlook for renewable energy, institutions that can facilitate international cooperation, and relatively low energy demand results in relatively low challenges to mitigation. At the same time, the improvements in human well-being, along with strong and flexible global, regional, and national institutions imply low challenges to adaptation.*

Additional information:

Motivating forces: Growing evidence of and accounting for the social, cultural, and economic costs of inequality and environmental degradation moves the world gradually, but pervasively, to prioritize progress towards achieving global and national development and sustainability goals, while reducing inequality (across and within economies). The shift is more pronounced in developed countries, which increasingly prioritize improvements in well-being over economic growth per se. Even in developing countries, where there is a continued focus on economic growth, goals are tempered by increased attention to ensuring this growth is broad-based and does not come at the expense of long-term degradation of local environments This shift evolves over time and is not uniform. The gradual accumulation of evidence of the costs of inequality and environmental degradation is punctuated by periodic tragedies that bring these *costs into stark relief. These events stimulate growing constituencies supporting change at the local, national, regional, and international levels. Over time, the initially disparate constituencies are mutually reinforcing, ultimately leading to effective and persistent cooperation and collaboration across these scales and between public organizations, the private sector, and civil society within and across all scales of governance, including local, regional, national, and international. These trends open the door to formal and informal actions that, over time, help to fundamentally restructure the relationships within and between societies, and between humans and the environment. Policies shift to align incentives with development and sustainability goals, including measures such as the adoption and use of standardized measures of well-being to complement GDP; a shift in taxes and subsidies towards a stronger recognition of environmental considerations; a tightening of environmental regulation on the national and regional level; optimizing resource use efficiencies associated with urbanizing lifestyles; and improving the access of developing countries to international markets, including the opening of agricultural markets. As a result of these changing incentives, as well as evolving norms, there are further shifts in public and private behavior reflected in changing consumption and investment patterns. Many of these developments are slow to take hold broadly, and face some resistance and experience setbacks along the way. However, over time they become increasingly selfreinforcing. It is a bumpy road, but one that eventually moves most of the world in a more sustainable direction.*

Policies, institutions and social conditions: Relatively effective and persistent cooperation and collaboration of national and international organizations and institutions, the private sector, and civil society help drive the transition from increased environmental degradation in the short-term to improved management of the local environment and the global commons over the longer term. For example, tighter controls on air pollution improve health in developing countries. Improvements in agricultural productivity through rapid diffusion of best practices and development of new cultivars and other technologies decrease challenges to food security. Research and technology development reduce the challenges of access to safe water. New global institutions evolve to support cooperation on sustainable development, with flexible roles played by other actors. Reductions in corruption levels, policies calling for greater transparency in all sectors of society, and strengthening of the rule of law gradually lead to greater effectiveness of development policies.

Human development: A large emphasis is placed on education and providing access to health care. Policies aim at achieving universal access and promoting higher education levels and gender equality. Relatively high economic growth in low-income countries reduces poverty, and a global focus on increasing equity also increases social cohesion, while maintaining high levels of social and cultural diversity within and across countries. Increasing access to health *care and to safe water and improved sanitation in low-income countries reduces the burden of preventable diseases. Economy and lifestyles: This development pathway implies that economic growth is relatively high in developing countries, although growth rates are moderated over time by a shift in emphasis from growth per se to well-being, equity, and sustainability. Inequality is reduced across and within countries. Markets are globally connected, but an emphasis on regional production reduces the incentives for specialization and limits the increase in trade volumes. Investment in environmental technology and changes in tax structures, including phase out of subsidies on fossil fuels, particularly coal and oil, lead to higher levels of resource efficiency, moderating overall energy and resource use over the longer term. Increased investment, lower taxes, and changing perceptions make renewables more attractive. The service sector grows relatively quickly. Consumption is oriented towards low material growth and lower resource and energy intensity, with a relatively low level of consumption of animal products. Population and urbanization: Investments in human capital and rapid technological change accelerate the demographic transition in currently high fertility countries, leading to a relatively low population. Economic optimism sustains or increases fertility levels toward the replacement rate in currently low fertility countries. Urbanization, while still rapid in many developing regions of the world, increasingly is directed via growth of civil society, governance capacity and engaged decision-making to promote environmental benefits, and limit negatives associated with urban growth and cities, reducing the incentives promoting urban sprawl and urban population deconcentration. Cities become more consistent incubators and promoters of sustainability practices. Migration is at intermediate levels. Although increasing integration of labor markets allows people to move around more freely, improved regional livelihoods and the renewed emphasis on regional production reduce migration incentives. - Environment and resources: The value shift toward prioritizing environmental sustainabiliy and associated policy focus on environmental protection and technology development implies that air and water pollution is likely to be low and results in improvements in environmental conditions and enhanced protection for vulnerable ecosystems and regions. Depletion of non-renewable resources is relatively low given the focus on environmentally friendly technology. Still, there are challenges with respect to the trade-offs between various resources (such as the use of bioenergy). Food security increases with attention paid to reducing the underlying drivers and increased investment in research and development. Land use is strongly regulated to avoid environmental tradeoffs.*

Technology: Relatively rapid technological change is directed toward environmentally friendly processes, including energy efficiency, clean energy technologies, and yieldenhancing technologies for land. Strong investment in new technologies and research improves energy access and advances alternative energy technologies. Technology transfer is facilitated by *international agreements on intellectual property rights and other issues. Challenges: Challenges to mitigation are low because of high mitigative capacity brought about by rapid technological change as well as effective institutions and willingness to cooperate, facilitated by a broad orientation toward environmental sustainability in an urban-dominated economy. Challenges to adaptation are low because of reductions in vulnerability at the individual and societal levels, and the increased effectiveness of governance and institutions reoriented toward cooperation and sustainability principles. Better-educated populations and high overall standards of living confer resilience to societal and environmental changes with enhanced access to safe water, improved sanitation, and medical care. Other factors that reduce vulnerability include, for example, the successful implementation of stringent policies to control air pollutants and reductions in energy, food, and water insecurity. If and when severe climate impacts do occur, coordination structures, e.g. integrated early warning systems, security alliances, disaster relief services, and risk reduction and resiliency promotion strategies are in place to assist those most at risk*."

ii. SSP5

Source: Supplementary Material of O'Neill et al. (2017), p.13-15

"*SSP5: Fossil-fueled Development – Taking the Highway*

Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, with interventions focused on maintaining competition and removing institutional barriers to the participation of disadvantaged population groups. There are also strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy. There is faith in the ability to effectively manage social and ecological systems, including by geo-engineering if necessary. While local environmental impacts are addressed effectively by technological solutions, there is relatively little effort to avoid potential global environmental impacts due to a perceived tradeoff with progress on economic development. Global population peaks and declines in the 21st century. Though fertility declines rapidly in developing countries, fertility levels in high income countries are relatively high (at or above replacement level) due to optimistic economic outlooks. International mobility is increased by gradually opening up labor markets as income disparities decrease. The strong reliance on fossil fuels and the lack of global environmental *concern result in potentially high challenges to mitigation. The attainment of human development goals, robust economic growth, and highly engineered infrastructure results in relatively low challenges to adaptation to any potential climate change for all but a few.*

Additional Information:

Motivating forces: Two major factors enable a break with historical patterns that showed a lack of regional convergence in institutional arrangements and economic growth. First, the economic success of emerging economies and more recently least developed countries gives rise to an emergent global middle class that has been lacking in most regions of the world. The new middle class stabilizes global economic development by promoting robust growth in demand for services and goods especially in cities. The new middle class also fosters the more widespread adoption of world views oriented towards market solutions and participatory societies in many world regions. In particular, developing countries aim to follow the fossiland resource-intensive development model of the industrialized countries. Second, the digital revolution enables a global discourse of a significant and increasing share of the population for the first time in human history leading to a rapid rise in global institutions and promoting the ability for global coordination.

Policies, institutions and social conditions: On a national and regional level, institutional changes are initiated to foster competitive markets, leading – by and large – to more effective institutions with lower levels of corruption, strong rule of law, and the removal of market entry barriers for disadvantaged population groups. Social cohesion, gender equality, and political participation are strengthened in most world regions. As a consequence, social conflicts are gradually decreased, although the more pervasive adoption of participatory and market oriented world views creates significant tension with traditional views during a transition phase. On the international level, countries pursue a global "development first" agenda and increasingly cooperate on economic, development, and security policies. Regional conflicts are met with assertive international action, and decline with rapid development and decreasing levels of social conflict. Institutions that further market penetration and lower trade barriers are strengthened, leading to accelerated globalization and high levels of international trade. International cooperation on environmental policies is much more limited due to a perceived trade-off between development and environmental goals for global, long-term issues.

Human development: Development policies emphasizing education and health are put in place to accelerate human capital development. These policies, aided by rapid economic development, lead to a strong reduction of extreme poverty and significantly improved access to education, safe drinking water and modern energy in the medium term.

Economy and lifestyles: Economies become increasingly globalized over time with high levels of international trade. The gross world product at the end of the century is very high. Per *capita incomes in developing countries increase rapidly, leading to strong convergence of interregional income distributions and a measurable decline of income inequality within regions. At the same time industrialized countries continue their focus on economic growth, driven in part by consumerism and resource-intensive status consumption, including a preference for individual mobility, meat-rich diets, and tourism and recreation. Developing countries rapidly adopt these consumption patterns.*

Population and urbanization: Global population peaks and declines in the 21st century, a result of rapid fertility declines in developing countries driven by improving education, health, and economic conditions. In high income countries, fertility is above replacement due to optimistic outlooks for economic conditions. International mobility is increased by gradually opening up labor markets as income disparities decrease. Migration from poorer to wealthier countries buffers the effect of aging populations in industrialized countries. All regions reach high levels of urbanization. Urban planning and land use management play crucial roles, but struggle to keep up with the rapid migration of rural population into cities in the first few decades of the century. While urbanization rates converge over time, urban structure and form develop in different world regions to reflect historic patterns and prevailing local and national policies. This includes dense mega-cities in densely populated countries, and large metropolitan areas with significant urban sprawl in other regions of the world.

Technology: Technological progress is seen as a major driver of development and economic growth. Fostered by widespread technology optimism, investments in technological innovation are very high, with a focus on increasing labor productivity, fossil energy supply, and managing the natural environment. In continuation of the current shale revolution, fossil resource extraction is maximized at low cost, and local externalities of fossil energy production (e.g. health effects) are well controlled by continued technological advancements in the fossil energy sector. Due to the strong reliance on fossil energy, alternative energy sources are not actively pursued.

Environment and resources: Environmental consciousness exists on the local scale, and is focused on end-of-pipe engineering solutions for local environmental problems that have obvious impacts on well-being, such as air and water pollution particularly in urban settings. On the other hand, individualistic lifestyles give rise to local opposition against engineering solutions that affect local environments (NIMBY). Agro-ecosystems become more and more managed in all world regions, facilitated by productivity improvements and the diffusion of resource-intensive management practices in the agricultural sector. The resulting large increases in agricultural productivity and a peaking and declining world population can support high per capita food consumption and meat-rich diets globally. However, some deforestation continues due to incomplete regulations. In the long run, land and environmental

systems are highly managed across the world, and there is a general tendency to decouple human-engineered systems from natural systems as much as possible.
Challenges: The strong reliance on fossil fuels and the lack of global environmental concern result in potentially high challenges to mitigation. The attainment of human development goals, robust economic growth, and highly engineered infrastructures results in relatively low challenges to adaptation for all but a few."

iii. NZE

Sources: IEA 2022a, 2022b

Net Zero Emissions by 2050 Scenario Definition:

"*A scenario which sets out a pathway for the global energy sector to achieve net zero CO2 emissions by 2050. It does not rely on emissions reductions from outside the energy sector to achieve its goals. Universal access to electricity and clean cooking are achieved by 2030. Objective: To show what is needed across the main sectors by various actors, and by when, for the world to achieve net zero energy related and industrial process CO2 emissions by 2050 while meeting other energy related sustainable development goals such as universal energy access*." (IEA 2022a, p.6)

"*The Net Zero Emissions by 2050 (NZE) Scenario shows a narrow but achievable pathway for the global energy sector to achieve net zero CO2 emissions by 2050, with advanced economies reaching net zero emissions in advance of the other scenarios. This scenario also meets key energyrelated United Nations Sustainable Development Goals (SDGs), in particular achieving universal ener gy access by 2030. The NZE Scenario does not rely on emissions reductions from outside the energy s ector to achieve its goals, but assumes that nonenergy emissions will be reduced in the same proportion as energy emissions. It is consistent with li miting the global temperature rise to 1.5 ° C without a temperature overshoot (with a 50% probability)*." (IEA 202b, p.463)

Details:

"*The Net Zero Emissions by 2050 Scenario (NZE Scenario) integrates three key objectives of the UN 2030 Agenda for Sustainable Development: universal access to modern energy services by 2030 (embodied in SDG 7), reducing health impacts of air pollution (SDG 3.9), and action to tackle climate change (SDG 13). As a first step, we use the GEC Model to assess how the energy sector would need to change to deliver universal access to modern energy services by 2030. To analyse electricity access, we combine cost-optimisation with new geospatial analysis that takes into account current and planned transmission lines, population density, resource* *availability and fuel costs. Second, we consider ambient and household air pollution and climate goals. The policies necessary to achieve the multiple SDGs covered in the NZE Scenario are often complementary. For example, energy efficiency and renewable energy significantly reduce local air pollution, particularly in cities, while access to clean cooking facilitated by liquefied petroleum gas also reduces household air pollution and overall greenhouse gas emissions by reducing methane emissions from incomplete combustion of biomass as well as by reducing deforestation. Trade-offs can also exist, for example between electric vehicles reducing local air pollution from traffic, but at the same time increasing overall CO2 emissions if there is not a parallel effort to decarbonise the power sector. Ultimately, the balance of potential synergies or trade-offs depends on the route chosen to achieve the energy transition, making an integrated, whole-system approach to scenario building essential. The emphasis of the NZE Scenario is on technologies with short project lead times in the power sector in particular, such as renewables, while the longerterm nature of climate change allows for other technology choices. Modern uses of biomass as a decarbonisation option is also less relevant in the NZE than in a single-objective climate scenario. This is because biomass is a combustible fuel, requiring postcombustion control to limit air pollutant emissions and – depending on the region in question - making it more costly than alternatives. Since its launch in 2021, the NZE Scenario, also looks at the implications for the energy sector for achieving several of the targets under United Nations Sustainable Development Goal 6 (clean water and sanitation for all) and what policymakers need to do to hit multiple goals with an integrated and coherent policy approach. In order to reflect in our modelling the announcements made by several countries to achieve carbon neutrality by 2050 and also allows us to model the potential for new technologies (such as hydrogen and renewable gases) to be deployed at scale, the time horizon of the model is 2050. The interpretation of the climate target embodied in the NZE Scenario also changes over time, as a consequence of both ongoing emissions of CO2 as well as developments in climate science (refer to the 8 Emissions section for more details). Despite the fundamental changes across all sectors the NZE scenario still ensures an orderly transition. This includes ensuring the security of fuel and electricity supplies at all times, minimising stranded assets where possible and aiming to avoid volatility in energy markets."* (IEA 2022a, p.9)

iv. Adv E[R]

Source: Teske et al. (2015)

Short description:

"*the advanced energy [r]evolution scenario, representing an ambitious pathway towards a fully decarbonised energy system already by 2050 with significant additional efforts compared to the "basic" Energy [R]evolution scenario*" (Teske et al. (2015), p.59)

Scenario storylines and main premises:

"*The new advanced energy [r]evolution scenario (adv e[r]) needs much stronger efforts to transform the energy systems of all world regions towards a 100% renewable energy supply. The consumption pathways remain basically the same as in the E[R]; however, a much faster introduction of new technologies leads to a complete decarbonisation of the power, heat and especially the transportation sector. The latter requires a strong role of hydrogen and other synthetic fuels complementary to battery electric vehicle concepts and (limited) biofuels. Due to higher efficiencies of new vehicle concepts and the assumption of much higher modal split changes compared to the basic E[R] resulting final energy demand for transportation is lower. However, this scenario requires more fundamental changes of mobility patterns, behaviour, and infrastructural needs to compensate for the high energy losses associated to the production of synthetic fuels based on renewable electricity. Also in the heating sector, electricity and hydrogen play a larger role substituting remaining fossil fuels. In the power sector, natural gas is replaced by hydrogen as well. Therefore, electricity generation increases significantly in this scenario, assuming power from renewable energy sources to be the main "primary energy" of the future.*" (ibid.)

Context:

"*The reference scenario (ref) is based on the Current Policies scenarios published by the International Energy Agency (IEA) in World Energy Outlook 2014 (WEO 2014).1 It only takes into account existing international energy and environmental policies. Its assumptions include, for example, continuing progress in electricity and gas market reforms, the liberalisation of cross-border energy trade and recent policies designed to combat environmental pollution. The Reference scenario does not include additional policies to reduce greenhouse gas emissions. As the IEA's projections only extend to 2040, they are extended by extrapolating their key macroeconomic and energy indicators forward to 2050. This provides a baseline for comparison with the Energy [R]evolution scenarios. unlike the previous Reference scenario of the Energy [R]evolution study published in 2012, it includes an increase in population and new market trends for renewable technologies The energy [r]evolution scenario (e[r]) is an update of the Energy [R]evolution scenario published in 2012, which followed the key target to reduce worldwide carbon dioxide emissions from energy use down to a level of around 4 gigatonnes per year by 2050 in order to hold the increase in global temperature under +2°C. A second objective is the global phasing out of nuclear energy. The new Energy [R]evolution scenario takes into account developments between the former base year 2009 and the new base year*

2012 as well as changes in the new Reference scenario based on WEO 2014, which serves as the baseline for additional measures assumed in the Energy [R]evolution. In addition, pathways for the deployment of renewable energy and efficiency measures are revised, reflecting technology trends of the last few years and new estimations of worldwide potentials and investment costs leading to partly different technology mixes.

Furthermore, the possibilities to implement new technologies by 2020 are now more limited than in 2012 due to the required development time of new power plants and other infrastructures. following the basic assumptions of the Reference scenario, these changes lead to higher peaks in energy demand and fossil energy supply compared to the Energy [R]evolution of 2012. In consequence, there is a lower decarbonisation pathway if we keep at the previous scenario approach of the Energy [R]evolution. Nevertheless the scenario still includes significant efforts to fully exploit the large potential for energy efficiency, using currently available best-practice technology. At the same time, various proven renewable energy sources are integrated to a large extent for heat and electricity generation as well as the production of biofuels and hydrogen. The general framework parameters for population and GDP growth remain unchanged from the Reference scenario." (ibid.)

Details:

"*The scenario building follows for both Energy [R]evolution scenarios a framework of targets and main premises that strongly influences the development of individual technological and structural pathways for each region and each sector. The main premises considered for this scenario building process are described in the following. • Strong efficiency improvements and the dynamic expansion of renewable energy in all sectors are the main strategies to meet the overall target of CO2 emission reductions. CCS technologies are not implemented, and nuclear power and lignite power plants are phased out quickly, followed by hard coal power plants. In developing countries in particular, a shorter operational lifetime for coal power plants (20 instead of 35 years) is assumed in order to allow a faster uptake of renewable energy. based on current knowledge about potentials, costs and recent trends in renewable energy deployment (see next section on 'Scenario approach and background studies'), a dynamic further growth of capacities for renewable heat and power generation is assumed*.

The global quantities of biomass power generators and large hydro power remain limited in the Energy [R]evolution scenarios, for reasons of ecological sustainability. Wind power and solar power (both photovoltaics and concentrating solar power (CSP)) are expected to be the main pillars of future power supply, complemented by smaller contributions from geothermal (hydrothermal and Enhanced Geothermal Systems (EGS)), ocean energy and the further expansion of small and medium sized hydro power. The scenarios follow the strategy to limit the share of fluctuating power generation and to maintain a sufficient share of dispatchable, *secured capacity. Therefore, power generation from biomass and CSP but also a sufficient share of gas-fired back-up capacities and storage are important factors for the security of supply in future energy systems.*

Global sustainable biomass potentials are assumed to be limited to less than 100 Ej according to background studies. Traditional biomass use is largely replaced by state-of-theart technologies, primarily highly efficient cogeneration plants. In developing regions with a high share of traditional biomass use an implementation of improved cooking stoves is assumed. No biomass trade is considered between world regions for the scenarios. However, the large-scale import of electricity from CSP is a promising option for some world regions, especially for OECD Europe, where a net import of up to 400 to 600 TWh per year from North Africa and the Middle East is assumed in the scenarios. CSP implementation after 2030 is assumed for all regions with a solar multiple of 3 and thermal energy storage able to provide energy for 12 h per day of full-load operation of the turbine.

Efficiency savings in the transport sector are a result of fleet penetration with new highly efficient vehicle concepts, such as electric vehicles but also assumed changes in mobility patterns and the implementation of efficiency measures for combustion engines. Mobility demand is expected to increase strongly in developing countries. The scenarios assume a limited use of biofuels for transportation following the latest scientific reports indicating that biofuels might have a higher greenhouse gas emission footprint than fossil fuels. There are no global sustainability standards for biofuels yet, which would be needed to avoid deforestation and competition with food crops.

Efficiency in use of electricity and fuels in 'industry' and 'other sectors' has been reevaluated based on technical efficiency potentials and energy intensities (see also next section 'Scenario approach and background studies'). A consistent approach is used to layout feasible, rather conservative pathways and result in converging specific consumptions in all world regions. In consequence, specific energy use for all applications and in all regions is assumed to decrease significantly.

Hydrogen generated by electrolysis using renewable electricity is introduced as a third renewable fuel in the transportation sector complementary to biofuels and the direct use of renewable electricity. Hydrogen generation can have high energy losses; however, the limited potentials of biofuels and probably also battery electric mobility makes it necessary to have a third renewable option. Alternatively, this renewable hydrogen could be converted into synthetic methane and liquid fuels depending on economic benefits (storage costs vs. additional losses) as well as technology and market development in the transport sector (combustion engines vs. fuel cells). The Advanced Energy [R]evolution scenario takes this strategy one step further, increasing the share of electric and fuel cell vehicles. Additionally, *renewable hydrogen is converted into synthetic hydrocarbons, which replace the remaining fossil fuels, especially for heavy duty vehicles and air transportation, albeit with low overall efficiency of the synfuel system.*

The Energy [R]evolution scenarios also foresee a shift in the heat sector towards an increasing direct use of electricity, thanks to the enormous and diverse potential for renewable power and the limited availability of renewable fuels for high temperature process heat in industry. In addition, a fast expansion of the use of district heating and geothermal heat pumps is assumed, leading to an increase in electricity demand, which partly offsets the efficiency savings in these sectors. A faster expansion of solar and geothermal heating systems is also assumed. In the Advanced Energy [R]evolution scenario hydrogen replaces 30-40% of the remaining gas consumption in 2040 and 100% in 2050 – not only for industry, but also for power production in cogeneration and gas power stations, providing back up capacities for variable power production as from wind and Pv. The increasing shares of fluctuating renewable power generation above all by wind farms and photovoltaics require implicitly the implementation of smart grids and a fast expansion of transmission grids, storage, and other load balancing capacities. Other infrastructural needs result, for instance, from an increasing role of district heating, electric and hydrogen mobility and the generation and distribution of synthetic fuels. In both Energy [R]evolution scenarios, it is therefore implicitly assumed that such infrastructural projects will be implemented in all regions without serious societal, economic and political barriers.

The scenarios only consider regional demand and supply excluding bunker fuels for international marine shipping and international air transportation. Today, 14% of all fossil transport fuels are used for bunkers. In order to replace bunker fuels entirely with renewables, a combination of energy efficiency and renewable fuels is required. Largescale biomass use for an additional biofuel generation is possible within the limit of the assumed sustainable biomass potential. However, it's obvious, that - depending on demand development – an additional large-scale generation of synthetic liquid hydrocarbons is necessary for a complete decarbonisation of bunker fuels. We estimate this additional demand in the range of 7,000 to 9,000 Pj of biofuels and synfuels, respectively. The latter would require an additional generation of renewable electricity of about 5,000 to 6,000 TWh per year. The Energy [R]evolution scenarios by no means claim to predict the future; they simply describe and compare three potential development pathways out of the broad range of possible 'futures'. The Energy [R]evolution scenarios are designed to indicate the efforts and actions required to achieve their ambitious targets and to illustrate the options we have at hand to change our energy supply system into one that is truly sustainable. They may serve as a consistent basis for *further analyses of possible ways and concepts to implement the energy transition."* (Teske et al. (2015), p.60-61)