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Climate Policy Imbalance in the Energy Sector: Time to Focus on the Value of CO_2 Utilization

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Abstract: Global warming is an existential threat to humanity and the rapid energy transition, which is required, will be the defining social, political and technical challenge of the 21st century. Practical experience and research results of recent years have showed that our actions to cover the gap between real situation and aims of climate agreements are not enough and that improvements in climate policy are needed, primarily in the energy sector. It is becoming increasingly clear that hydrocarbon resources, which production volume is increasing annually, will remain a significant part of the global fuel balance in the foreseeable future. Taking this into account, the main problem of the current climate policy is a limited portfolio of technologies, focused on replacement of hydrocarbon resources with renewable energy, without proper attention to an alternative ways of decreasing carbon intensity, such as carbon sequestration options. This study shows the need to review the existing climate policy portfolios through reorientation to CO_2 utilization and disposal technologies and in terms of forming an appropriate appreciation for the role of hydrocarbon industries as the basis for the development of CO_2-based production chains. In this paper we argue that: (1) focusing climate investments on a limited portfolio of energy technologies may become a trap that keeps us from achieving global emissions goals; (2) accounting for greenhouse gas (GHG) emissions losses, without taking into account the potential social effects of utilization, is a barrier to diversifying climate strategies; (3) with regard to hydrocarbon industries, a transition from destructive to creative measures aimed at implementing environmental projects is needed; (4) there are no cheap climate solutions, but the present cost of reducing CO_2 emissions exceeds any estimate of the social cost of carbon.

Keywords: climate policy; carbon tax; CO_2 costs; value of CO_2 utilization; hydrocarbons; energy sector; carbon capture; carbon utilization; carbon storage; climate change mitigation; climate change adaptation

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1. Introduction

Countering climate change is one of the key challenges of the 21st century. Solving this problem involves reducing the amount of greenhouse gases such as CO_2, CH_4, N_2O, and others. [1]. Given that different greenhouse gases have different impacts on global warming processes, the total estimate is usually made in terms of CO_2, for example, through the Global Warming Potential (GWP) indicator proposed by the Intergovernmental Panel on Climate Change (IPCC), which is widely used in scientific literature [2]. Therefore, in this article greenhouse gas (GHG) emissions will be given without division, assuming that all of them are converted to CO_2

Reduction of GHG emission implies implementation of several environmental initiatives in three key areas [3]:

(1) Reduced consumption of products with greenhouse gas emissions
(2) Decrease in greenhouse gas emissions per unit of output
(3) Gradual phase-out of carbon-intensive technologies.

A balanced approach to the implementation of these three lines of development should have ensured a gradual transition from points 1, 2 to 3; however, the successful development of renewable energy in recent years has created the misperception of the need to shift towards a forced abandonment of carbon-intensive industries (Figure 1), instead of searching the ways of their sustainable development [4].

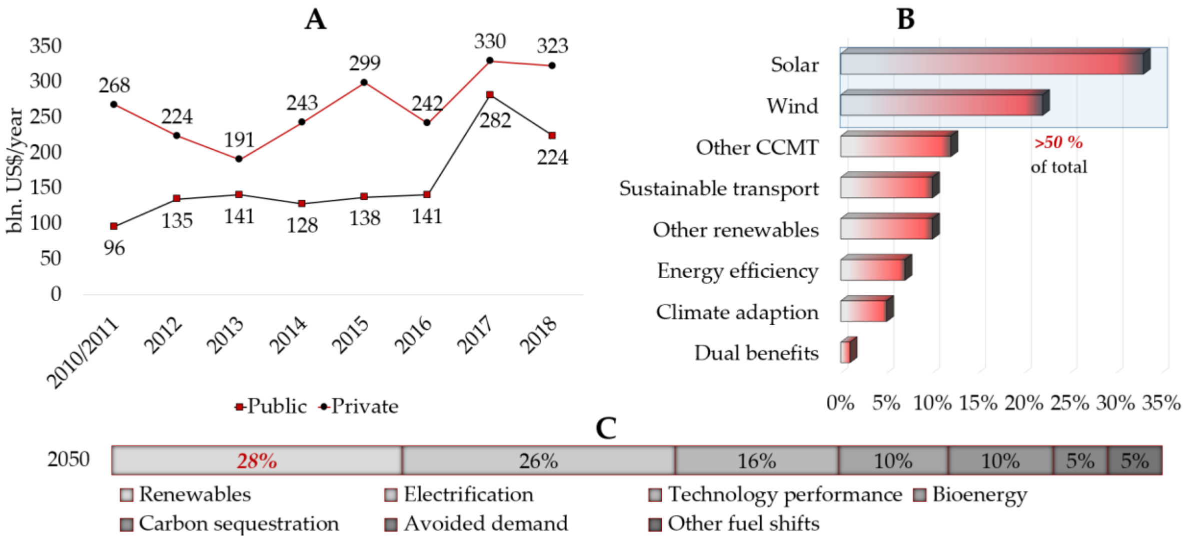

Figure 1. Total global climate change expenditures (**A**), distribution of climate change expenditures in 2011–2018 (**B**) and CO_2 emissions reductions by measure in 2050, compared to 2019, % of total reduction (**C**). Data from [5,6].

The total volume of investment in climate technologies has been growing, albeit intermittently, but noticeably, including from the private sector, which is explained by the desire to participate in rapidly developing markets, mostly solar and wind energy. More than half of all investments are concentrated in these two technologies, which led us to a series of problems:

(1) the lack of climate policy targets justification [7] and orientation on the prospects of renewable sector development, mostly;
(2) focus on unidirectional policy regulation for various industries [8] (only taxes or only incentives);
(3) necessity to support the raising number of both, producers and consumers of green energy [9];
(4) rapid development of new renewable energy facilities with some problems that have not yet been solved [10], such as relatively low energy return on energy invested [11] and the problem of disposal of worn-out equipment [12,13];
(5) make a bet on substitution of existing energy infrastructure without proper attention to alternative technologies, allowing to expand carbon-intensive technological chains with environmentally-friendly solutions [14].

These problems have the greatest impact on hydrocarbon energy, the contribution of which to global CO_2 emissions is as high as 45–60% [15], depending on the boundaries adopted in the industry. According to the results of 2019, electricity production from coal-fired power plants in developed economies decreased by almost 15% (5% globally), which is especially noticeable in the USA. Solar power (+17%) and wind power (+12%) accounted for the largest relative growth. Such rapid development of renewable energy made it possible to achieve some success in terms of limiting the growth rate of GHG to 33 Gt of CO_2 in 2019. This short-term slowdown is likely to continue in the next few years due to the impact of COVID-19 on the economies [16]. But there is no guarantee that renewable energy will allow to show the same growth rate in the long term, even with introduction of stricter climate regulation [17], since it is necessary to engage countries with strong support of hydrocarbon energy.

Despite the need for further development of renewable energy, we have to agree that it is promising solution but not a panacea for solving the problem of raising GHG emissions. In terms of climate policy, the existing hydrocarbon energy infrastructure should be considered not only as an object of substitution, but as a functioning base for the development of alternative climate mitigation solutions, which also require proper attention, investments and regulation [18].

The aim of this paper is to address the necessity of improving existing climate policy through a proper consideration of carbon sequestration technologies, which could provide a sustainable pathway for existing hydrocarbon energy infrastructure, instead of its total replacement by renewable energy facilities. The remaining parts of this paper are organized as follows: in Section 2, Theoretical Background and Practical Issues are presented, including Section 2.1. Social Cost of Carbon and Carbon Taxes, Section 2.2. Climate change mitigation options and Section 2.3. Methods of Scaling Solar and Wind Energy; the discussion is presented in Section 3 and conclusions are drawn in Section 4.

2. Theoretical Background and Practical Issues

According to [19], the warming process is likely to be a result of technogenic GHG emissions, which led to an unprecedented rate of increasing in mean surface temperature over the last 1000 years [20], as well as to a highest concentration of CO_2 in the atmosphere over the last 650,000 years [21]. Despite the regional differences in regional climate change [22], this process impacts the whole global economy and could lead to irreversible consequences [23]. In order to slow down global warming processes, a number of ambitious initiatives have been proposed, which in some cases are economically controversial (in short and medium term), such as "European Green Deal" program [24] or the introduction of the transboundary carbon tax [25], losses from which only for Russian companies may amount to 1.8 to 8.2 billion Euros per year, including 0.9 to 3.8 billion Euros in the oil and gas industry.

It is beyond the scope of this paper to analyze one or the other position on the causes and consequences of global warming. The key position is that the growth of technogenic GHG emissions is a problem for humanity. The discussion field for this review is built around the decisions that are made within the framework of climate and energy policies under the presence of uncertainty in the range of economic, social and technological issues. The methodological framework of this review is showed in Figure 2.

2.1. Social Cost of Carbon and Carbon Taxes

Carbon taxes are a widespread instrument of modern climate policy, which have been implemented in more than 25 regions [26]. Despite widespread use, such relatively simple tax regimes cannot fully address GHG emissions [27]. First, there are inequalities in access to raw materials. Therefore, the main supporters of such a measure will be the importing countries of raw materials, which is quite clearly demonstrated at the example of the European Union. Secondly, in an effort to show the devastating impact of CO_2 on the environment, we are moving further into long-term forecasting, which complicates implication of real market mechanisms. Thirdly, when comparing the tariffs for renewable energy sources (RES) and hydrocarbon power generation, it is usually not mentioned that the competitiveness of RES is ensured by state support. Moreover, we do not take into account that further intensification of RES generation will require the development of storage and transportation infrastructure, which will lead to increased government influence on tariffs. Fourth, today there are no effective mechanisms to assess and control the carbon intensity of imported products. Fifth, there are many questions about the methodology of determining the amount of carbon tax, which are usually based on the so-called Social Cost of Carbon (SCC).

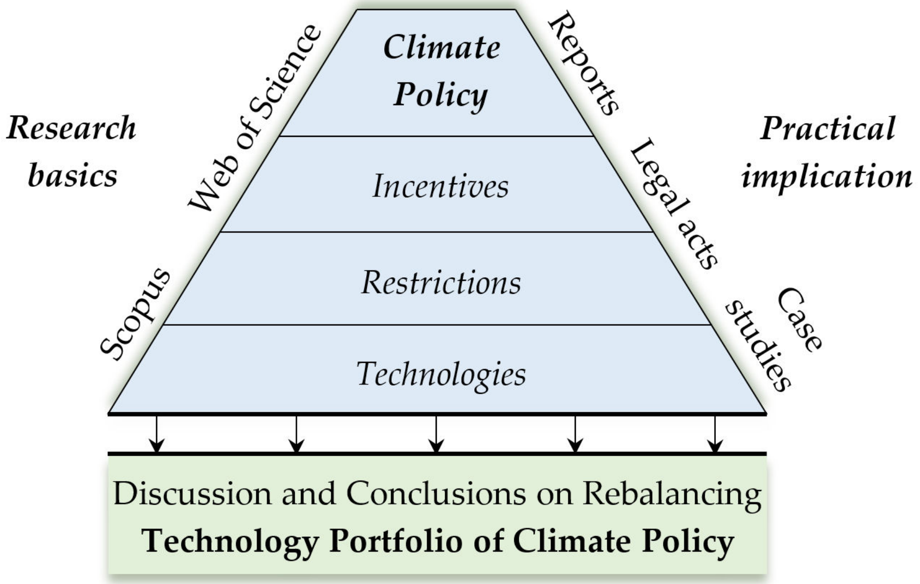

Figure 2. Framework of the review.

The SCC evaluation is usually performed using Integrated Assessment Models [28], the most well-known of which are DICE (Dynamic Integrated Climate-Economy) [29], FUND (Climate Framework for Uncertainty, Negotiation and Distribution) [30] and PAGE (Policy Analysis of the Greenhouse Effect) [31]. Estimates under these models vary quite a lot, including when comparing the same models of different years [32]. As a rule, they are at least 10–20 USD/t CO_2 in the second decade of the 21st century [33]. According to other estimates, already now, SCC, and, accordingly, carbon tax, can reach several hundred of USD [34], and, taking into account the regional influence, more than 800 USD/t CO_2 [35], with a median value of 417 US$/t CO_2. In this case, as the main factor determining the differences between SCCs in different countries, [36] refers to the impact of global warming on the level of income of the population, which, in fact, almost nothing is known about. It is also interesting that although Social Cost of Carbon is positioned as a measure of influence on the welfare of mankind, today there is a huge lack of social climate research on climate change mitigation technologies conducted under the agenda of the leading organization on this issue-Intergovernmental Panel on Climate Change (IPCC) [37].

The paper [38] argues that despite the short-term possible benefits of global warming, especially in the agro-industrial sector of dry regions, long-term negative effects will outweigh them, which will particularly affect the poor part of the world population [39]. It is this thesis that is central to the defense of SCC models, which aim to model the long-term effects of CO_2 on the well-being of society, and even more so, to make projections for the indefinitely long-time horizons [40].

Focusing only on long-term benchmarks, with little or no assessment of the current state and structure of industrial production, may not provide for an objective picture of the impact of CO_2 emissions on the well-being of society [41] and, as a result, lead to disruptive policy decisions for global industry.

The evolution of CO_2 estimation methods has led to the development of a new approach, which was described in [42], cleared of the uncertainty associated with estimating environmental damage in the scope of planning for decades [43]. The use of this method provides an extremely important lever for shaping climate and energy policies based on the short-term conditions, without the need of taking into account long-term dynamics. This allow to make a more balanced decisions regarding taxation and also to increase the level of understanding of companies that plan their low-carbon activities, based on different cost-benefit approaches [44].

But even with this new model, the cost is more about eliminating technogenic CO_2 by reducing fuel combustion and switching to renewable energy rather than by involving CO_2 in production process. In other words, current and future opportunities for CO_2 projects, examples of which are already exist in the world practice, are practically not taken into account.

Performance of SCC assessments, even taking into account the noted uncertainty, has positive effects on the formation of human responsibility for environmental preservation. Nevertheless, it is necessary to clearly see the boundary between theoretical calculations and real market regulation measures.

As an alternative to the carbon tax, some authors propose a resource tax [45] as a more effective method to strengthen control over the activities of extractive companies. However, this approach overlooks the fact that hydrocarbon industries are the raw material base not only for the energy sector, but also for a number of chemical industries, which today have no substitutes in principle. The possibility of introduction of such tax should be considered only under condition of return of the majority of funds back to the industry for the targeted use.

2.2. Climate Change Mitigation Options

At present, there are a number of promising alternatives for reducing emissions of anthropogenic GHG (Figure 3), which, due to the complexity of scaling, high calculated values of capital intensity, etc., are given relatively little attention in the mechanisms for regulating GHG emissions [46,47].

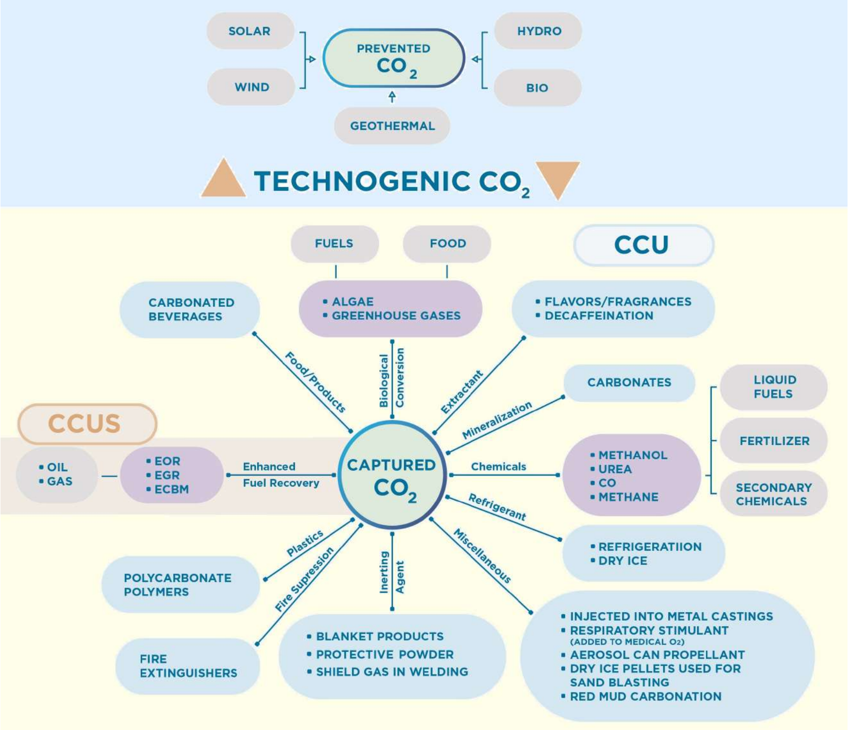

Figure 3. Cluster of Carbonless and Low-Carbon Technologies. Acronyms: CCUS—Carbon Capture, Utilization and Storage, CCU—Carbon Capture and Utilization, EOR-Enhanced Oil Recovery, EGR—Enhanced Gas recovery, ECBM—Enhanced Coal Bed Methane Recovery.

One of the first widely known CO_2 abatement cost curve, which combined almost the entire range of environmental technologies, was proposed back in 2009, in a report by McKinsey [48]. According to this curve, carbon capture and storage (CCS) projects had the greatest potential to reduce emissions (up to 38 $GtCO_2$/year), although they had the maximum cost of 30–55 Euro/t CO_2, depending on the type of source. Solar panels and wind generators cost 15–25 Euro/t CO_2, with a reduction potential of about 30 $GtCO_2$/year. This is one of the facts that easily explains why most climate policies have taken a course to scale up RESs.

However, 10 years later, this situation can already be seen from the perspective of the results and the real effectiveness of the selected measures. According to [49], the cost of reducing emissions of 1 ton CO_2 in the U.S. is between 115 and 530 USD, which is 10–50 times higher than most estimates of the SCC, which was mentioned earlier, and an order of magnitude higher than those given in the report by McKinsey. Even the current cost of capturing CO_2 from the atmosphere is estimated at 94–232 USD/per ton CO_2 [50]. By 2030, it may be less than 75–300 USD/t CO_2 [51], and by 2040, it may already reach USD 50 [52]. In [53] an analysis of the cost of reducing CO_2 emissions through various government regulation measures is made, the results of which are partly shown on Figure 4.

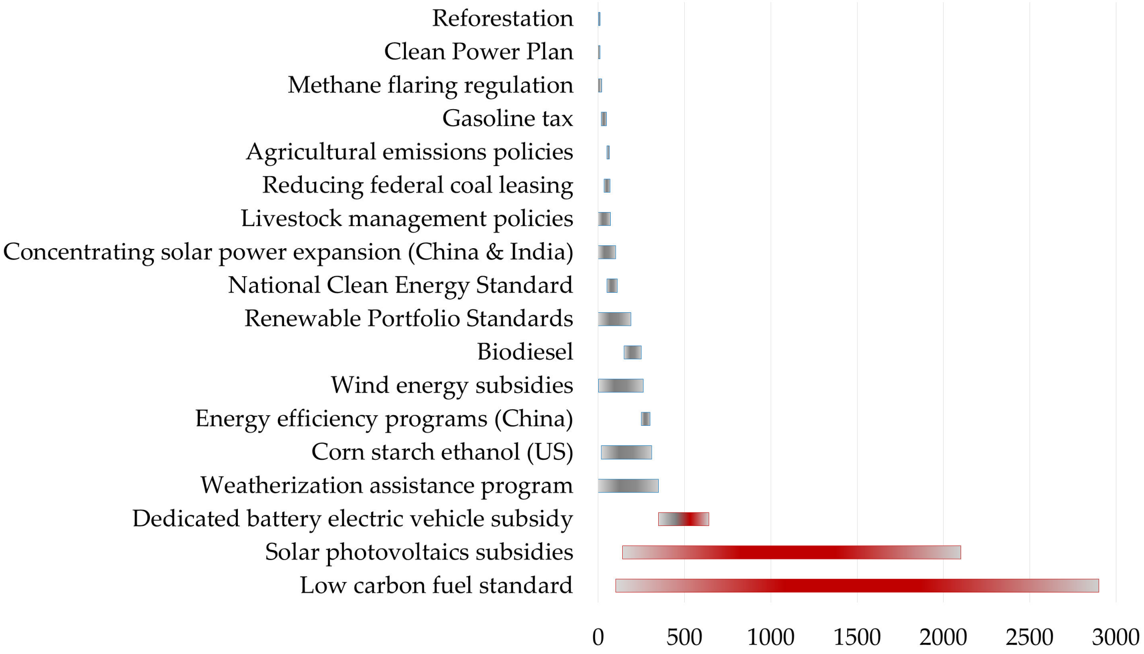

Figure 4. Static costs of policies, USD/t CO_2.

Thus, in an effort to focus on renewable energy, which had an optimal estimated price/potential scale-up ratio, we have come to a situation where costs are several times higher than expected, while further significant reductions in GHG emissions are occurring at a much lower rate than expected.

The [54] paper shows current results of estimating the necessary cost CO_2 to implement CCUS technologies at emission sources in the U.S. (80% of stationary sources are covered). The cost range varies from 40 to 260 USD/t CO_2 to cover 2 billion tons of CO_2 per year (of 2.6 billion tons of CO_2 from all stationary sources). The authors identify three key transition points in the cost curve [54]:

- Activation stage (up to 50 USD/t CO_2), like ethanol production with CCS (29 USD for capture + 17 USD for transport and storage = 46 USD/t CO_2);
- Expansion stage (50–90 USD/t CO_2), like for cement industry with CCS (64 USD for capture + 23 USD for transport and storage = 87 USD/t CO_2);
- At-scale deployment (90–110 USD/t CO_2), for national gas power system with CCS (93 USD for capture + 14 USD for transport and storage = 107 USD/t CO_2).

Similar values are shown in a recent report by McKinsey [55], according to which capturing and transporting CO_2 can cost as much as $80 per metric ton. Table 1 shows the cost of avoided CO_2 for various CCUS technologies and Table 2 shows the cost for CCU.

Thus, CCU and CCUS technologies are now quite competitive alternatives to renewable energy in terms of the cost of reducing CO_2 emissions. Despite this, very little research is being done today on the practical implementation of CCU technology chains on a global scale [56], which is one of the factors contributing to the imbalance in the feasibility of climate policies.

Table 1. Approximate cost of CCUS and CCS, USD/t CO_2.

Technology	**Data Collected by Budinis et al. [57]**		**Bhadola A. et al. [58]**		**Rubin E.S. et al. [59]**	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
Coal-fired power	24	110	23	36	-	-
Gas-fired power	67	115	12	102	-	-
Iron and steel	52	120	-	-	-	-
Refineries	6	160	-	-	-	-
Pulp and paper	47	93	-	-	-	-
Cement production	27	146	-	-	-	-
Natural Gas Combined Cycle	10	146	-	-	-	-
Oxyfuel combustion	48	99	36	102	-	-
Integrated Gasification Combined Cycle	3	140	-	-	-	-
Chemicals + bio or synfuel	20	111	-	-	-	-
Post-combustion (amine)	63	87	34	58	-	-
Pre-combustion	47	60	12	23	-	-
CCS	20	113	-	-	3.1	31.4
Enhanced oil/gas recovery	71	84	-	-	1.6	22
Transport. Onshore pipelines (30 $MtCO_2$/y)	-	-	-	-	1.3	2.2
Transport. Offshore pipelines (30 $MtCO_2$/y)	-	-	-	-	1.9	2.4

Table 2. Approximate cost of CCU, USD/t CO_2.

CCU Industry	IGU (2019) Global Gas Report		Source [60]		
	Min	Max	Min	Max	Capturable Volume in Europe, Mt CO_2/y
Iron and Steel	65	240	70	95	69
Aluminium	60	80			
Natural Gas Combined Cycle	55	170	-	-	-
Refining	45	130	40	103	59
Hydrogen	40	65	-	-	-
Cement	30	155	-	-	-
Petrochemical	15	30	65	113	-
Ammonia	15	25	-	-	-
Biomass-to-ethanol	15	25	-	-	-
Natural gas processing	10	45	-	-	-
Mineral	-	-	60	120	109
Chemical	-	-	-	39	39
Waste	-	-	150	200	61
Power	-	-	70	105	841

Reference [61] points out that the contributions of the CCU technologies traditionally considered are negligible against the background of the overall emission scale as well as the potential of CCS and CCUS technologies. However, this is only true in the context of their limited adoption and as long as we do not start to consider possible ways to integrate sequestration technologies with hydrogen economy technologies [62]. The CO_2 hydrogenation technology has a huge potential for development (Figure 5), which has not been sufficiently explored so far [63,64].

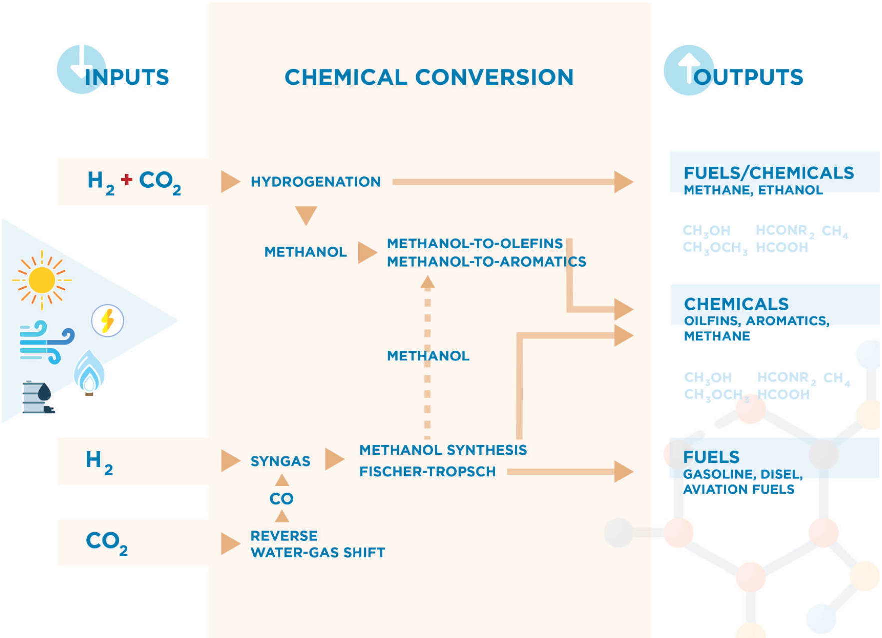

Figure 5. Cluster of CO_2-H_2 technologies.

Some of the hydrogen technologies already have industrial implementation, some are at the stage of laboratory testing [65]. However, for both groups, it is fair to say that there is a lot of work to be done before their large-scale use, for example in Europe, together with Russia [66].

Stern's [67] conclusion that there are many promising but underestimated ways to improve our climate initiatives that require further study seems to be the most true. For the CCUS technology group (including CCU), this is also confirmed by a special report by IEA [6], which allocates at least 15 percent of the global reduction in greenhouse gas emissions. The value of developing CCU, however, lies in the fact that part of this technology group has a negative carbon intensity [68]. In addition, potential markets that CCU projects can reach are estimated at USD hundreds of billions [69], and CO_2-based products can be quite competitively priced [70].

2.3. Methods of Scaling Solar and Wind Energy

Today's huge investments in renewable energy have naturally led to an increase in scientific research and patentable technical solutions in this field [71], which is generally considered a positive trend. However, it should be borne in mind that technological advances and research efficiencies may increase disproportionately to the amount of investment [72]. Today, there is no research that shows the correlation between the volume of investment and the efficiency of scientific activity, which is associated with a number of objective problems in evaluating science as such. It is important, that in market economy, such unlimited amounts of financial support could lead to a loss of competitiveness and, consequently, to a decrease in efficiency and quality.

As a confirmation of the insufficient impact of technological progress in the field of renewable energy on global trends in carbon intensity, we can consider the results of the study [73]. This article shows that the reduction of carbon intensity correlates much stronger with the volume of research and development (R&D) activity in the field of hydrocarbon energy than with the volume of R&D in the field of renewable energy. This can be interpreted as "industry over-financing," which points to the need to diversify technology portfolio of climate policies.

Large-scale introduction of RES technologies directly affects the cost of electricity, which is true for almost all renewable energy sources, except relatively cheap hydro power [74–76]. It is believed that in developed societies people are ready to pay a higher price for environmentally clean electricity. This theory is reflected in the Kuznets curve [77], which shows the dependence of the average cost of electricity on living standards. Many scientists have investigated this issue for individual countries [78,79] as well as in panel data analyses [80,81]. Despite a number of confirmations, there is a fair skepticism on this dependence, due to superficial approach to data collection, factors determination, panel balancing and results interpretation [82]. It should also be taken into account that expensive carbon-free energy generation does not mean that all parts of power facilities were produced with the same carbon-free technologies [83]. So that, even if one argues that Kuznets curve was found, there could also be enough space for carbon-intensive technologies.

An alternative method to clarify the possibility of introducing "environmentally friendly" energy technologies is the "willingness to pay" research [84]. Many of them show that there is a potential for electricity cost growth, although it may be quite limited [85]. In contrast to these results, there is also evidence of negative attitudes towards energy tariffs growth [86].

In order to reduce the price of green energy for consumers, many countries are introducing feed-in-tariff (FiT) systems [87]. This makes renewable energy more attractive in comparison with fossil fuels and it is recognized as one of the most effective methods of renewable energy large-scale development, despite the possible negative impact on macroeconomics [88]. Its practical use began in the U.S. in 1978, then in Germany in 1990, and today it is used in more than 45 countries [89]. Some countries also use its analogues and modifications, such as feed-in-premium, which is a form of fixed price that is paid to a green energy producer [90].

An alternative scheme to reduce the cost of electricity is the renewable portfolio standard, which, however, is difficult to implement and requires the creation of stable market mechanisms to replace the direct FiT government funding. This scheme is applied today in the U.S. [91], UK and is in the formation phase in China [92,93]. Although, as mentioned earlier, the effectiveness of its implementation in the U.S. is highly questionable due to the huge costs exceeding any SCC estimates.

At this point in the "willingness to pay" research there is a significant methodological deficiency. It is related to the fact that respondents express their willingness to pay for changes in vacation rates, but no one informs them that such green projects also require taxpayers' money. Therefore, the overpayment for 1 kWh should be calculated not as a difference in tariffs, but as a difference in unit level remuneration of traditional and renewable electricity generation, taking into account government subsidies. However, no such studies have been conducted so far, among other things, due to the fact that it is necessary to determine the total amount of financial incentives per unit of produced electricity, including the share of subsidies, which are distributed between already functioning and planning facilities. It will also require a calculation of the share of taxes, which were forwarded to support specific units of green electricity, provided to a consumer. All these calculations should be explained to an interviewee, which could be a complicated task.

3. Discussion

3.1. Policy Balancing

The fight against global warming is a multifaceted problem, the solution of which requires the development and implementation of multi-directional strategies, which, conditionally, can be divided into mitigation strategies and adaptation strategies [94]. If mitigation strategies involve the introduction of technologies to reduce or prevent greenhouse gas emissions [95], then the sense of adaptation strategies is to find ways to organize our activities, including those that are carbon-intensive, to stay in peace with nature [96] or at least not to aggravate the current situation. Thus, while the first strategy is more technical, the second one implies a paradigm shift in the perception of climate change and our role in these processes, although they are quite closely related [97].

Mitigation strategies, which include all technologies considered above, including renewable energy, are undoubtedly of paramount importance in the fight against global warming today. However, it is the focus on mitigation that leads to a misunderstanding of the role of raw materials in the global economy. The emerging paradigm of a negative perception of carbon-intensive industries, technologies and resources is in practice transformed into a poorly balanced climate policy focusing on supporting a limited list of technologies (Figure 6).

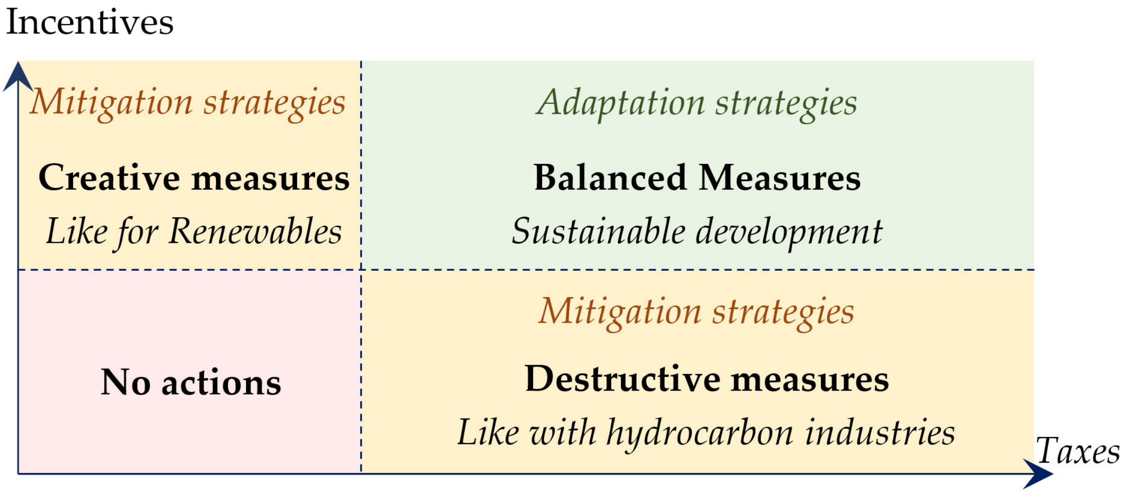

Figure 6. Essence of climate policy imbalance.

Instead of focusing on destructive measures for one group of industries and creative measures for another, it is necessary to find balanced measures, aimed at pushing carbon-intensive industries on the sustainable development pathway. It requires to reconsider our policy approach towards CO_2, which, given the extensive list of recycling technologies, may already be perceived not as gaseous waste of production, but as a resource [98], which also has its economic value. To implement this approach, in addition to technical complexity, there are two methodological barriers:

(1) To determine the utility of natural resource we have to rely on market valuation methods, despite their subjectivity. Moreover, using such methods under conditions of negative projects' profitability and volatility of markets is a rather complicated task, which bring significant uncertainty in the results of calculations. On the other hand, in order to develop adequate measures of state regulation, we have to use financial estimates [99], which can be easily interpreted by policymakers and companies, in contrast to qualitative or technical evaluation methods, like energy [100] or energy [101] analysis.

(2) In an attempt to solve the first problem, SCC estimation methods focusing on the loss of society from one ton of CO_2 emissions were proposed. Despite the supposed similarity of estimates, they have differences. The current situation is comparable to the fact that within the cost-benefit analysis we zero out some of possible benefits. It is explained by a huge gap in our knowledge about scalability of CO_2-based production chains, available to be captured amount of CO_2 and influence of carbon emission on a social welfare [102]. As a result, there is a stable belief that (1) there could be no benefits from CO_2 emission; (2) utilization pathways are much more cost-intensive than renewable energy. However, today we see that it might be wrong, since (1) CO_2 utilization could give us various valuable products; (2) the cost of renewable energy support is one-two orders of magnitude higher than expected.

Thus, a shift from the current unipolarity in defining the key areas of climate policy to comprehensive solutions that take into account not only the harm from CO_2 emissions, but also possible societal effects from its utilization (Figure 7), is needed today to maximize the economic utility of each ton of CO_2, an example of which can now be seen in the Oil and Gas Climate Initiative [103] through the implementation of CCUS projects.

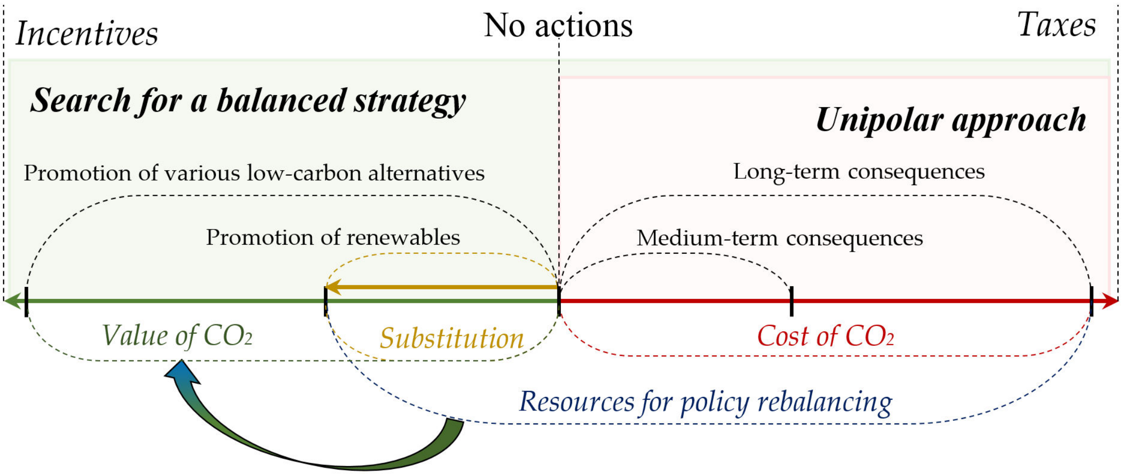

Figure 7. Pathway for climate policy rebalancing.

To date, there is only one major CCUS support initiative in the world-45Q Credit [104], introduced in the U.S. Industrial enterprises can receive up to 50 USD/t CO_2 in case of its geological disposal (CCS) and up to 35 USD/t CO_2 in case of its utilization in projects of enhanced resources recovery. Despite the timeliness and relevance of this measure, the issue of the list of supported options for utilization and the specific amount of financial support, which is especially important for regions with less developed technologies, are a matter of discussion.

The 45Q experience can be scaled by enabling CCU options to expand the technology portfolio. CCS/CCUS/CCU incentive measures should not be isolated, as this may lead to a shift in priorities towards one of the sequestration technologies, for example, as a result of lobbying for the interests of a specific companies. The most reasonable approach is to divide payments into two parts (Figure 8). The first is a fixed credit for the capturing per 1 ton of CO_2, which is the same for all options. The second is a premium for the characteristics of the technological chain and final products. In determining the amount of premium it is necessary to take into account that CCS has the greatest technical potential for reducing CO_2 emissions, but is a non-profit project. In this regard, it is necessary to ensure such a difference between the premiums for CCS and CCU/CCUS in order to maintain the interest of the private sector in the entire technology portfolio.

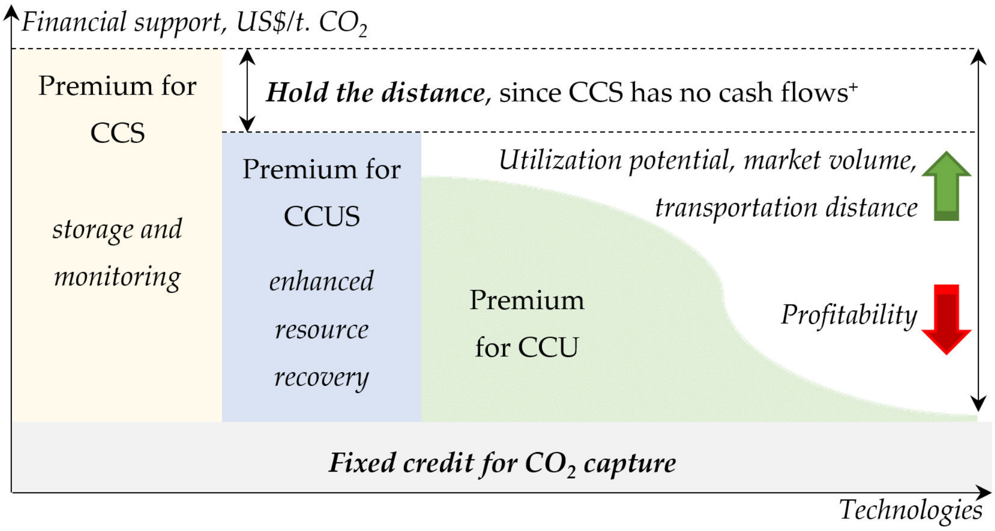

Figure 8. Framework for extending 45Q support mechanism.

Given much more extensive list of utilization options compared to CCS/CCUS, this can be a comprehensive task to combine the assessment of national/regional market characteristics and technical potential to reduce CO_2 emission of specific technology. Such policy can be implemented in any regions, including those that do not have suitable geological storage sites or necessary technologies/experience. A single policy for sequestration technologies support will allow: (1) to control the specific costs of reducing carbon intensity; (2) to systematize the support measures for the entire cluster of sequestration technologies; (3) to create a link between the emission trading schemes and markets of CO_2-based products.

In other regions, at the time of writing this article, similar support measures are not available. Specific cases of CCS and CCUS government co-financing in Europe, China, Middle East, etc. are usually implemented as direct investments in specific projects [105,106]. Taking into account the potential amounts of CO_2 utilization in CCS and CCUS projects [107], the relevant and timely solution is to adapt the experience of 45Q Credit in other leading countries in terms of extraction of raw materials, including hydrocarbons and extend it to a wider list of CCU options.

3.2. *Green Paradox: Imposed Climate Change Mitigation Pathway*

Today, there is the so-called green paradox [108], which consists in increasing hydrocarbon production (for example, in the U.S., prior to COVID-19), despite the implementation of increasingly stringent climate policy [109]. This is explained by the fact that the long-term goals of stricter taxation and infringement of the market position of hydrocarbon companies lead to a natural reaction to increase production volume [110]. The unwillingness to voluntarily reduce production has also shown the situation in spring 2020, after Russia withdrew from the deal with OPEC. Despite the fact that this situation originated from Russia and Saudi Arabia conflict, it influenced on all oil producers and led to a series of debates on the distribution of oil production reduction between countries. The return to the agreements became possible only after a catastrophic drop in oil prices and after a series of bankrupts, simultaneously caused by COVID-19.

Given the simultaneous and longer-term impact of the coronavirus, which may delay the implementation of a number of planned climate policy measures, the green paradox, i.e., an increase in the rate of growth of production and use of raw energy resources, can be expected in the coming years. Although some studies point to the possibility of only a local strengthening of the green paradox in some regions [111], such a scenario seems unlikely to occur, since hydrocarbons are an object of geopolitical interests (in terms of energy security and control of reserves) [112] and are a part of global energy market.

Given the inability to significantly reduce the production and use of hydrocarbon resources in the energy sector, both from an economic and technical point of view, it is necessary to reconsider the incentives in our climate policies for raw-materials companies to introduce low-carbon technologies, including CCS, CCUS and CCU. In addition to this, a two-way impact is required (Figure 9), since CO_2 sequestration alone does not involve market formation or technology development, and market support alone does not involve CO_2 sequestration. For example, even for CO_2-EOR, which is relatively profitable, both of these factors are of crucial importance [113]. In other words, in order to achieve climate goals, we need to accept that we cannot immediately abandon hydrocarbons resources and that we need to rethink how to encourage scaling up of environmental technologies in these industries.

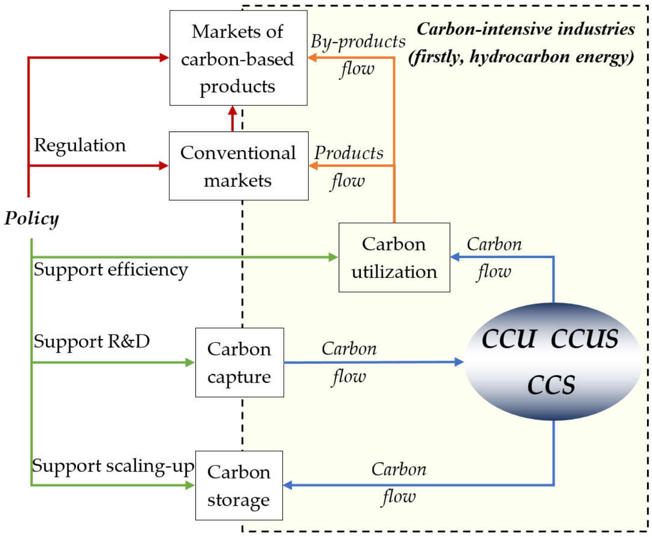

Figure 9. Conceptual framework for CO_2 sequestration support.

Redistribution of funds for the purpose of their investment in green technologies of hydrocarbon energy will allow to reduce excessive capital intensity of climate policy measures being implemented today [114].This is important not only in terms of diversifying the instruments of carbon intensity reduction, but also in terms of eliminating the duplicate and, in some cases, opposite effects of combined incentives on renewable energy markets, such as FiT + subsidies, which was defined in the last years [115,116].

3.3. Focus on Carbon Capture

Capture is a major challenge for CCU and CCUS, the solution to which depends entirely on the ability to increase the efficiency of available technologies [117].The cost of CO_2 capture varies widely enough from 15 to 60 USD/t CO_2 for concentrated sources, from 40 to 80 USD/t CO_2 for gas and coal power plants, and is over 100 USD/t CO_2 for small, dilute point sources (e.g., industrial furnaces) [118,119]. Nevertheless, the potential for cost reduction is quite extensive (Figure 10), especially with combined CO_2 capture methods [120].

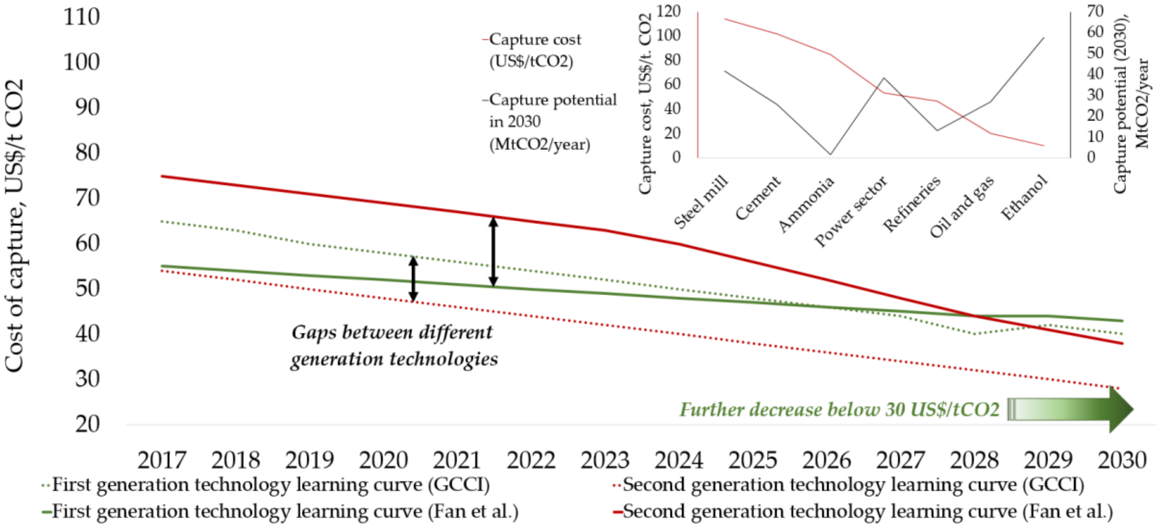

Figure 10. Learning curves of capture technologies. Based on [121–125].

However, even without taking into account the potential reduction in value, the range is from 15 to 100 USD/t. CO_2 can be considered as a relatively cheap option when compared to the current costs of some renewable energy initiatives. It seems fair to argue that the cost of renewable energy may also fall in the coming years, given the trends of recent years [126], but the curves of learning are not linear and they are characterized by a gradual slowdown in the rate of decline, which may happen to RESs in the near future.

Most of the CO_2 capture technologies, due to the much lower support, are at an earlier stage of technological development (Table 3), which gives prospects for significant price reductions and efficiency improvements. The key issue remains scalability [127]. Despite the fact that CCUS and CCU are not the most actively developing climate options today, the forecasts [128,129] show their potential for intensive expansion after 2030, which requires detailed planning of technological chains in the next decade, for which substantial investment costs are needed [130].

Table 3. Technology readiness level (TRL) of various CCUS/CCU options*. Based on [54,131].

CCUS/CCU Option	Mature	Early Adoption	Demonstration	Large Prototype	TRL
		Capture			
Natural gas processing	🟩				Absorption: TRL1-TRL9 Adsorption: TRL2-TRL7 Membranes: TRL3-TRL8 Cryogen: TRL3-TRL6 Oxy-combustion: TRL2-TRL4
Hydrogen		🟨			
Chemicals (ammonia)	🟩	🟨			
Chemicals (Methanol)		🟨	🟧		
Power		🟨	🟧		
Cement			🟧	🟥	
Iron and steel		🟨	🟧	🟥	

Table 3. *Cont.*

CCUS/CCU Option	Mature	Early Adoption	Demonstration	Large Prototype	TRL
			Transport & Compression		
CO_2 pipelines		🟨			Ship: TRL3-TRL7 Pipeline: TRL7-TRL9 Compression: TRL8-TRL9
CO_2 shipping			🟧	🟥	
			Storage		
Saline formations		🟨			TRL5-TRL9
Depleted Oil/Gas reservoir			🟧		TRL5-TRL8
			Use		
Chemicals (urea)	🟩				Electro/Photochemical: TR:1-TRL4 Thermochemical: TRL2-TRL5 Biological: TRL3-TRL9 Carbonation: TRL5-TRL8 EOR: Conventional-TRL7-TRL9 Unconventional-TRL3-TRL6
Enhanced oil recovery	🟩				
Building materials		🟨			
Synthetic methane			🟧		
Methanol			🟧		
Bioethanol			🟧	🟥	
Synthetic fuels				🟥	
Required measures to support CCUS/CCU at different stages	Market mechanisms for support (carbon pricing, regulatory standards, feed-in-tariffs/prices, operating subsidies)		R&D incentives, capital expenditures compensation		

As a whole, the involvement of CO_2 in production processes should not be a one-time thing. CCU should be advanced complementary to mitigation technologies and can unfold its potential in creating circular economy solutions [132,133]. It is precisely the circular economy will allow to close the gap between the actual and required carbon intensity of hydrocarbon energy, as well as laying the foundation for creating technological chains [134], including chains with negative carbon intensity (Table 4).

Table 4. Promising options with possible negative carbon intensity.

Option	Royal Society [135]			Fuss et. al. [136]		Hepburn et al. [137]	
	Potential, Gt CO_2/year	**Cost, US$/t$CO_2$**	**TRL**	**Potential, Gt CO_2/year**	**Cost, US$/t$CO_2$**	**Potential, Mt CO_2/y**	**Cost, US$/t$CO_2$**
Afforestation and re-forestation	3–20	3–30	8–9	0.5–3.6	5–50	70 to 1100	−$40 to $10
Forest management	1–2	3–30	8–9	-	-		
Wetland, peatland and coastal habitat restoration	0.4–20	10–100	5–6	-	-	900 to 1900	−$90 to −$20
Soil carbon sequestration	1–10	10 profit-3 cost	8–9	2–5	0–100	-	-
Biochar	2–5	0–200	3–6	0.5–2	30–120	170 to 1000	−$70 to −$60
Bio-energy CCS	10	100–300	Bioenerg: 7–9	0.5–5	100–200	500 to 5000	$60 to $160

Table 4. *Cont.*

Option	Royal Society [135]			Fuss et. al. [136]		Hepburn et al. [137]	
	Potential, Gt CO_2/year	Cost, US$/t$CO_2$	TRL	Potential, Gt CO_2/year	Cost, US$/t$CO_2$	Potential, Mt CO_2/y	Cost, US$/t$CO_2$
Enhanced weathering	0.5–4	50–500	1–5	2–4	50–200	n.d.	Less than $200
Mineral carbonation	-	50–300 (20 in situ)	3–8	-	-	-	-
Ocean alkalinity	40	70–200	2–4	-	-	-	-
Direct air capture	0.5–5	200–600 (100 mature)	4–7	0.5–5	100–300	-	-

4. Conclusions

The success achieved by RES in recent decades, mainly by wind and solar power, has created the misperception that this is the only true way to decarbonize the global economy. Simplicity of commercialization in conditions of almost unlimited financial support from the state attracts more and more new participants, thus making invisible the strengths of alternative climate technologies. A similar situation was observed in the oil market at a time of ultra-high commodity prices, as a result of which the efficiency of companies was declining and alternative investment options were practically not considered.

Today it becomes obvious that the measures taken are not enough, and the impact of renewable energy research on the process of carbon emission reduction is lower than needed [73]. Under these conditions, it is necessary to develop new conceptual approaches to reconsider the processes of forming energy and climate policies and to treat CO_2 as an industrial resource. There is no doubt that carbon is an integral part of our lives. Therefore, the fight against anthropogenic CO_2 emissions must not escalate into a war with industries, which provides for our current needs, as it goes against the concept of sustainable development, despite achieving the goals of the climate agenda.

As a result of the analysis, the following conclusions were drawn:

(1) The need to diversify the climate policy portfolio of technologies was already ripe at the beginning of the 21st century [138], but the necessary actions were not taken. The existing imbalance of financial support for climate technologies will not allow achieving the targets of keeping the temperature growth rate below 1.5 °C and, in case of an unfavorable scenario, will not allow achieving the climate targets of 2 °C. This is due to the fact that full replacement of hydrocarbon resources by renewable energy is impossible in the short and medium term [139].

(2) Focusing only on potential losses from CO_2 emissions may lead to a more dangerous conclusions than the need to combat oil, gas and coal companies, as the main driver of energy consumption growth is the growth of the world's population, which will increase by 30 percent by 2050. If climate targets are not met by that time, and if the flagship hydrocarbon industries, which are bound to finance renewable energy, are weakened, we will have to conclude that strict global population growth control is needed.

(3) Today it is necessary to switch from destructive measures (in terms of taxes and subsidizing competitor industries) in relation to the hydrocarbon industry to creative measures (in terms of incentives), which will provoke the introduction of environmental technologies at all production and processing facilities. It is these industries that are able to ensure a smooth and environmentally balanced energy transition [140], but only when conditions are created for the development of sustainable investments, including in renewable energy, but mainly in sequestration technology, as the main instrument of rational management of CO_2 [141,142].

(4) Today, there is no single cost-effective technology that can provide the necessary reduction of technogenic CO_2 emissions. This is also fair for almost all CCU and CCUS options, which require financial support to improve technology readiness level [143,144]. In this regard, it is advisable to start with enhanced fuel recovery technologies (like CO_2-enhanced oil/gas recovery) that have already proven themselves and require minimal support [145]. At the same time, despite some positive examples of their economic efficiency, such industrial applications require the improvement of regulatory mechanisms, which is superficial in many countries or absent at all [146]. It is crucial for late-production and post-production periods, while careful monitoring of depleted field is needed.

(5) The history of sequestration technology development is quite long and has both positive and negative examples that, in fact, caused the reduction of the attractiveness of these projects [147]. In documents available to the general public, the language should be accurately chosen, since conclusions such as "must not only focus on reducing emissions but also on reducing the amount of raw material used as inputs to the global economy" [148] can easily be taken out of context to develop abandonment activities as such, while the main goal is to maximize the value created by a unit of raw material, as well as to organize closed technology cycles which, combined with an effective climate policy, can help reduce global CO_2 emissions by 63 percent by 2050 [149]. This applies to both traditional raw materials such as hydrocarbons and CO_2 directly [150].

Despite the probable high climate change mitigation potential of CCU and CCUS technologies, there is a set of problems which remain unanswered. There are no clear estimations of how much CO_2 we could capture and what the price of this technology will be in the near future. It is also questionable, which part of captured CO_2 will be possible to use in production processes and which part will go into a geological storage. While these questions are not properly addressed, the value of CO_2 capture for the climate policy portfolio of technologies will not be fully appreciated.

Another significant factor constraining the development of CO_2 utilization technologies is the imperfection of the methodology for SCC evaluating, due to (1) the presence of regional differences and different models, which give divergent results, and (2) difficultness of determining social effects of CO_2 utilization. Development of methods and approaches in this area will make it possible to shift the focus from unidirectional measures of solar and wind energy support to capture and utilization technologies. Proper attention to the development of this cluster of technologies could make it possible to obtain CO_2 from natural and non-stationary sources with high efficiency in the near future, and, consequently, to ensure the emergence and scaling of projects with negative carbon intensity. However, such projects will make a sense only with functioning carbon and carbon-based product markets.

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