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CORSIA - A Feasible Second Best Solution?

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Abstract

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This paper studies the feasibility of CORSIA's carbon neutral growth goal based on verified carbon offsetting. It is motivated by an ongoing general debate about the climate and regulatory integrity of carbon offsetting, thus systematically identifying critical carbon offset characteristics. Using registry data from the largest carbon offset verifiers eligible under CORSIA, we show that the majority of carbon offsets has minor climate integrity and price differentials are only weak signals for climate integrity. This challenges CORSIA's neutral growth objective. To increase environmental effectiveness, a narrower scope of eligibility rules is necessary, ensuring maximum compliance of projects and to strengthen the necessary price effect of carbon offsets. However, it is highly questionable whether there is enough potential supply of offsets ensuring such high integrity, indicating that carbon offsetting should be considered as a transitory measure only.

Keywords: CORSIA; Aviation; Offsetting; Climate

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1 Introduction

In 2010, the International Civil Aviation Organization (ICAO) has decided to achieve Carbon neutral growth (ICAO, 2016). The Stern-Stiglitz High-Level Commission on Carbon Prices recognized that carbon pricing are indispensable for reducing emissions in an efficient way (Stiglitz et al., 2017). However, marginal abatement costs and political coordination costs had made it impossible to implement a global carbon price in aviation. In 2016, ICAO adopted the carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), requiring airlines to purchase carbon offset credits for emissions above average 2019 levels on international flights starting in 2021. Carbon offset projects reduce or store carbon dioxide or other greenhouse gas emissions by investing in renewable energy or the preservation of forests, for example, in order to compensate for emissions elsewhere. In aviation, carbon offsetting is a potential second best solution because GHG-reduction is immediate and technological driven alternatives like electric flying or synthetic fuel are not yet operational.

CORSIA's climate and regulatory integrity will highly depend on the offsets used. For example, the charming idea of storing global emissions by only planting trees is widely considered as challenging due to the lack of available land and the fact that the existence of large woodlands would have to be secured forever or for at least 100 years, assuming that climate change will have been solved by that time (Thamo and Pannell, 2016). As a consequence, forest carbon credits have been kept out of several key carbon markets, such as the European Unions Emission Trading Scheme (Chagas et al., 2019). Instead of carbon storage, carbon reduction by increasing energy efficiency has become more popular for offsetting although it is controversial as well. Frequently, carbon reduction projects do not depend on offsets and would have occurred anyway. Hence, the required additionality is questionable. In general, current low offset prices reduce incentives to invest in the technologies needed to decarbonize industries. Besides climate integrity, carbon offsetting challenges regulatory integrity by inducing adverse effects (Cames et al., 2016).

This paper is motivated by these drawbacks of carbon offsetting. It tries to answer the question whether CORSIA is a feasible second-best solution. Therefore, we systematically identify conditions that must be fulfilled for regulatory and climate integrity and highlight critical CORSIA eligible offset characteristics. Based on these findings, we empirically analyze the carbon offset market supply that is currently eligible under CORSIA and discuss how the market will likely interact with airlines and how the regulatory and climate integrity of aviation can be improved. We focus on the carbon reduction potential, on adverse effects and on prices. The drop in air traffic from the COVID-19 pandemic makes it unlikely that the airline sector will be required to offset any emissions in the next years, resulting in a window of opportunity for improving CORSIAs regulations.

The basic economic idea behind carbon offsetting resembles cap and trade systems but differences in the realization are huge. In both cases, differences in marginal abatement cost allow costs efficient emission reductions by trading CO_2 permits. However, cape and trade systems are capped in absolute terms, closed and balanced. Increases need to be counterbalanced by reductions, often in comparable general regulatory settings within countries, sectors or economic areas. In most cases, carbon offsetting is uncapped in absolute terms and operates in segregated jurisdictions, potentially requiring extensive bureaucracy to guarantee climate and regulatory integrity. To ensure climate and regulatory integrity, carbon offsetting and cap and trade systems require monitoring, reporting and verifying of emissions. However, offsetting projects need to fulfill criteria like additionality, permanency and no adverse effects. This is why quality standards have emerged guaranteeing that most important criteria are satisfied.

The complexity of carbon offsetting is expressed by its high transaction costs (Cacho et al., 2013). Under CORSIA, currently projects verified by six organizations are eligible to offer a heterogeneous portfolio of offsets from all over the world, of different sizes, types, investment costs, developers, verifiers and prices - even within standards. As a result, guaranteeing full compliance for all registered projects is challenging and the probability of adverse selection depends on project characteristics (Broekhoff et al., 2020). In order to better understand potential draw-backs of CORSIA eligible offsets we explain related critical characteristics and their consequences for climate and regulatory integrity to evaluate the eligible offset supply using registry data of the largest suppliers CDM, VERRA and Gold Standard - accounting for two third of all traded offsets (Hamrick and Gallant, 2017).

Due to the ambiguous climate benefits of carbon offsetting, offset prices are important to incentivize emission reductions in the buying sector. Currently, the carbon offset market is characterized by a structural oversupply. Today, offsetting a ton of CO_2 under CORSIA would cost less than $1. Moreover, the potentially long lasting drop in air traffic from the COVID-19 pandemic and the general increase in fuel efficiency makes it unlikely that the airline sector will need to offset emissions in CORSIA's first year (IATA, 2020). This limits CORSIA's price effect. Future offset price developments likely depend on other factors like regulatory changes under the Paris Agreement which could reduce the offset supply. However, the uncertainty is high, expressed by large variation in predicted price ranges. Whereas NGOs focused on carbon markets state that offset prices might end up anywhere between $0.70 and $12 by 2035, IATA assumes prices between 20$ to 40$. High price variation is observable today – even within carbon offset standards. Atmosfair, a German nonprofit organization offering voluntary offsets, charges $28 per ton under the Gold Standard certification whereas other Gold Standard offsets are available for $3. Given the uncertainty of future price developments, we refrain from predicting future price impacts on climate integrity. Instead, we focus on today's high price variation and evaluate whether prices are useful as a signal for climate and regulatory integrity.

This paper adds to the literature by pinning down those characteristics of CORSIA eligible offsets that jeopardize climate and regulatory integrity. In comparison to the related literature, we connect theoretical consideration on critical offset characteristics with the offset composition of eligible programs using corresponding registry data to discuss how airlines will interact with the offset market. Based on this findings, we show how the eligibility criteria need to be adjusted to increase climate and regulatory integrity under CORSIA and discuss alternative regulation.

The results of our paper indicate that CORSIA's eligibility criteria increases climate and regulatory integrity. However, a series of challenges remain to guarantee full climate and regulatory integrity using carbon offsetting. Still, there is high variation in eligible offsets and many of them challenges climate and regulatory integrity with a high probability. Our results indicate, that carbon offset prices can not be used as a signal for regulatory or climate integrity.

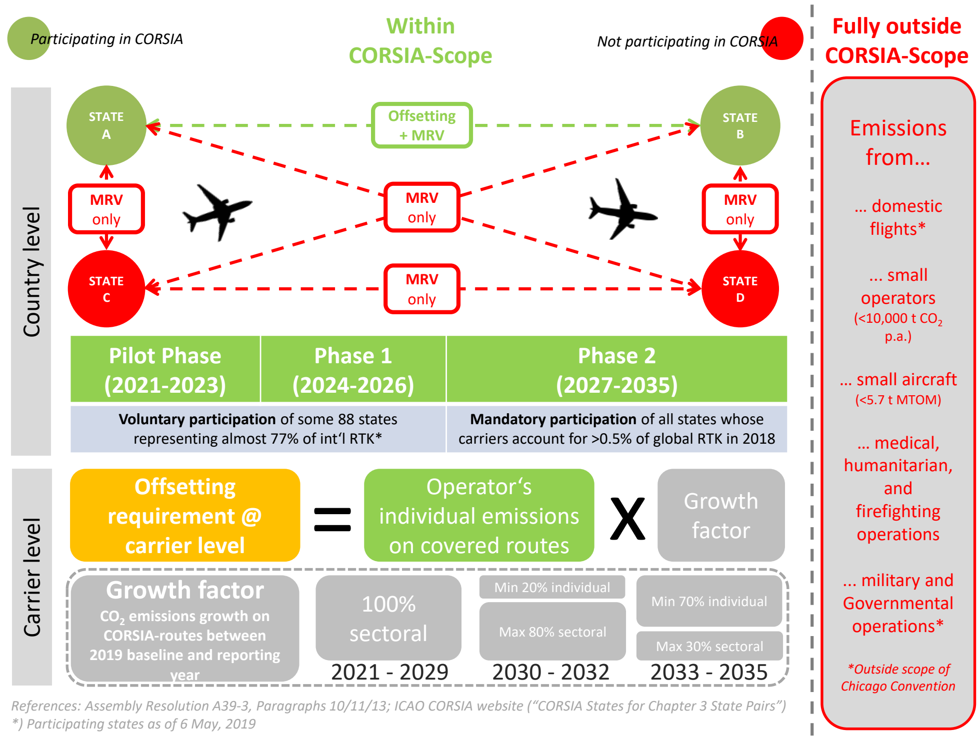
The paper is structured as follows: In Section 2, we show the institutional and technical background explaining the technical boundaries in aviation and critical offset characteristics. In Section 3, we analyze the carbon Offset market with a specific focus on carbon offsets that are eligible under CORSIA using registry data. Section 4 discusses our findings in light of alternative concepts. Section 5 concludes.

2 Institutional and Technical Background

This section highlights CORSIA's institutional and technical background which is important to understand why it has been implemented and why it has often been criticized. We explain offset characteristics in more detail to increase awareness of potential conflicts with climate and regulatory integrity.

2.1 Scope of CORSIA and eligible Offsets

In October 2016, CORSIA was agreed at the 39th ICAO Assembly after decades of difficult international negotiations (Assembly Resolution A39-3). CORSIA aims at supporting ICAO's Carbon Neutral Growth (CNG) goal from 2021 onwards. CORSIA is a baseline-and credit-scheme. The baseline above which emissions will have to be compensated or abated was initially defined as the average total CO_2 emissions of all international flights under the scheme in the years 2019 and 2020, respectively. To reflect the Covid-19-related decline in 2020, this was – in the meantime – changed to 2019 only. CORSIA is the first global scheme for the limitation of aviation's CO_2 emissions. However, criticism has been raised concerning CORSIA's environmental ambitiousness which we will discuss below. CORSIA will capture an increasing number of participating states over time. In the medium term, roughly 90 per cent of civil international air traffic shall be included. CORSIA is a baseline-and credit-scheme, requiring offsets for all CO_2 emissions exceeding the 2019 emission baseline. Of course, a number of exemptions apply. For instance, CORSIA only applies to CO_2 emissions from international flights, as ICAO is the UN Agency for international civil air transport while domestic operations are fully under responsibility of the individual states. Other exemptions refer to emissions from small aircraft with an MTOM below 5.7 tons, small emitters emitting less than 10,000 tons of CO_2 annually and to humanitarian, medical and firefighting flights. As ICAO is responsible for civil operations only, military and governmental flights are completely excluded. However, monitoring, reporting and verification (MRV) of CO_2 emissions under CORSIA is mandatory for all ICAO contracting states, irrespectively of any voluntary or mandatory participation. MRV obligations started in 2019. CORSIA consists of three phases: Pilot Phase (from 2021-2023), Phase 1 (2024-2026), and Phase 2 (2027-2035). Whereas Pilot Phase and Phase 1 are voluntary, the participation in Phase 2 is mandatory for all states whose airlines accounted for more than 0.5 of global international RTK in the year 2018. Only least developed countries, land-locked developing countries as well as small islands are exempted from this obligation. Of course, voluntary participation is possible for any ICAO contracting state. Offset requirements are defined by the routes flown. Only routes between participating states ('CORSIA States') are subject to these offsetting requirements. The following figure summarizes CORSIA's main characteristics:



Notes: This Figure highlights the principle design of CORSIA in 2021. Source: Own Figure Maertens et al., Options to Continue the EU ETS for Aviation in a CORSIA-World, Sustainability, 2019.

Figure 1: **Principal design of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).**

In March 2019, the ICAO Council adopted Emission Unit Eligibility Criteria (EUCs) which specify the requirements for carbon offset credits to be eligible under CORSIA. Carbon-offsetting programs have to fulfil these requirements and need to be approved by the ICAO Council as eligible programs. Currently six offset program standards are eligible: Clean Development Mechanism (CDM), Gold Standard (GS), Verified Carbon Standard (VERRA), American Carbon Registry (ACR), Climate Action Reserve (CAR), China Greenhouse Gas (GHG) Voluntary Emission Reduction Program. Among these programs, offsets are eligible from projects that started their first crediting period from 1 January 2016 and in respect of emissions reductions that occurred through 31 December 2020. Some program specific offsets have been declared as non-eligible (ICAO, 2020).

2.2 Technical Boundaries justifying Offsetting

In the past, fuel efficiency in aviation has increased by around two percent per year. These environmental benefits have been outpaced by sustained growth in air traffic which is likely to double in the next decade (ICAO, 2019). Under such growth scenarios, sector-wide net emission reductions are very ambitious, especially since advanced technologies for clean flying such as synthetic fuel are not yet in operation.

Offsetting seems to be particularly attractive for the air transport industry. This industry is considered to be a 'hard(er)-to-abate sector', both for technological and economic reasons. Marginal abatement costs in the aviation sector are considerably higher than in other (transport) sectors. This is because fuel costs have a share of about one third of total production costs in air transport and the sector has constantly been trying to cut fuel costs for decades. Therefore, it is reasonable to assume that reducing fuel costs has been in the very interest of the aviation industry for many years and relatively less expensive solutions have mostly been implemented.

Hydrocarbons, which are the root cause of the carbon emissions of air transport, can be regarded for aviation applications as optimal energy carriers. They feature an optimal combination of chemical characteristics, first and foremost energy density, but also further properties (freezing point, handling safety, storability) and economic characteristics, such as ubiquitous availability and affordability.

Alternative energy carriers and propulsion technologies, which can be introduced in ground transport with relative ease do not work as technological equivalent in air transport. Batteries will allow electrical aircraft for the foreseeable future to be operated with only a small payload over distances of less than 500km. Unless a not foreseeable progress in battery technology is being made, long-haul flights will remain unfeasible on battery power.

Hydrogen would be technologically feasible, but is associated with numerous disadvantages. Firstly, an enormous amount of green electricity would be required to produce hydrogen for the air transport sector alone. Secondly, storage and distribution is challenging due to its physical properties, such as the propensity to diffuse through tank walls. Thirdly, the low overall efficiency measured as a proportion of final energy content available for propulsion to the energy input required to produce green hydrogen will likely lead to relatively high prices. Fourthly, the size and weight of hydrogen tanks would reduce energy efficiency of aircraft. Lastly, emissions of water vapor, contrails and nitrogen oxides (in case of direct hydrogen combustion in gas turbines) at high altitudes will also occur with hydrogen powered aircraft and contribute to so-called non-CO_2 climate effects. Aviation contributes to climate change by both CO_2 and non-CO_2 effects, such as ozone and methane changes from NOx emissions or contrails and contrail cirrus. The climate relevant effect from non-CO_2 species can be even larger than the effect from CO_2 (Lee et al., 2021). Hence, even with an air transport sector hypothetically relying on hydrogen as energy carrier, the need to offset climate impacts will still be present to a certain extent. This will similarly apply to a situation where hydrocarbons synthetized from water and CO_2 captured from ambient air under utilization of green electricity would be utilized. While the CO_2 would be subject to a circular economy where the same amount of emitted CO_2 is captured and recycled to produce new hydrocarbon fuels, the non-CO_2 effects of water vapor, contrails, cloud-inducing ice crystals and nitrogen oxides would still persist.

Hence, a completely climate-neutral aviation system is far from being realistic in the foreseeable future and mitigation of climate impacts of aviation by other means remains a necessity.

2.3 Necessary Conditions for Climate and Regulatory Integrity

Carbon offsetting can be a step towards climate protection in the short-term especially if sectoral marginal abatement cost are relatively high as it is the case with aviation and potential first best solutions are politically not feasible due to high political coordination costs. However, carbon offsetting is costly as well as it is depends on extensive bureaucracy to ensure regulatory and climate integrity. From a policy makers perspective carbon offsetting is extreme complex. It brings together subjects from very different jurisdictions, usually highly regulated carbon emitters and carbon savers that operate in less developed and regulated markets. Thus, it is not only carbon that is traded but also regulation of economic activity, increasing the risk for adverse effects like social oppression.

The second basic problem is the identification of actual net carbon reductions, stemming from asymmetric information and uncertainty. Most importantly, the climate effect of carbon offsets hinges on whether the projects would have occurred in its absence - known as additionality. It can be argued that additionality is an inherently uncertain concept due to its dependence on an unobservable counter-factual scenario (Gustavsson et al., 2000). If the project would have be conducted anyway, emissions are not reduced by the offset scheme. Due to asymmetric information, opportunity costs of investors are private knowledge and thus investment decisions, leading to a free riders problem by generating additional revenues with carbon offsets. Carbon offset dependency of projects that reduce GHG-emissions can be divided into two phases. Some projects only depend on start-up financing whereas other projects needs offsets to finance the running costs. Even if it was known that carbon offsets are necessary for today's investments there would be uncertainty if tomorrows investors would have invested in the same project without carbon offsets in case the carbon offset project would not have been realized. Later investments could be driven by changes in legislation or efficiency gains. For example, many countries have introduced legislation to support the use of efficient lighting, which has been the scope of some offset projects (Warnecke et al., 2017).

Besides additionally, permanency and the prevention of carbon leakage are two major challenges to ensure effective net carbon reductions. However, non-permanency and carbon-leakage are rather project-type specific problems, challenging projects based on carbon storage like reforestation, for example. By declaring regions as protected carbon leakage may occur if the agricultural industry simply shifts to unprotected locations. It is possible that offset projects are only delaying carbon releases, since fossil fuels or biomass stocks will remain unused only until someone finds it convenient to use them (Espejo et al., 2020). Guaranteeing permanency of carbon storage is important as it can only develop its climate effect if storage is guaranteed for at least 100 years, assuming that climate change will have been solved by that time (Thamo and Pannell, 2016).

To ensure regulatory integrity and actual carbon reductions verification standards have been established which include assessment procedures for carbon offset projects. Safeguard clauses have been developed to identify and reduce adverse effects and verification and monitor processes have been implemented to ensure additionality, permanency and no carbon-leakage (Michaelowa, 2014). A critical challenge is determining the optimal balance between compliance and supply. If quality standards are too stringent, some desirable projects may not participate (Chomitz, 1998). Satisfying requirements for additionality, permanence and to encounter adverse effects increases transaction and investment costs. For example, where there is a risk of non-permanence, verification standards requires carbon offset projects to insure against it by making use of buffer accounts. Projects contribute a share of carbon credits to a buffer account and, in case of reversals, an equivalent number of buffer credits are canceled. This creates high opportunity costs.

These may be reduced by simplifying validation processes, but at the cost of lower climate and regulatory integrity (Cacho et al., 2013). As a result, adverse selection challenges offset standards (Bushnell, 2011; Bento et al., 2015). Many certified offset projects are suspected of being no effective net GHG reduction (Cames et al., 2016; Warnecke et al., 2017). Trade-offs arise by project characteristics as assessments are partially subjective and difficult to validate (Schneider, 2009) and core indicators could be subject to manipulation (Haya et al., 2012). Thus, ensuring full compliance for all projects is challenging for verification standards given high heterogeneity in sizes, types, investment costs, developers, verifiers and prices.

Some unsolved issues remain apart of the verification standards scope. One example is double counting, where the same emission reduction is counted of both the host country and the offset purchaser. Prior to the Paris Agreement, this was less of a concern because only developed countries had absolute emission reduction targets. As countries with a reduction target were able to purchase offsets from countries without such targets, the risk of double counting was less relevant. Under the Paris Agreement, all parties have absolute emissions reduction targets. Therefore, it has to be ensured that emission reduction counted for offsets are not also counted by the host country's Paris target as well. It remains unclear how such double counting can be avoided (Schneider and Healy, 2019).

2.4 Critical Carbon Offset Characteristics

Most challenges for regulatory and climate integrity differ by project type, region and size – some are unilateral. By implementing safeguard clauses, verification and monitor procedures carbon reductions verification standards have put a lot effort to ensure the climate and regulatory integrity of carbon offsetting.

For a better understanding of the development of the carbon offset's market regulatory integrity, it is important to know that the CDM – which has laid the foundation of certified offsetting – started as a market mechanism designed to foster sustainable development in developing countries and simultaneously assist developed countries in cost-efficiently complying with their emission reduction targets. The CDM is a mechanism defined in the Kyoto Protocol that provides offsets which may be traded in emissions trading schemes. Compared with today's certification procedures, regulatory integrity had a lower priority which encouraged adverse effects like social oppression (Finley-Brook and Thomas, 2011; Newell, 2012). Moreover, no particular institutional or financial incentives for projects that benefit the local communities have been implemented. Facing trade-offs between quantifiable emission reductions and hard to quantify sustainable development benefits, project developers seem to prefer the former. As a response, private programs like the Gold Standard have developed project methodologies taking sustainable development benefits and safeguard clauses into account (Michaelowa, 2014). Offset portfolios and certification procedure have been adjusted in response to lacks in regulatory and climate integrity. For example, Gold Standard has decided to exclude controversial project types like large dams from its portfolio (Goldstandard, 2019). The CDM has regularly adjusted its monitoring and verification methodology.

Project characteristics are much more important for regulatory integrity than differences between verification standards (Drupp, 2011). For example, large scale projects are frequently more prone to direct adverse effects like social oppression (Haya et al., 2012) and small-scale projects often deliver a higher number of co-benefits. Furthermore, there is substantial variation in co-benefits and adverse effects across different project types (Alexeew et al., 2010; Ellis et al., 2007; Olsen and Fenhann, 2008; Schneider et al., 2007; Subbarao and Lloyd, 2011; Sutter and Parreño, 2007). For example, biomass, land-use and wind projects contribute more co-benefits and less adverse effects compared to projects targeted on industrial emissions or large dams (Alexeew et al., 2010; Finley-Brook and Thomas, 2011; Jagger and Rana, 2017).

Currently, small scale energy efficiency projects targeted to the local population like cook stove projects which replace fireplaces with efficient stoves tend to be best practice, especially due to their high financial need. From an economic point of view it appears counter intuitive to invest in inefficient projects. However, this is a simple mechanism to guarantee additionality, often used in carbon offset standards. The less profitable a project is the less likely it is that a private investor would have invested in it anyway. However, the corresponding literature does not analyze how such inefficient investments affect the local economy in the longer term. In theory, it could crowd-out more efficient and long-lasting investments that would have been installed by the local government due to political pressure or by local businesses, thus reducing economic growth (Djankov et al., 2008). The current best practice in offsetting potentially induce a trade-off between additionality and indirect adverse effects whose importance might be limited today due to the small share of such projects but could became sizable if offsetting regain importance.

As already mentioned above, project characteristics matter in terms of climate integrity. Small scale projects outperform large scale projects due to lower economic returns of scale. Most large scale projects would have occurred independent of offsetting investments either due to high profitability or due to public investments (Cames et al., 2016). The scale of activities also matters for permanence risks and leakage. Large-scale forest programs, for example, are more difficult to control and predict given the size of territories, political priority shifts, oscillation in prices of agricultural commodities, and variations in government budgetary spending for forest protection (Chagas et al., 2019).

The project region can also have a sizable impact on the climate integrity, especially with respect to carbon-leakage of land-use projects. The more attractive the land that is used for reforestation is for agricultural production, the higher the probability of carbon-leakage by cutting unprotected forests as substitute. Thus, climate integrity is higher in areas with degraded peatlands, for example, which are no longer in agricultural usage (German Emissions Trading Authority, 2018).

As mentioned in section 2.3, there is a trade-off between climate and regulatory integrity with respect to transaction costs in general. Additionally, large scale project have lower transaction costs than small scale projects and transaction costs vary between project types. For example, they are on average lower for carbon storage compared to carbon reduction (Antinori and Sathaye, 2007).

Taken together, there are several trade-offs between additionality and adverse effects on the one hand and permanency and leakage on the other. Carbon reduction projects suffer more from additionality and adverse effects while carbon storage like reforestation is more prone to permanency problems and carbon leakage. Furthermore, there is a trade-off between transaction costs and additionality with regard to project size. Transaction costs are low for large scale projects. However, large scale project have a lower probability of being additional.

3 The Carbon Offset Market

In this section we describe the current carbon offset market using registry data of the three most important offset certification programs under CORSIA. These are Gold Standard, VERRA and the CDM. After describing the offset market, we analyse the carbon offset price as a signal for climate and regulatory integrity. We focus on variation in program standards, project types and sizes as Section 2.4 has shown how important these characteristics are to asses offset quality.

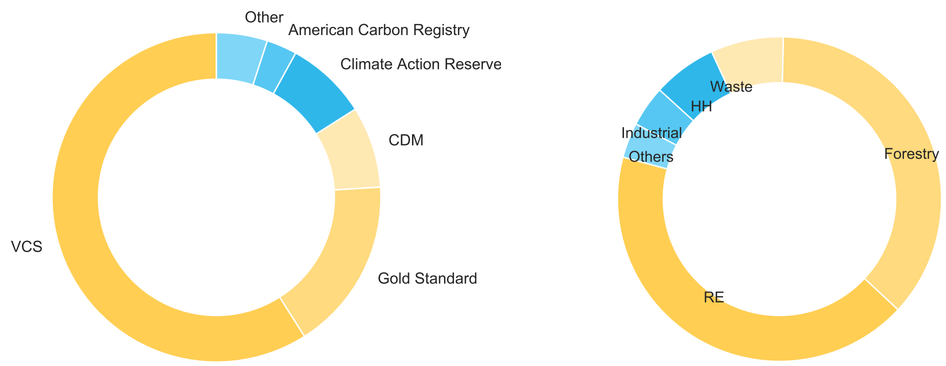
3.1 Market composition

The regulated carbon offset market in form of the CDM has lost relevance in the last decade because limits on the use of offsets in the EU ETS were reached and due to the delay in agreeing on a new successor regime for the Kyoto protocol (Michaelowa et al., 2019). Nevertheless, the market rationale survived in the private sector through a host of voluntary carbon offsetting schemes regulated by private offset certification programs. Offsets are traded at the secondary market, on stock exchanges or directly bought from the offset project at the first market. The governance of the voluntary offset market is loosely structured.

While offsetting standards set the rules and monitor compliance, there are a number of different types of organizations that generate the offset supply. Some span the hole process from initiating and implementing greenhouse gas reduction projects and managing their assessment and verification to selling the resulting credits to emitters. Other offset organisations act more like brokers, simply buying and selling offsets (Lovell et al., 2009). Offset projects are regionally centralized, predominately located in the Global South due to lower marginal abatement costs and development assistance. For example, 60 % of the total CER supply potential comes from China alone (Schneider et al., 2017).

The carbon offset market is concentrated among carbon offset project types. In 2019 around 100 Million tonnes of CO_2 equivalents were traded (Donofrio et al., 2020). Renewable energy and forestry and land use are the most important offset types by far, representing 79% of offsets traded in 2019 (see Figure 2). For example, projects which focus on the exchange of household devices with less energy consumption, like cook stove projects only account for 6.4 % of all traded offsets in 2019.

Offset certification programs are highly concentrated on private companies. The most common standard is VERRA's Verified Carbon Standard, accounting for around 60% of all offset transactions in 2019. Other popular standards are Gold Standard (17%), CDM (8%), Climate Action Reserve (8%) and American Carbon Registry (3%) - all of which are eligible under CORSIA (see Figure 2). Public standards lost importance, as the small share of CDM transactions indicates, due to the collapse of the market in the early 2010s. As a result, only one third of CDM projects continued issuing offsets. However, the majority of projects continue GHG abatement without issuing offsets while other project developers have gone bankrupt (Schneider and Cames, 2014; Warnecke et al., 2017). Especially vulnerable projects did not survive (Kreibich and Obergassel, 2019). Still, the CDM has by far the largest capacities of carbon offsets, although other certification program standards could steadily increase their supply (see Figure 3a).

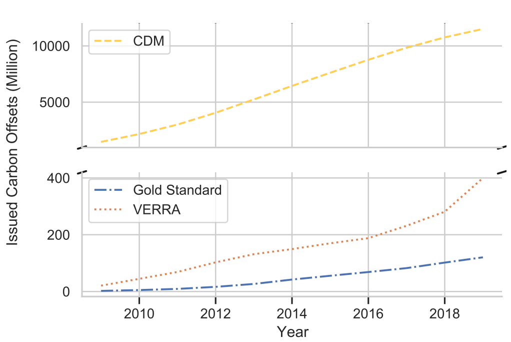


(a) **Carbon offset certification programs** (b) **Carbon offset project types**

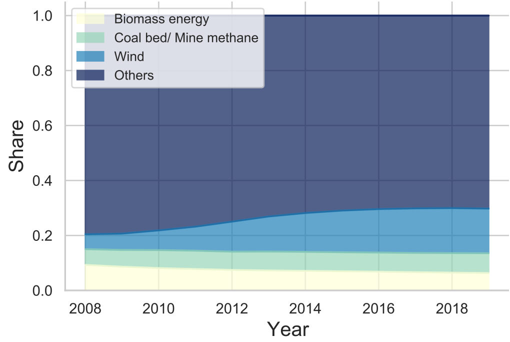
Notes: Panel (a) shows the market share of carbon offset certification programms in 2019 based on traded carbon offsets. Panel (b) shows the market share of carbon offset project types in 2019 based on traded carbon offsets. RE: Renewable Energy, HH: Household energy efficiency. Source: Donofrio 2020, own illustration.

Figure 2: **Market share of program standards and project types in 2019.**

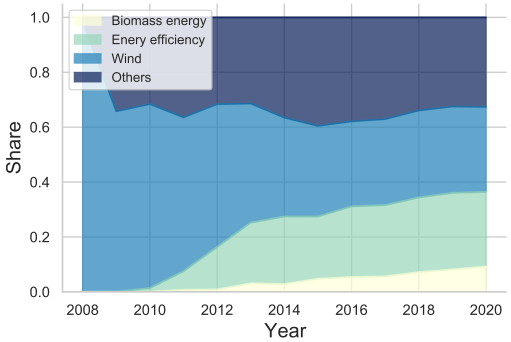
CORSIA's selection of eligible certification program standards is essential for the project type composition of CORSIA's offset supply because private standards tend to specialize their offset portfolio. Figure 3 shows the program standard specific composition of offset project types over time by focusing on those three project types per program standard that deliver the largest relative amount of offsets. Smaller project types are summarized under 'others'. Figure 3b shows that the composition of the CDM is heterogeneous and constant over time. Wind is the most important source accounting for 16 % of supply in 2020 followed by projects that reduce coal-mine methane and biomass energy, both accounting for around 6 % of supply in 2020. Other project types that are smaller than 6 % account for 71 % of supply in 2020. Figure 3c and Figure 3d show that project type composition of the Gold Standard and VERRA has developed more dynamic. For example, the Gold Standard was heavily focused on wind energy 13 years ago. It has diversified since and is now the leading program standard for domestic energy efficiency projects which account for 27 % of Gold Standards total offset supply in 2020. VERRA, on the other hand, has become today's leading supplier for land-use projects like reforestation. However, wind energy remains the most important source of offsetting supply in general.



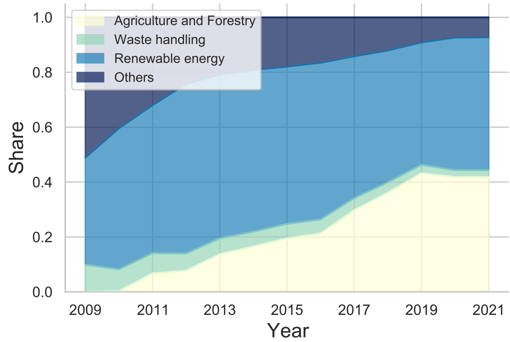
(a) **Cumulative issued carbon offsets**



(b) **Project type share of CDM**



(c) **Project type share of Gold Standard**

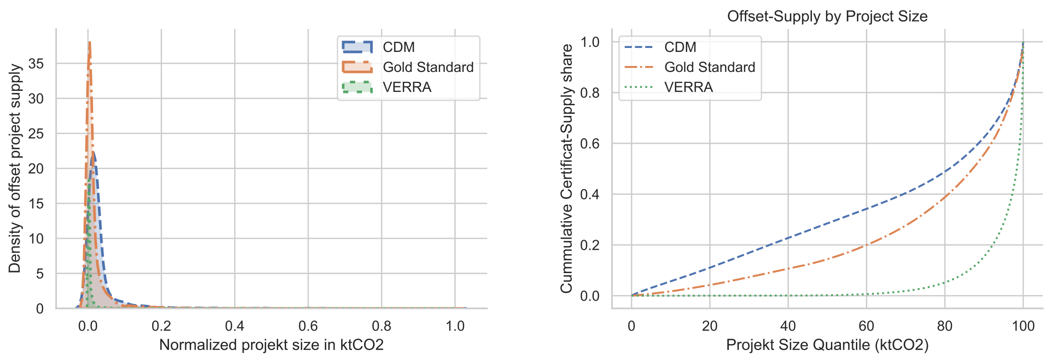


(d) **Project type share of VERRA**

Notes: Panel (a) shows the cumulative issued carbon offsets of the CDM, Gold Standard and VERRA over time. Panel (b), Panel (c) and Panel (d) show the time-varying share of carbon offset projects types for cumulative issued carbon offsets of the CDM, Gold Standard and VERRA. Source: Own calculation.

Figure 3: **Supply of carbon verification standards programs and share of offset types by program.**

Offset certification programs also differ with respect to project size. Figure 4a shows that the large majority of offset projects are very small, irrespective of the program. The Gold Standard has the largest share of small scale projects. However, Figure 4b reveals that a naive look on the number of small scale projects would be misleading. For example, the largest 20 % of offset projects account for 60 % of total Gold Standard supply. In case of the CDM, the largest 20 % account for 50 % of offset supply. VERRAs total offset supply is almost entirely based on large-scale projects. The CDM portfolio is more divers with respect to project size than VERRA or Gold Standard.



(a) **Distribution of program standards' project sizes** (b) **Share of different project sizes on total supply**

Notes: Panel (a) shows the distribution if the normalizes project size measured in ktCO_2 for CDM, Gold Standard and VERRA. Panel (b) shows the share of different project sizes for the total total supply for for CDM, Gold Standard and VERRA. Source: Own calculation.

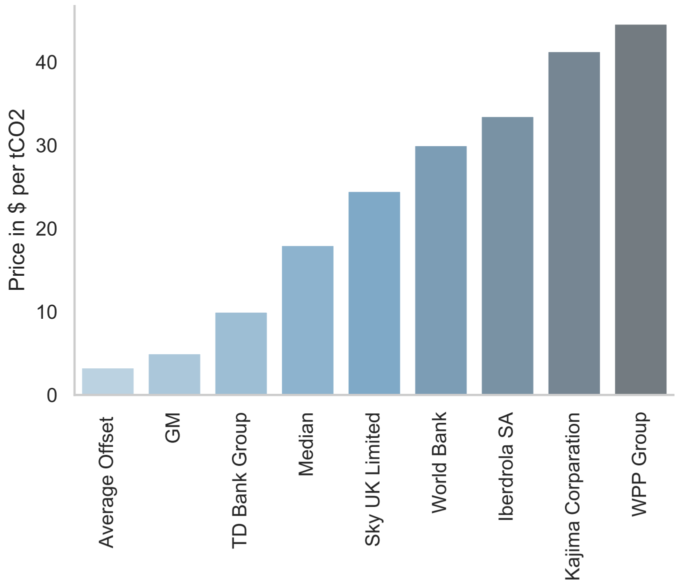
Figure 4: **Distribution of carbon offset supply by project size.**

3.2 Price as a signal

Prices are important signals for market participants. They can be useful to identify market failures. The discourse between supply and demand has had a dramatic effect on prices, especially on the regulated carbon offset market, from which the market has never recovered. While the demand side collapsed, the supply side was stably delivering carbon offsets as it is weakly price sensitive, once the initial investments are undertaken (Michaelowa et al., 2019). In case of voluntary offsets, trade volume and prices stabilized at a lower level, traded at the first market.

Today, many companies estimate their individual price on carbon as a shadow price, using it as an input factor for cost benefit analyses to get a sense of climate risks. A survey among 435 international companies revealed a median carbon price of \$18 per ton of CO_2 in 2016. The World Bank estimated a price for one tone of carbon as be equivalent to its social costs of \$30 per ton of CO_2 in 2016. The average price at the voluntary offset market was around \$3 (see Figure 5). This strong discrepancy between demand and supply side prices indicates the failure of the carbon offset market.

Carbon offset prices vary substantially by certification program standard and project type. According to Figure 6, there is sizable variation in the amount and price of traded offsets at the voluntary primary market in 2019. Figure 6a shows a negative correlation between the program standards trade volume and the average traded prices of the program standards' offset portfolios. VCS accounted for almost 2/3 of traded carbon offsets in 2019 and offered the lowest prices of relevant

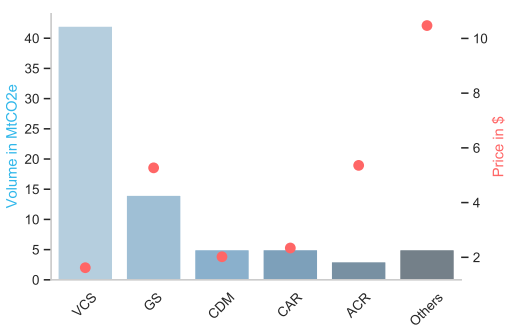


Notes: This Figure shows companies' individual prices per ton CO_2. Source: Marketplace 2016, own illustration.

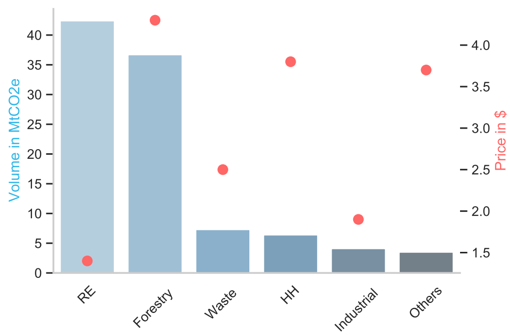
Figure 5: **Companies individual price on carbon**

program standards by far. This is in line with other findings, showing a negative correlation between the volume of traded offsets and offset prices (Hamrick and Gallant, 2018), even if offset prices are far below companies' prices for carbon shown in Figure 5.

However, the overall picture is a bit more complex. Figure 3 has shown that VERRA is the largest supplier among program standards for renewable energy offsets which were the most traded and cheapest offset project type in 2019 (see Figure 6b). Figure 6b shows that the correlation between prices and trade volume is not as strict as Figure 6a suggest because forestry and land use is the second most often traded type in 2019 and the most expensive offset type on average. This is in line with other findings, showing that carbon offset markets are not only determined by prices. Buyers are interested in credits which match with their firm characteristics and 'co-benefits' seem to become increasingly important (Hamrick and Gallant, 2017). Accordingly, demand differs by project type and the project location, with domestic projects generating by far the highest demand (Ivleva, 2015).



(a) **Offset volume and price by program**



(b) **Offset volume and price by type**

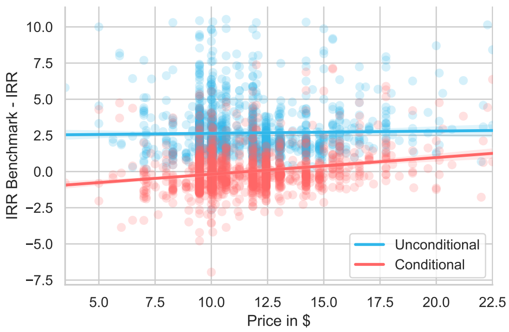
Notes: Panel (a) shows traded offset volumes in $mtCO_2e$ and prices in \$ in 2019 per offset program while Panel (b) shows the same for offset types. Source: Marketplace 2020, own illustration.

Figure 6: **Variation in market share and prices in 2019 of offset verification programs and project types**

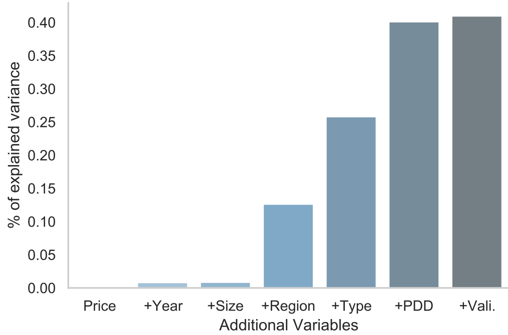
Nevertheless, offset prices are important for the purchase decision. Therefore, it is important to analyse whether prices can be used as a signal for climate integrity. We do this by using the CDM-registry data, where we regress prices of offset projects on the difference between their internal rate of return IRR_i and its benchmark $IRR_{benchmark}$. The IRR_i is a major indicator for climate integrity as it guarantees additionality (Michaelowa and Purohit, 2007). It represents the net present value of an investment's yearly cash-flows. For each project type $IRR_{benchmark}$ values have been estimated by offset certification programs, indicating a threshold above offsets are considered as non-additional because projects would be profitable without offsets.

Figure 7a plots the differences between the offset project IRR_i and the $IRR_{benchmark}$ $(IRR_{benchmark} - IRR_i)$, against the offset project prices. The blue line shows a bivariate correlation between $(IRR_{benchmark} - IRR_i)$ and prices, indicating no correlation. The red line shows the correlation of $(IRR_{benchmark} - IRR_i)$ and prices conditional on project type, region and the year of establishment. Again, no correlation is observable. Thus, our results indicate that offset prices can not be used as a signal for climate integrity. However, climate integrity can be observed by other major offset characteristics. Figure 7b shows the explained variation of $(IRR_{benchmark} - IRR_i)$ for major offset characteristics. It starts with a regression on the left hand side where $(IRR_{benchmark} - IRR_i)$ is regressed on individual offset prices. From left to right, single independent variables such as the offset location are included. The figure indicates that most of the variation in $(IRR_{benchmark} - IRR_i)$ derives from the project type and the PDD Consultant (the firm that prepares the project design document and accompanies it through the whole process. This is in line with other findings in Section 2.4 highlighting the importance of the project type with respect to climate and regulatory integrity. Furthermore, project developers - indicated by PDD Consultant - do have a strong influence an $(IRR_{benchmark} - IRR_i)$, independent of the project type, size or region. However, project size, which is in general an important aspect for climate and regulatory integrity is not reflected in $(IRR_{benchmark} - IRR_i)$ indicating minor importance for additionality. Taken together, high prices do not indicate climate integrity. Instead, a closer look on project characteristics and PDD Consultants is indispensable.

Similar to climate integrity, the literature has shown that prices can not be used as a clear and general signal for regulatory integrity due to the strong impact of project characteristics, such as the project type. However, unconditional price differences between program standards like the CDM and the Goldstandard arise by higher initial costs of stricter assessment. This reduces the share of projects with lower climate and regulatory integrity in the program standard portfolio. (Drupp, 2011)



(a) **Correlation of climate integrity and prices**



(b) **Explained variation of climate integrity**

Notes: Panel (a) shows the unconditional and conditional (on project type, region and year) relationship of $(IRR_{benchmark} - IRR_i)$ and offset prices. Panel (b) shows the explained variation of $(IRR_{benchmark} - IRR_i)$ for major offset characteristics. From left to right, single independent variables are additionally included. Source: Own calculation.

Figure 7: **The relationship between climate integrity and project characteristics**

4 Discussion

Actual competition in the airline sector varies between different direct and indirect origin-destination markets (Maertens, 2018). Competition may occur from other modes of transport (e.g. cars and trains) on short-hauls, from other airlines operating on the same city-pairs or even airport-pairs, and from other (hub) airlines operating alternative routings between a given origin and a given destinations. Consequently, passengers - in many cases - have the choice between different travel options. Along with other factors (subsidization of carriers, political influence, overcapacities, seasonality of demand), this may partly explain why airlines tend to historically operate with low margins (Taneja, 2017)

As a result, it is reasonable to assume that under CORSIA airlines will have the incentive to buy the cheapest offsets available. While this is not per se ineffective from an environmental view, as our results have shown that the offset price is not a sufficient indicator for the offsets' integrity, we can expect the demand for offsets (from the airline sector) to rise significantly once the COVID-19 crisis has been overcome and air transport will have surpassed 2019 (the baseline year) volumes. This will, automatically, mean that offsets with low integrity will also be purchased, especially as there will hardly be any additional willingness to pay for any premium in offset quality.

While the issue of (potentially) low offset integrity is less critical for the private, voluntary offset market, low offset integrity in a large scale legally binding setting like CORSIA lulls industries, policymakers and eventually also consumers into a false sense of security.

The only way to increase the effectiveness of CORSIA would, hence, indeed be a drastic increase of the offset requirements with regard to additionality, non-leakage and permanence, along with improved monitoring and reporting standards. As a result, offset prices would significantly rise. This is unlikely to be accepted at ICAO level.

However, from an environmental point of view the situation is urgent now. The impacts from climate change are tangible but technological solutions are only feasible in the long-term. In the short term, an alternative approach could be a 'laissez-faire' regarding CORSIA offset requirements and to convince or force a growing number of airlines to voluntarily buy additional, better offsets, stemming from small-scale, well-curated projects, or to introduce more ambitious requirements at regional levels, e.g. in the EU.

'EcoLabelling' for offsets could be a way to do this, as known from animal welfare labelling in the meat industry in countries like Germany where labels differ between, e.g., a lowest score for meat meeting the legal requirements and a highest score for organic meat (Sørensen and Schrader, 2019). Especially airlines under public ownership could be forced by their public shareholders to buy higher-quality offsets, and other airlines may jump in for greenwashing and marketing reasons.

5 Conclusions

In this paper, we show that carbon offsetting - even under well established program standards - can not support its promise of climate neutral growth in aviation, significantly. This finding is based on a systematic review of carbon offset characteristics with regard to climate and regulatory integrity and an empirical analysis of the registry data of the most important offset standards under CORSIA.

These findings have implications for policy. Based on carbon offsets, CORSIA has been launched to ensure climate neutral growth from 2021 on international flight. Thus, airlines need to compensate every additional ton above the 2019 baseline with one equivalent carbon offset ton released by carbon offset projects. Eligibility Criteria have been established by the ICAO Council which specify the requirements for offsets that can be used, currently resulting in six eligible offset program standards.

CORSIAs failure stems from the insufficiency of carbon offsets used under CORSIA which are certainly useful as a voluntary additional concept to promote projects focusing on GHG-reduction but should not be used in a legal framework which would require every offset to mirror net carbon reduction. Carbon offsetting simply can not guarantee this. Inherently, offsetting faces three major challenges: additionality (carbon reductions would not have occurred without the offset project), non-leakage (carbon reductions somewhere does not increase carbon emissions somewhere else) and permanency (today's reduction might be released tomorrow). Ensuring maximum climate integrity under CORSIA would dramatically reduce the carbon offset supply and would increase transaction costs even more. This stems from the fact that while all offset programs offer projects with high integrity, most of their offset supply is generated in large-scale projects considered as non-integer such as renewable energy projects. However, CORSIA's financial attractiveness is based on those offsets.

Another critical characteristic of carbon offsetting are adverse effects. Program standards have considerably improved their regulatory integrity by implementing safeguard clauses taking effects on the local community into account. However, where direct effects on the local community like social oppression can be reduced by monitoring compliance with safeguard clauses indirect effects like crowding-out are hardly observable. Our results show, that offset prices can not be used as a signal to maximize climate or regulatory integrity. Projects with higher offset prices are not necessarily more vulnerable or do take more care of the local community.

To ensure maximum climate and regulatory integrity of CORSIA, policy makers should consider prioritizing carbon reduction projects that are relatively small aiming at energy efficiency at consumer level and selected carbon storage projects. Positive examples exists among established climate programs. In case of small energy efficient projects, some climate programs have focused on such projects including the World Bank's Pilot Auction Facility for Methane and Climate Change Mitigation or the Norwegian purchase program. However, the current supply of such offsets is extremely low and does not meet CORSIAs demand (Fearnehough et al., 2020). Furthermore, it is unclear if there is enough potential supply. Thus, we emphasize the importance of carbon storage under high standards – despite its own weaknesses – to achieve urgent large scale carbon reductions to mitigate climate change.

However, the more relevant carbon offsetting becomes as an instrument for climate legislation and the more it becomes present in the public awareness, the more important rebound effects get. Offsetting negative externalities of consumption increases its utility by lowering shame of consumption. This can increase demand (Günther et al., 2020). Such rebound effects can become a serious problem in a situation where carbon offsetting does not hold its net carbon reduction promises, potentially resulting in a net carbon increase. CORSIA's rebound effects should be addressed by future research.

Taken together, our results reveal carbon offsetting as a weak second best solution which must be considered as transitional. Airlines should invest in advanced technologies for clean flying such as electric flying as soon as possible if they really want to achieve carbon neutral growth. Taxes or carbon cap and trade schemes can provide important incentives for this in the medium term.

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