Green Domestic Product: Netting Greenhouse Gas Emissions from Gross Domestic Product

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Summary

The Gross Domestic Product (GDP) is rightly criticized for not being an accurate measure of economic value added since it does not account for the environmental damages caused by the underlying economic activity. In this paper, we propose a simple adjusted measure of domestic product which subtracts the monetary value of Greenhouse Gas (GHG) emissions from GDP to obtain a measure of Green Domestic Product (GrDP). We provide the calculations for Switzerland from 1990 to 2018, a period during which a significant increase in GDP of approximately 60% was compatible with a slight decrease in GHG emissions. This is a noticeable form of decoupling between economic growth and GHG emissions. Assuming a Social Cost of Carbon (SCC) of CHF 96 per ton, we find that GrDP is between 0.62% and 1.5% lower than GDP in 2018 depending on the methodology used for measuring GHG emissions. During the studied period, the growth rate of GrDP was marginally larger than the GDP growth rate. Our sectoral analysis highlights the low and decreasing carbon efficiency of the primary sector. It also suggests that the decoupling between economic growth and GHG emissions is entirely attributable to the increasing relative importance of the significantly more carbon-efficient tertiary sector. From a policy point of view, while the identified decrease in GHG emissions provides a ray of hope, current trends do not appear in line with Switzerland's commitments to the Paris agreement. More forceful policies and an increased awareness leading to changes in behaviors, notably in regard to individual mobility (land and air transportation) are needed. Our calculations provide a very partial estimate of the economic cost of environmental damages arising from economic activity based on a static backward-looking national income accounting approach. The cost of other forms of pollutions and of lost biodiversity is not accounted for. More complex forward-looking models are needed to make predictions about the path of GHG emissions under alternative policies and their potential cost in terms of foregone economic growth.

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*If we measure the wrong thing, we will do the wrong thing. If our measure tells us everything is fine when they really aren't, we won't make the right decisions. (*J. E. Stiglitz et al., 2009)

1. Introduction

Gross Domestic Product (GDP) is meant to be a measure of the economic value added in an economy over a given period of time, a month, a quarter or a year. In this paper we address an important deficiency of GDP, that it is a gross measure (as its name indicates), i.e., the fraction of the capital resources that are used up in the value creation process is not subtracted from the final aggregate number. This deficiency is well understood when it comes to the physical and intangible capital resources consumed in the production process and the national income accounts indeed include a complement in the form of an estimate of the Net Domestic Product. The latter is of limited interest however because the capital depreciation figures that are used are mostly based on accounting conventions and not on meaningful market estimates of the true economic equivalent of the corresponding depreciation.

The correction needed to move from a gross to a net measure of value added is much more interesting when one focuses on a number of non-priced environmental resources that are consumed in the process of creating economic value. These resources are extremely valuable because our lifestyle has led to a perilous potentially irreversible depreciation of the corresponding capital which in turn could massively hinder the value creation potential of future generations. It is therefore of utmost importance for policy guidance to arrive at a reasonable measure of what we will call the Green Domestic Product (GrDP).

We propose to do so in a modest and hybrid fashion. Modest because in this first attempt we are going to focus exclusively on the environmental capital depreciation provoked by Greenhouse Gas (GHG) emissions. Hybrid because we are going to leave aside the conceptually equally important netting associated with the consumption of fixed capital. Our Green Domestic Product will thus be a measure of value added that is gross in terms of physical and intangible capital, but net of an estimate of the consumed environmental resources associated with the GHG emissions. We provide the results for Switzerland under alternative methods of measuring and valuing GHG emissions.

The ambition of this project is thus limited compared to the massive amount of work that is needed to develop a truly net Domestic Product indicator. By considering only GHG emissions, we exclude bigger and as (or even more) relevant damages notably those associated with the loss in biodiversity. The methodological issues are complex and diverse enough to justify focusing first on the most pressing problem which is the climate change challenge. GrDP is to be understood as a first, concrete step towards the construction of more inclusive indicators, integrating additional external costs and providing a better representation of the true net value created in an economy during a period of time.

As mentioned above, a truly net Domestic Product should also consider the fixed capital that has been used up and consumed over a given period. Fixed capital consumption represents about 20% of GDP for the period 1995 to 2018 in Switzerland. It is largely measured on the basis of accounting numbers and not of market estimates. Taking it into account in our analysis would therefore obscure the effect of GHG emissions without bringing any novel information. We thus leave it out of our analysis.

2. The GDP Critiques: some valid, other less!

GDP is subject to a lot of critiques, not all of them being justified. The main source of criticism probably originates in the perception that governments aim at maximizing the growth rate of the economy as measured by the yearly GDP change. There might be some reality behind this perception, notably because a growing GDP delivers on average raising incomes and increasing tax receipts and is therefore a facilitator for the actions of politicians whether directly (more tax receipts means more possibilities to accommodate the spending demands of the various constituencies) or indirectly (incumbents have a better chance to be re-elected in a positive economic environment). However, there is nothing normative behind this perception and economic models typically aim at maximizing social welfare rather than the growth rate of the economy.

Another common critique is that GDP is a bad measure of well-being or social welfare since it doesn't account for the distribution of revenues and focuses on material values that may not correlate well with happiness. This critique is largely unfounded however because GDP was never meant to be such a measure. While in many modelling contexts well-being increases with GDP, a fact which may explain the confusion, GDP was not meant to be anything else than a measure of economic value added.

Even at that modest level, GDP should not be viewed as an all-purpose final indicator! Indeed, to arrive at an estimate of how much value a sector or activity is creating, GDP is limited to adding up values as defined by market prices. This means that value-creating activities outside a market context are not counted and there exists many such activities (e.g. unpaid work or volunteerism). Moreover, the social value of an activity may not be well approximated by the market remuneration attached to it: it is hard for instance to argue that a financial speculator receiving a bonus of CHF 100 million has created 1'000 times more value than a teacher with income of CHF 100'000.

While we should aim at better accounting for non-market sources of value creation, income remains an important yardstick for most human beings. In this sense, GDP does provide an unavoidable perspective because it is also (by construction) a measure of the income distributed in an economy over a period of time. This view point is illustrated in Figure 1 which represents the almost parallel evolution of GDP and Gross National Income (GNI) the latter being an indicator of a country's income. In comparison with GDP which looks at the total value of the goods and services produced within a country's territory by residents and non-residents, GNI accounts for the income generated by the economic activity of a country's residents at home and abroad, i.e., independently of the activity's location. In Switzerland, GNI is on average 2.6% greater than GDP indicating that revenues earned by Swiss residents abroad exceed revenues earned in Switzerland by non-residents. This is largely due to income arising from Swiss capital infrastructure abroad, itself the result of earlier foreign direct investment by Swiss firms. However, the evolution is very similar as shown in Figure 1 with a correlation of 0.97 confirming that GDP is a closely approximated statement of income and for that reason cannot be dismissed as a highly meaningful indicator.

A final valid critique of GDP relates to the fact that the activities contributing to economic added value might cause environmental damages, the value of which should be subtracted from the total value created. The economic loss attributable to these damages is generally not taken into account in GDP because there are no corresponding markets where a price for these damages could be determined. This is precisely the deficiency that the present note is aimed at correcting. In what follows we will propose a simple adjusted measure based on GDP which accounts for the monetary value of Greenhouse Gas Emissions, i.e. Green Domestic Product (GrDP).

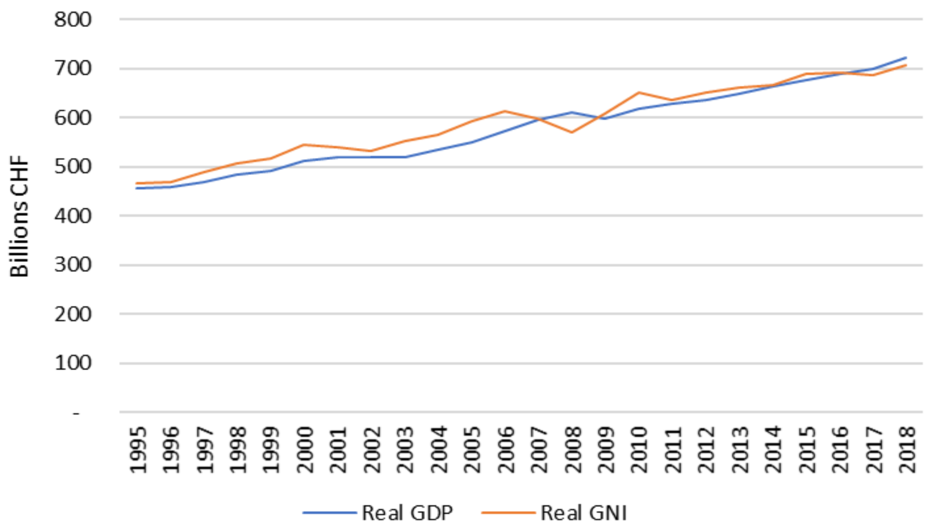

Figure 1 - GDP and GNI in Switzerland over 1995-2018

3. Measuring Greenhouse Gas Emissions

We start by clarifying the various terms associated with the alternative methodologies for measuring Greenhouse Gas (GHG) emissions. All estimations of GHG emissions are expressed in tons of CO_2 equivalent, where other gases are converted according to their Global Warming Potentials (GWPs). The gases usually taken into account are carbon dioxide (CO_2), methane (NH_4), nitrous oxide (N_2O) and synthetic gas (HFC/PFC/SF_6). There are four different perspectives for measuring GHG emissions as presented in Table 1.

The first perspective refers to the **National GHG Inventory** following the **Intergovernmental Panel on Climate Change (IPCC)** guidelines (see column 1 in Table 1). This measure is based on the **territorial principle** so it accounts for all GHG emissions generated by the economic activity of residents and non-residents within a country's territory. The GHG emissions associated with the economic activity of Swiss firms abroad or international transportations are left out by this approach. Several international agreements, such as the Kyoto Protocol or the Paris Agreement use this definition as a basis for setting CO2 reduction targets. The National GHG Inventory is also required annually by the United Nations Framework Convention on Climate Change (UNFCCC) from all signatory countries. In Switzerland, the measure is published once a year by the Swiss Federal Office for the Environment (SFOE).

We also propose an adjusted National GHG inventory measure by adding GHG emissions attributable to **international transportation** using the estimate provided separately by the IPCC guidelines. The latter considers the emissions corresponding to the quantity of fuel purchased in Switzerland for international flights leaving Switzerland, both for resident and non-resident airlines (i.e. see column 2 in Table 1).[3]

The third approach proposed by the **Systems of Environmental and Economic Accounts (SEEA)** is called the **Air Emissions Accounts (AEA)**. This measure is based on the **residential principle:** it sums up all emissions resulting from the economic activity of Swiss residents either in Switzerland or abroad (including terrestrial transports) and it excludes emissions resulting from the economic activity on Swiss territory by non-residents. By default, this measure also accounts for GHG emissions arising from international transportation (aviation and navigation) based on the same residential principle. Thus, it includes emissions corresponding to all fuel bought within Switzerland and abroad for all flights (leaving and arriving) but for resident airlines only. In addition, the SEEA include the GHG emissions arising from biomass combustion.[4]The SFOE produces the conversion table from the IPCC measure to the SEEA measure.

Therefore, the main difference between the two measures arises from the principle based on which they are constructed: territorial principle (IPCC) vs residential principle (SEEA). For example, emissions of foreign tourists driving in Switzerland (with a foreign car) will be included in the IPCC measure for Switzerland, but not in the SEEA. At the opposite, emissions of Swiss tourists driving abroad (with a Swiss car) will be accounted for by the SEEA approach but not by the IPCC approach.

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[3] There exists a growing literature suggesting that emissions relative to air transport should be given twice the weight of corresponding emissions on the ground, to reflect the release of further harmful gases and the magnified climate impact of high-altitude emissions (Brülhart et al. 2020). Our intention being to align our findings with official numbers for comparability, we do not adopt this approach in the main part of our analysis. We will however report how our results are affected when we double the CO2 equivalent of air transport emissions.

[4] Under SEEA, emissions relative to biomass burning are included in the Air Emissions Accounts as they arise from economic activity. Under IPCC, such emissions are not included in the national totals, but are presented separately under the Land Use, Land Use Change and Forestry (LULUCF) category. LULUCF emissions include emissions resulting from biomass burning, and more generally gains and losses in living biomass, resulting from (but not solely) deforestation and afforestation. LULUCF emissions are regulated by the No-Debit Rule in the Kyoto Protocol: emissions accounted for in LULUCF should entirely be compensated by an equivalent removal of CO2 from the atmosphere through action in the LULUCF sector. The net total of emissions/removals within LULUCF should therefore be 0 or lower on average over the period of 1990-2018, which is effectively observed in the data. We choose not to include LULUCF net total in this analysis as it is not included in the national total and global reduction targets.

Moreover, the emissions due to international transports (aviation and navigation) are measured differently by the two perspectives. It turns out that the level of emissions due to international transport is lower under IPCC than under SEEA by 18% on average.[5]

Table 1 - Summary of the different methods for measuring GHG emissions

Name	**National Inventory**	**National Inventory (Adjusted for Intl. Transp.)**	**Air Emissions Accounts**	**GHG Footprint**
Guidelines	IPCC	IPCC	SEEA	SEEA + IOT
Principle	Territorial	Territorial	Residential	Residential
Data availability	1990-2018	1990-2018	1990-2018	2000-2018
By economic sectors	NA	NA	1990-2018	NA
International transports (aviation, navigation)	No	Yes	Yes	Yes
Emissions of terrestrial transport of **Swiss residents** emitted **abroad**	No	No	Yes	Yes
Emissions of terrestrial transport of **non-residents** emitted in **Switzerland**	Yes	Yes	No	No
Emissions related to **imports** of goods and services	No	No	No	Yes
Internal emissions related to **exports** of goods and services	Yes	Yes	Yes	No
Emissions related to **biomass burning**	No	No	Yes	No

However, none of the above methodologies include GHG emissions generated by the production of imported goods and services. For instance, under both IPCC and SEEA guidelines, the emissions caused by the production of an imported vehicle in Switzerland would not be considered in the Swiss GHG emissions statistics, but only in the country of production. This omission is particularly significant for an economy like Switzerland. This is because the carbon intensity of Swiss imports is much higher than the carbon intensity of the goods and services it exports. To complete the overall

[5] Here is an example to make sense of the differences in accounting for international transport by the two methodologies: Swiss International Airline (a resident of Switzerland) operates return flights from Geneva to New York. Under IPCC, only the emissions relative to the flight leaving Geneva will be counted, because the only time fuel will be bought on Swiss territory is in Geneva, before leaving. Under SEEA, all emissions, for both flights, will be taken into account, even when fuel is purchased in New York, simply because the airline is a Swiss resident unit. However, if these flights were operated by a non-resident airline, no emissions would be counted under SEEA in Switzerland, while emissions under IPCC would stay unchanged.

picture, we thus consider an alternative approach known as the **Greenhouse Gas Footprint** which includes GHG emissions generated by the **production of imported goods and services** but excludes those associated to exports. In terms of methodology, this measure is a combination of the SEEA methodology and of the Input-Output Tables (IOT) produced under the Systems of National Accounts, where goods and services are weighted according to their carbon intensity.[6]

In what follows we analyze the dynamics of GHG emissions in Switzerland following these different approaches. Figure 2 displays the evolution of GHG emissions measured according to the IPCC standard (without and with international transportation) and the SEEA standard over the period 1990-2018 and the GHG Footprint over the period 2000-2018.[7] Firstly, we observe that the level of emissions measured by the GHG footprint definition is almost twice as high as the emissions measured according to the IPCC and SEEA standards over the 18 years for which the GHG footprint data is available. As already mentioned this indicates that the carbon intensity of Swiss imports is much higher than the carbon intensity of the goods and services it exports. In 2018 for instance Switzerland produced 113.81 million tons of CO2 equivalent according to the GHG Footprint and 60.38 million tons according to SEEA. In addition, emissions are on average larger under the SEEA perspective than under the IPCC perspective implying that greater efforts for emission reductions would be needed under SEEA than under the latter which is however the reference for international agreements.

Secondly, we see a downward trend for all measures of GHG emissions, some being more pronounced than others. The GHG Footprint measure displays a 13.51 million tons decrease between 2000 and 2018, which represents a reduction of 10.61 %. This happened while the quantity of imports continued growing at an average of 3% per year, suggesting that the production of Swiss imports has become less carbon intensive over time. Emissions under IPCC and SEEA follow a similar path, although, total emissions decrease more significantly under the IPCC perspective. Over the same period, GHG emissions under SEEA decreased by 4.16 % (-2.62 million tons) and those under IPCC by 12.83% (-6.83 million tons).

Next, we look in detail at the difference between IPCC (without and with international transports) and SEEA, over the extended 1990- 2018 period for which both measures are available. GHG emissions remain on average higher under the SEEA guidelines than under IPCC guidelines. While under the IPCC perspective, the GHG emissions were reduced by 14% during the 28 years (-7.73 million tons of CO2 equivalent), under the adjusted IPCC perspective including international transportation, they decreased by 9% (-5.2 million tons of CO2 equivalent) and under the SEEA perspective they declined only by 2.1% (-1.3 million tons of CO2 equivalent). The higher decrease in GHG emissions under the IPCC perspective may be attributable to mitigation efforts stimulated by the implementation of the Kyoto Protocol.[8]

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[6] The Federal Statistical Office has an ongoing study to compute the national GHG Footprint. However, the methodology still needs to be consolidated.

[7] Data sources: FOEV (IPCC) and OFS (SEEA and Footprint)

[8] Between 2008 and 2012, Switzerland was bound to reduce its emissions by 8% compared to the 1990 levels and by 20% for 2020. As the IPCC methodology serves as reference for setting and monitoring these targets, one suspects that efforts at reducing emissions have been particularly targeted to a reduction of this measure.

Let us now zoom in on the different components of the two measures and see how they help making sense of the observed differences. As we have seen above, the level of GHG emissions related to international transports is lower under the IPCC guidelines than under SEEA guidelines. Under IPCC, emissions related to international transports rose by 83%, which corresponds to an increase of 2.5 million tons of CO2 equivalent (from 3.15 million tons in 1990 to 5.69 million tons in 2018), mainly driven by the development of aviation. This increase is even more significant under SEEA: 2.9 million tons for aviation alone. The difference between IPCC (adjusted or not) and SEEA is also explained by the fact that SEEA includes emissions of resident abroad, such as terrestrial transports, and combusting biomass, two categories which saw their emissions increase. Biomass combustion went from 4.8 million tons to 7.9 million tons of CO2 equivalent (so an increase of 3 million tons), while terrestrial transport of Swiss residents abroad increased by 0.5 million tons of CO2 equivalent.[9]

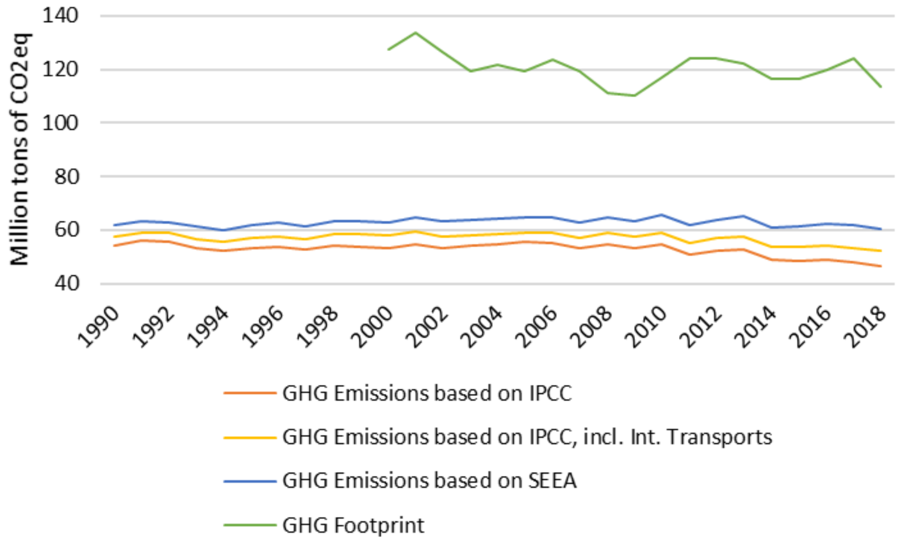

Figure 2 – GHG Emissions according to alternative calculation methods

In conclusion, there are different methodologies we can make use of for measuring the GHG emissions. The common factor in these perspectives is made of the emissions caused by the production and consumption of Swiss residents on the Swiss territory. While the IPCC approach seems to be closer to the GDP logic (i.e. territorial principle), the SEEA approach is closer to the logic of GNI (i.e. residential principle, including emissions caused by terrestrial transport of residents abroad and excluding those caused by terrestrial transport of non-residents in Switzerland). However, the SEEA approach gives a more complete measure of GHG emissions since it accounts for a wider measure of international transports than the one proposed by the IPCC as well as biomass combustion. As we have discussed above, these additional sources of emissions are important and they should not be ignored. Moreover, the SEEA approach allows us to separate the impact of GHG emissions by economic sectors (see Section 6). As for the GHG footprint approach, it considers both emissions resulting from international transportation and from imported goods and

[9] Emissions relative to terrestrial transports of non-resident in Switzerland are deducted, but their amount stayed constant over the period.

services which are very relevant for Switzerland. However, this latter measure is the farther away from the national economic indicators, it is available for a shorter period of time and it doesn't allow us to separate by economic sectors. For all these reasons, we will calculate the Green Domestic Product net of the monetary value of GHG emissions using all three approaches.

4. Valuing Green House Gas Emissions

How can one associate monetary values to GHG emissions? To do so, we rely on the Social Cost of Carbon (SCC), which provides an estimation of the price per ton of CO2 equivalent. The SCC is a highly debated issue and the subject of considerable research efforts. The current estimates vary from USD 40 to USD 200 per ton and even beyond, depending on the goals set and the models used. Gollier (2019) for instance concludes that a price of EUR 50 per ton of CO2 is a well-justified estimate, while a ton of CO2 has traded in the EUR 25-30 price range lately in the European Union Emissions Trading System.[10]

The monetary value of the total Greenhouse Gas emissions for year t is therefore defined as:

$$V(GHG_t) = SCC * \sum CO2eq_t$$

where the sum represents the total amount of GHG emissions in a given country converted into CO2 equivalent for year t. For measuring the SCC, we will pragmatically use the effective tax rate for heating fuel set by the Swiss CO2 Act which is a reference value commonly used in Switzerland. The price is set at CHF 96 per ton of CO2 equivalent over the period 2018-2020. All data (including real GDP) are at 2015 constant prices. This would mean a SCC of CHF 96.26 (adjusted with the barely changed CPI level). For simplicity, we round off the SCC price at CHF 96 per ton. This is our baseline. In the appendix we provide results for a SCC of CHF 200 per ton.[11]

Ideally the appropriate SCC should be inferred from a full economic modelling perspective. Existing attempts are mostly based on Integrated Assessment Models (IAMs) which aim at combining different global economic and atmospheric features. These models approximate the impact of CO2 emissions on the global economic output and the results are used by policymakers in their cost-benefit analysis. However, the estimates vary a lot mostly due to parameters that are difficult to estimate with precision, in particular the factor with which future costs and benefits are discounted to permit a comparison with current costs and benefits.[12] Moreover, these models are not robust to variations in basic hypotheses, for example, they are based on a business-as-usual economic

[10] This is a market price, which depends heavily on the quantity of "rights to pollute" granted the EU bigger polluters. Because this limit is set excessively high, the equilibrium price is abnormally low.

[11] In the new revision of the Ordinance on CO2 by the Federal Council, the possibility of an increase of the tax to CHF 120 per ton in 2021 if the reduction in GHG emissions is insufficient is mentioned.

[12] As Stern (2016) puts it: "Most current models of climate-change impacts make two flawed assumptions: that people will be much wealthier in the future and that lives in the future are less important than lives now. The former assumption ignores the great risks of severe damage and disruption to livelihoods from climate change. The latter assumption is 'discrimination by date of birth'. It is a value judgement that is rarely scrutinized, difficult to defend and in conflict with most moral codes."

scenario, they generally omit the cost of air pollution from fossil fuels and do not consider the impact of innovation on institutional and behavioral changes (Stern, 2016). More sophisticated models have been recently proposed, such as DSGE (dynamic stochastic general equilibrium) or ABM (agent based) models.

Pindyck (2019) proposes a "more transparent approach" based on a survey of experts. In his view, estimates of the average SCC should correspond to "the ratio of the present value of damages from an extreme outcome to the total emission reduction needed to avert such an outcome". The estimates obtained from experts vary largely, but narrowing down the focus to the most credible experts and eliminating the outliers he obtains SCC values between USD 80 and USD 100 per ton.

Importantly, there are good grounds to hypothesize that the SCC should be increasing over time because the price justified today may not be sufficient to reap the higher hanging fruits which may be necessary to collect if one aims at a zero net carbon economy in the future (Wagner, 2020). Gollier (2018) for example proposes "a growth rate of expected carbon price around 3.5% per year (plus inflation), which is much larger than the 1% equilibrium interest rate in our economy."

5. Green Domestic Product (GrDP)

Before describing how we construct the Green Domestic Product, let us analyze the evolution of real GDP and the GHG emissions over the period 1990-2018.[13] In Figure 3, both GDP and GHG emissions were set equal to 100 in 1990 such that their evolution could be compared on the same scale.[14] We first observe that over this period of almost 30-year GDP has grown by almost 60% while GHG emissions have decreased. This move is almost negligible according to SEEA (-2.1%) but more significant for IPCC (-14.27%). In terms of international agreements, the Kyoto Protocol set a target of 20% reduction in GHG emissions compared to 1990 by 2020, under IPCC guidelines, while the Paris Agreement aims at a 50% reduction by 2030.[15] While the goal of 2020 seems reachable, the target for 2030 would require a stronger decreasing path of GHG emissions. The strong reduction observed during the pandemic of Covid-19 in 2020 will certainly help, but it is doubtful whether this decrease will be persistent since the first estimates show that emissions were already increasing after the first lockdowns were lifted (Liu et al., 2020).

Figure 3 delivers an important message: There is a form of decoupling between the evolution of GDP and GHG emissions. The strong increase in GDP since 1990 is accompanied by an (admittedly small) decrease in emissions. The possibility of decoupling is a highly contested topic in the literature. However, we can find here some favorable evidence and this is more telling since the

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[13] Source of GDP: OFS; Source of GHG emissions: mentioned above.

[14] Since emissions are evaluated at a constant price, the evolutions of the quantity of GHG emissions and their monetary value are identical.

[15] Compensation of emissions realized by purchasing foreign carbon credits as well as carbon sinks from Swiss forests, which are not considered in the National Inventory (IPCC), may be, and typically are, taken into account when assessing the fulfilment of these targets. In 2012, these compensations amounted to 2.5 million tons of CO_2 equivalent for foreign carbon credits and 1.6 million tons for Swiss carbon sinks.

public awareness about the global warming effect of CO2 emissions was relatively weak for most of the covered period. In light of the recent change in the public perception regarding the urgency to act for reducing GHG emissions, one can expect that much more focused and radical measures may yield a much starker form of decoupling. The sectoral analysis in Section 7 offers additional insight on the drivers of this observed decoupling.

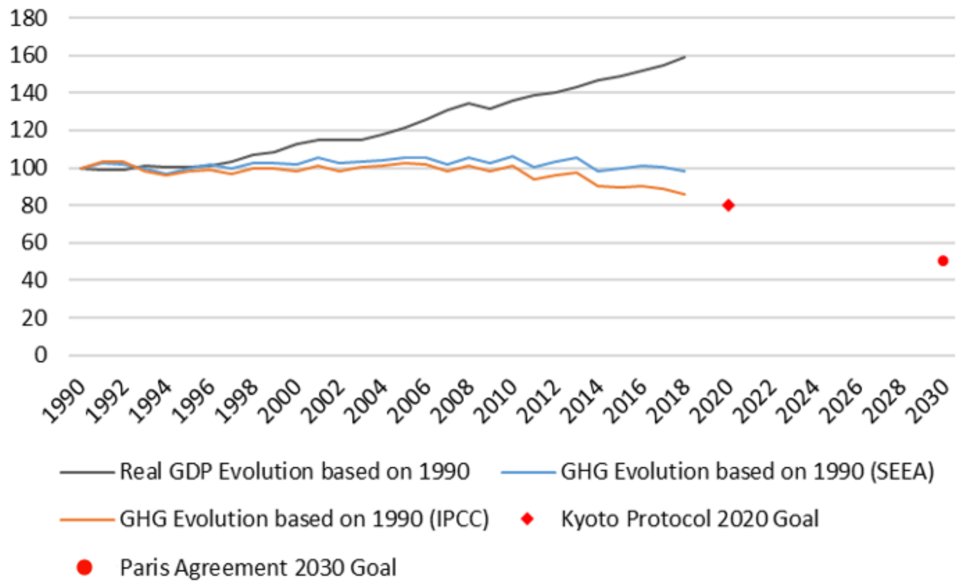

Figure 3 – Comparing the evolution of GDP and GHG emissions relative to the reduction goals

We are now able to define our alternative economic indicator net of the economic value of GHG emissions. More exactly, we will subtract the monetary value of the GHG emissions from real GDP as follows:

$$GrDP_t = GDP_t - V(GHG_t)$$

where all terms are measured at constant 2015 prices.

All data come from the Federal Statistical Office, the State Secretariat for Economic Affairs and the Federal Office for the Environment. For the whole economy, we rely on the IPCC and SEEA measures for the period 1990-2018 and on the GHG Footprint measure for the period 2000-2018. We are then able to disaggregate the Green Domestic Product by economic sector using the SEEA measure for 1995-2018, since this is the period for which GDP by sector is available.

Figure 4 displays the Green Domestic Product under three alternative emission measures and for the lower estimate of the Social Cost of Carbon aside with GDP itself.[16] They are all deceptively close; all measures of GrDP are slightly smaller than real GDP as must be the case but the difference is

[16] We refrain from plotting GrDP under IPCC adjusted for international transportation for better readability as it is almost not distinguishable from the unadjusted measure.

barely noticeable. In other words, for the chosen value of SCC the monetary value of the cost of GHG emissions is small in relation to aggregate Swiss GDP. Moreover, GrDP is smaller than GDP but it displays a slightly higher growth rate which is not surprising since GDP kept growing while all GHG emissions had a decreasing trend.

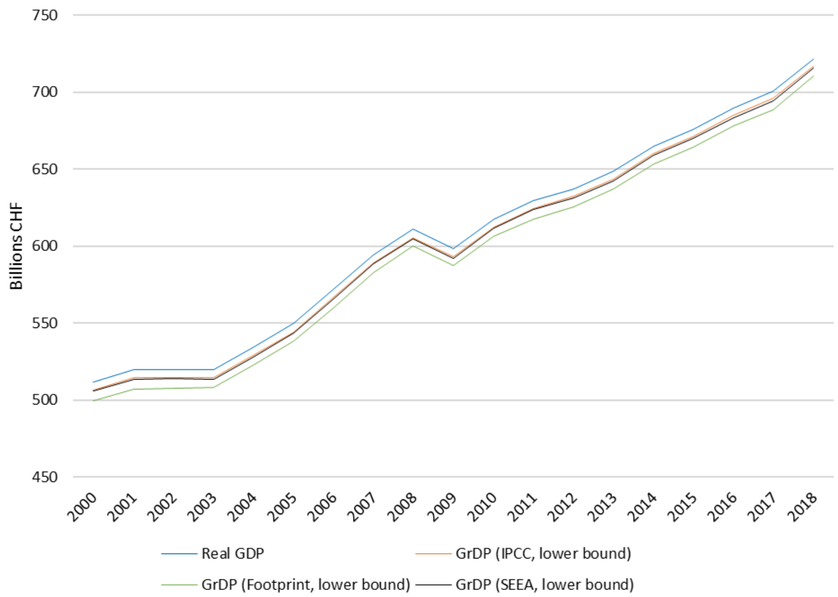

Figure 4 – GDP and GrDP under different methods

Table 2 provides the corresponding data. It shows that under the IPCC measure GrDP was 1% lower than GDP in 2000 when the monetary value of GHG emissions was CHF 5.11 billion. In 2018, the latter number was CHF 4.46 billion or 0.62% of GDP. Under SEEA, GrDP was 1.18% smaller than GDP in 2000 for a value of GHG emissions of CHF 6.05 billion. In 2018 the corresponding numbers were CHF 5.8 billion or 0.8% of GDP. The GHG Footprint approach implies the largest difference between GDP and GrDP, the latter being 2.39% below the former in 2000 due to a cost of GHG emissions estimated at CHF 12.22 billion. In 2018, the corresponding numbers were 1.51% and CHF 10.92 billion.[17] On a per capita basis the cost of GHG emissions in 2018 was CHF 522 under IPCC, CHF 678 under SEEA, and CHF 1279 under the GHG Footprint. If we use the higher SCC (CHF 200 per ton instead of CHF 96), the cost of GHG emissions and thus the difference between per capita GrDP and per capita GDP reaches CHF 2664 in 2018 under the Footprint method, compared to CHF 1086 under IPCC (See the Appendix for the full table using the higher SCC).

[17] If we double the impact of GHG emissions due to air transportation as suggested in Brülhart et al. (2020), the monetary value of GHG emissions would be increased by at least 0.1 percentage points of GDP. Under IPCC, the difference between GrDP and GDP would represent 1.18% in 2000 and 0.77% in 2018 (respectively CHF 6.04 and 5.56 billions). Under SEEA, it would amount to 1.29% in 2000 and 0.89% in 2018 (respectively CHF 6.62 and 6.45 billions). Under the GHG footprint, the shortfall would be 2.5% (CHF 12.79 billions) in 2000 and 1.6% in 2018 (CHF 11.58 billions).

Table 2 - GrDP and GDP Summary Statistics for 3 emission measures and a SCC of CHF 96

	GrDP - IPCC	GrDP - SEEA	GrDP - Footprint	GDP
	Low SCC	**Low SCC**	**Low SCC**	**-**
Average annual growth Rate, in %	1.960	1.960	1.989	1.938
Total Growth over 2000-2018, in %	41,555	41,552	42,275	41,012
	1990			
DP, in billion CHF	448.49	447.77	n/a	453.69
Value of GHG emissions, in billion CHF	5.20	5.92	n/a	--
DP per capita[18], in CHF	66,437	66,329	n/a	67,207
Per capita cost of GHG emissions, in CHF	770	877	n/a	--
	2000			
DP, in billion CHF	506.61	505.68	499.50	511.73
Value of GHG emissions, in billion CHF	5.11	6.05	12.22	n/a
DP per capita, in CHF	70,323	70,193	69,336	71,033
Per capita cost of GHG emissions, in CHF	710	840	1 697	n/a
	2018			
DP, in billion CHF	717.14	715.80	710.67	721.59
Value of GHG emissions, in billion CHF	4.46	5.80	10.93	n/a
DP per capita, in CHF	83,929	83,772	83,172	84,451
Per capita cost of GHG emissions, in CHF	522	678	1,279	n/a

In an approach that is similar to ours, Mohan et al. (2020) proposes to subtract from GDP not only the monetary value of CO2 emissions (estimated at a lower SCC of USD 36 per ton deducted from a hypothesized 3% discount rate) but also an estimate of the monetary value of excess mortality caused by pollution attributable to fine particulate matter (PM) emissions. Moreover, their perspective is global which introduces a further discrepancy because the global trend in emissions is increasing over the last two decades while Switzerland's emissions decreased over the same period. Mohan et al. (2020) find that EVA growth was higher than GDP growth from 1998 to the financial crisis; in 2010, the two growth rates turn out to be similar; while after 2015 global GDP surpassed EVA growth.

Using a dynamic stochastic general-equilibrium (DSGE) model with an externality due to climate change, Dyens (2020) develops a simple formula that subtracts from GDP the discounted expected sum of future damages on output due to atmospheric carbon concentration.[19] For the same reason as Mohan et al. (2020), the inverse trend in global and Swiss GHG emissions, he finds that including the externality due to climate change reduces world GDP growth for the period 2007-2016 by 0.1 percentage points per year if the hypothesized discount rate is set at 1.5% and by 1.1 percentage points with a discount rate of 0.1%. However, when computing the externality at the country level,

[18] Using total resident population.

[19] The formula only requires knowledge on the discounting rate (i.e. the lower the rate, more important the future is estimated to be in comparison with the present), the expected damage semi-elasticity (i.e. how many percent of the output flow is lost from an extra unit of carbon in the atmosphere), and the structure of the carbon cycle.

Dyens (2020) finds an interval going from USD 0.8 billion to USD 7 billion for Switzerland; the latter is in line with our findings under the low SCC hypothesis.

6. Sectoral Analysis

In this section, we look at the result of our analysis at the sectoral level using the sectoral disaggregation permitted by the SEEA accounts which distinguish GHG emissions in the productive sector (primary, secondary and tertiary) [20] and the household sector (transports and heating) [21]. The productive sector emissions represent about two thirds of total GHG emissions and they have increased by 6.7% over the period 1990-2018 while the household sector emissions represent one third of total emissions and they have decreased by 16.33%.

Figure 5 shows the evolution of GHG emissions within each sector. The secondary sector is the biggest contributor to GHG emissions in Switzerland, accounting on average for 29% of total emissions. Follow, in order of average contribution to total emissions, the tertiary sector with 23%, the Household heating sector with 20.6%, Household transportation with 15.4% and the primary sector comes with 11.5% of emissions on average. Moreover, one observes that the tertiary sector has registered the biggest increase in GHG emissions (28%) while the emissions due to Household transportation have increased by +6.14%. The other sectors have seen a decrease in their emissions, most pronounced for Household heating (-31.25%), less so for the primary sector (-10 %), while the emissions of the secondary sector have stayed practically constant (- 0.36 %).

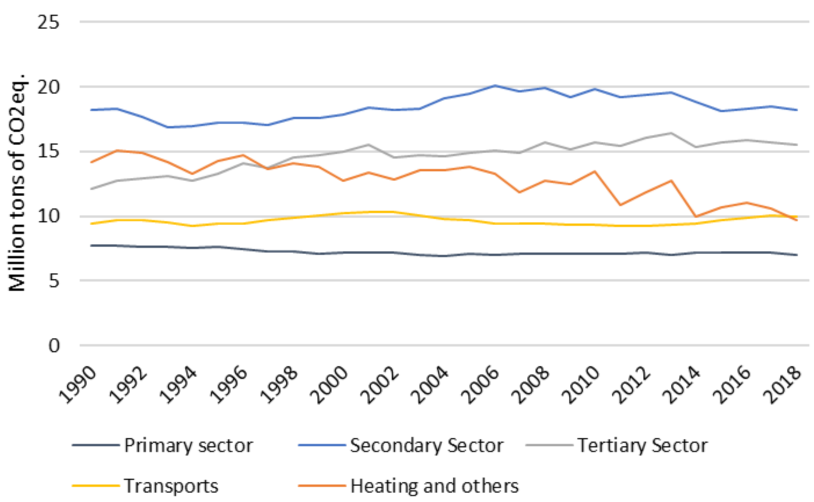

Figure 5 - Evolution of GHG emissions within the productive and households' sectors

[20] Note that the sum of sectoral GDP is not equal to total GDP because of unaccounted taxes and subsidies. The sum of sectoral GDP needs to be understood as the sum of Gross Value Added (GVA). When taxes and subsidies are taken into account, the totals correspond.

[21] Within households, only emissions relative to transports and heating are taken into account to avoid double counting. The emissions relative to the household consumption outside of these two categories are accounted for through the productive sectors (or not accounted for if coming from imports).

The GHG emissions data following the SEEA approach by sector is available from 1990, but data on GDP by sector[22] only from 1995, thus we will construct a net value added (NVA) by sector for the period 1995-2018 by employing the SEEA methodology. Figure 6 displays the co-evolution of GDP and GHG emissions for each sector, by all series normalized at 100 in 1995. As we can observe, the economic value added of the primary sector has decreased by 28.8% while its GHG emissions have only decreased by 8.18% over the period. By contrast the secondary sector's value added increased by 33.9% and its emissions by 5.8%. Finally, the tertiary sector saw the biggest growth in value added with a 70.8% increase that has been accompanied by a more modest 17.13% increase in GHG emissions.

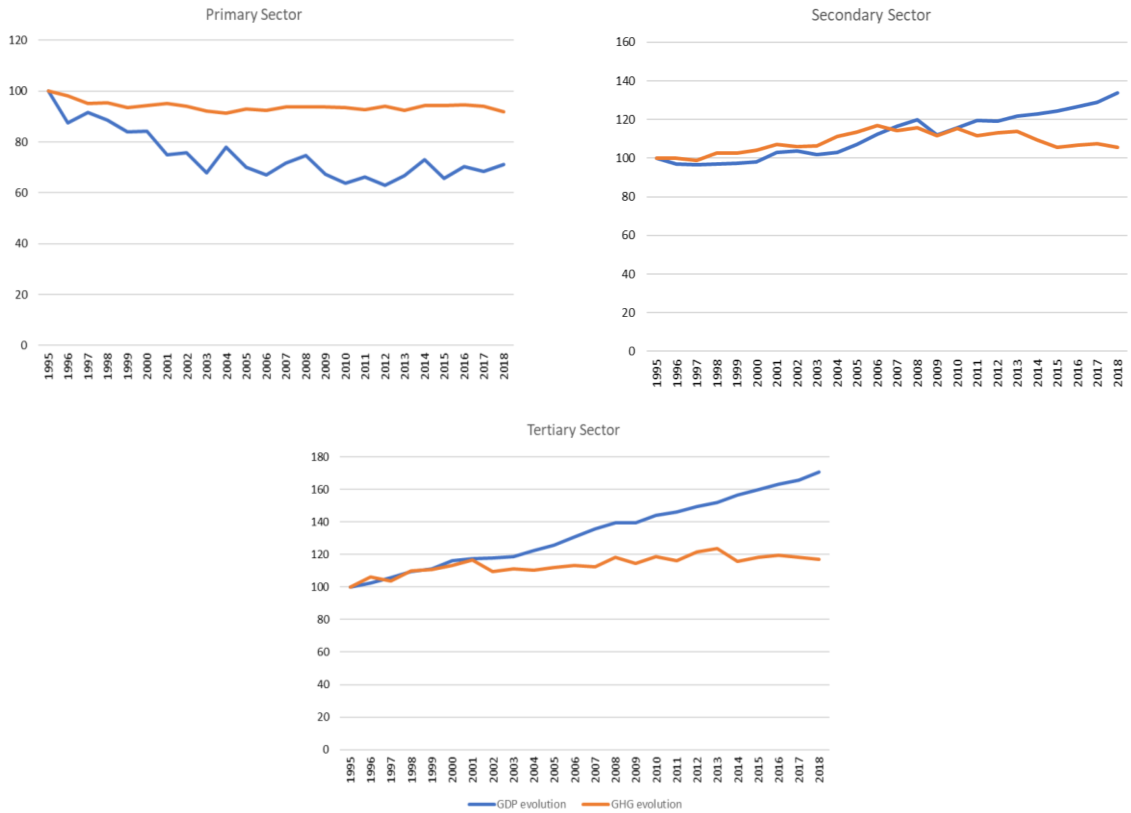

Figure 6 – Co-evolution of GDP and GHG emissions for each sector

Figure 6 delivers an important message: it is through the tertiarization of the economy that the decoupling between growth and GHG emissions observed in Section 5 was made possible. Within each economic sector the correlation between value added and GHG emissions has remained positive although at very different levels: the strong growth in the relative importance of the tertiary sector has been accompanied by a modest but significant increase in emissions; the strong decrease in the value added of the primary sector has been accompanied by a slower decrease in GHG

[22] Source: OFS

emissions and the secondary sector has displayed a significant increase in value added with a more modest increase in GHG emissions.

We now dive deeper into the detailed performance of each sector, specifically by matching the contribution to GDP, on the one hand, and the production of GHG emissions, on the other hand, in order to obtain a measure of each sector's carbon efficiency. More exactly, we compute the **GHG to GDP ratio** for each sector which indicates how many kg of CO2 equivalent is associated with one extra Swiss franc of value added in the sector. The results are striking (see Table 3). For each additional Swiss franc contributed to GDP, the **primary sector** produces 1.534kg of CO2 in 2018 against 1.19kg in 1995. The **secondary sector**, is considerably more carbon efficient and has been getting more so: the GHG to GDP ratio has decreased from 0.129kg in 1995 to 0.102kg per CHF in 2018. Finally, the **tertiary sector** is clearly the most carbon efficient with a GHG to GDP ratio of only 30 grams/CHF in 2018 against 40 grams/CHF in 1995.

Two messages stand out from these computations. First the **primary sector** is relatively carbon inefficient and has been getting worse. Its GHG to GDP ratio is 50 times the one of the tertiary sector. A reflection on the future of agriculture is clearly warranted; in a sense the primary sector offers the best opportunity to reduce GHG Emissions. Second, while the tertiary sector is considerably more carbon efficient, given its absolute and growing size the zero carbon objective for the Swiss economy requires the full de-carbonization of the tertiary sector which should within reach without handicapping in a major way its value creation potential.

Table 3 – Summary statistics of sectorial analysis

	Primary sector		**Secondary sector**		**Tertiary sector**	
Period 1995 to 2018, under SEEA	1995	2018	1995	2018	1995	2018
Gross Value Added[23], billion CHF	6,38	4,55	133,05	178,11	303,64	518,51
Weight in Gross Value Added, %	1,44	0,65	30,03	25,40	68,53	73,95
GrDP (lower-bound), billion CHF	5,65	3,877	131,40	176,37	302,37	517,02
Amount of GHGE diminution, billion CHF	0,729	0,670	1,65	1,75	1,27	1,49
Weight in GHG Emissions, %	12,32	11,55	27,86	30,10	21,50	25,72
GHG to GDP ratio, in kg/CHF	1,19	1,53	0,13	0,10	0,04	0,03

[23] Gross Value Added corresponds to GDP before adjusting for taxes and subsidies. In GVA, subsidies are included, taxes are excluded.

7. Conclusions and one proposal: a zero carbon economy by 2025

In this paper, we propose a simple adjusted measure of the domestic product which accounts for the monetary value of Greenhouse Gas emissions, i.e. Green Domestic Product (GrDP). For Switzerland, we find that this adjusted measure is 0.62% to 1.5% lower than the standard GDP in 2018 depending on the methodology used for measuring GHG emissions. The corresponding estimates of the monetary value of GHG emissions range from CHF 522 to CHF 1279 per capita per year. The trend reduction in GHG emissions since the nineties translates into a GrDP growth rate that is slightly larger than the GDP growth rate in Switzerland. This is a form of decoupling that is worth highlighting given the intensity of the debate around this issue. The 60% growth in Swiss GDP since 1990 has been compatible with a reduction of GHG emissions at the economy-wide level.

The surprisingly small adjustment to GDP that is warranted to take account of GHG emissions suggests another surprising possibility worth considering in light of the warming emergency, that the Swiss economy becomes zero net carbon much earlier than planned, why not by 2025? Indeed, for a very reasonable per capita sacrifice Switzerland could decide to compensate immediately the GHG emissions that it cannot eliminate, at a cost that would be certainly considerably less than 1% of GDP. This is because the current price of compensations is much lower than CHF 96 per ton. Of course this should not weaken but rather strengthen the determination to reach zero GHG emissions much earlier than 2050.[24] But in light of the climate emergency this would set a fantastic example for the world in the context of a plan to progressively decrease the reliance on compensations as policies that forcefully decrease direct emissions take effect!

Our sectoral analysis highlights the low and decreasing carbon efficiency of the primary sector. However, while the other two productive sectors are significantly more efficient, their increasing contribution to the value added by the Swiss economy nevertheless results in an increase in their GHG emissions. The decoupling between economic growth and GHG emissions is thus entirely attributable to the increasing relative importance of the more carbon-efficient tertiary sector. It is also worth noting that if the past trend is a good predictor of the future evolution, the decrease in GHG emissions at the economy-wide level will not be sufficient for Switzerland to satisfy its commitment according to the Paris agreement. More forceful policies and increased awareness leading to changes in individual and corporate behaviors are needed. It is notable that the most disturbing trend is observed in household transportation with both terrestrial and air transport emissions increasing over the last decades. In the case of household transportation, a more determined push towards cars emitting much less CO_2 (notably electric cars) can considerably improve the situation with little or no loss in wellbeing. In the case of air transportation, despite accrued fuel efficiency in aircrafts, it is highly unlikely that a change in trend will be possible without additional measures to reduce air traffic.[25]

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[24] We are fully aware of the broad opposition to compensations on moral and effectiveness grounds. While we have nothing to say on the former, we believe that suspicions of ineffectiveness, while warranted, can be properly addressed and will be overcome as soon as it is clear that compensations are not a way to avoid taking radical measures to limit GHG emissions. They should be meant as a temporary complement to real actions in order to meet the urgency of the situation and anticipate the date at which the objective of zero GHG emissions in the country will be reached.

[25] See Brülhart et al.,2020 for a deeper analysis of the prospects and a review of alternative options.

We conclude by repeating that what we have provided here is a very partial estimate of the economic cost of environmental destructions arising from economic activity. Firstly, the different methodologies for measuring GHG emissions lead to an economic impact that varies hugely. Today, the method of reference (IPCC) gives the lowest estimations of GHG emissions, translating into less ambitious reduction policies. Secondly, the appropriate SCC level is subject to considerable uncertainty. We have conducted our analysis by reference to the CO2 levy for Switzerland set at CHF 96 per ton over the period 2018-2020. If we adopt a higher carbon price (CHF 200/ton), the distance between GrDP and GDP more than doubles. Last but not least, netting for the monetary value of GHG emissions only, although it addresses the more urgent climate change issue, is not enough to account for the complete range of environmental damages that we should be considering, notably the loss in biodiversity. The case for doing so using a purely economic approach is however less clear-cut and the methodological issues that such a project raises are particularly complex.

Our approach in this note has been static and backward-looking in line with the national income accounting perspective. A forward-looking approach is needed to provide an answer to the following two important questions: 1. What carbon price or alternative set of policies are likely to enable the Swiss economy to reach the goal set forth by the Swiss government? 2. Would this more ambitious path of GHG emissions reduction be compatible with a continuation of the current growth path of the Swiss economy? In other words, what would be the cost in foregone GDP growth of a GHG emissions path in line with a zero-carbon economy in 2050 or before? Exploring these questions will constitute the next steps of our inquiry.

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Appendix

Social Cost of Carbon

We have the SCC/ton for the year 2018, but all other data are in real terms, i.e. at constant price of the year 2015. We need to convert the amount of 2018 into the equivalent of 2015, using the Consumer Price Index. By doing so, we compare GDP at constant price of 2015 with monetary evaluation of GHG emissions fixed on the same base year. The CO2 price is set at CHF 96 for 2018 (or CHF 200 for the upper-bound) and, by a rule of three, we use the CPI to find the adjusted price for the year of reference (2015):

$$SCC = \frac{SCC_{2018} * CPI_{2015}}{CPI_{2018}}$$

Where SCC indicates the Social Cost of Carbon per ton of CO2 equivalent for the year 2015, applied to the entire period and CPI_2015 is the average Consumer Price index for the year t. This leads to a price of 2015 of CHF 96.26. As mentioned in the text, we keep the price of CHF 96 per ton for simplicity and because prices between 2015 and 2018 stayed rather constant.

Analysis with high SCC

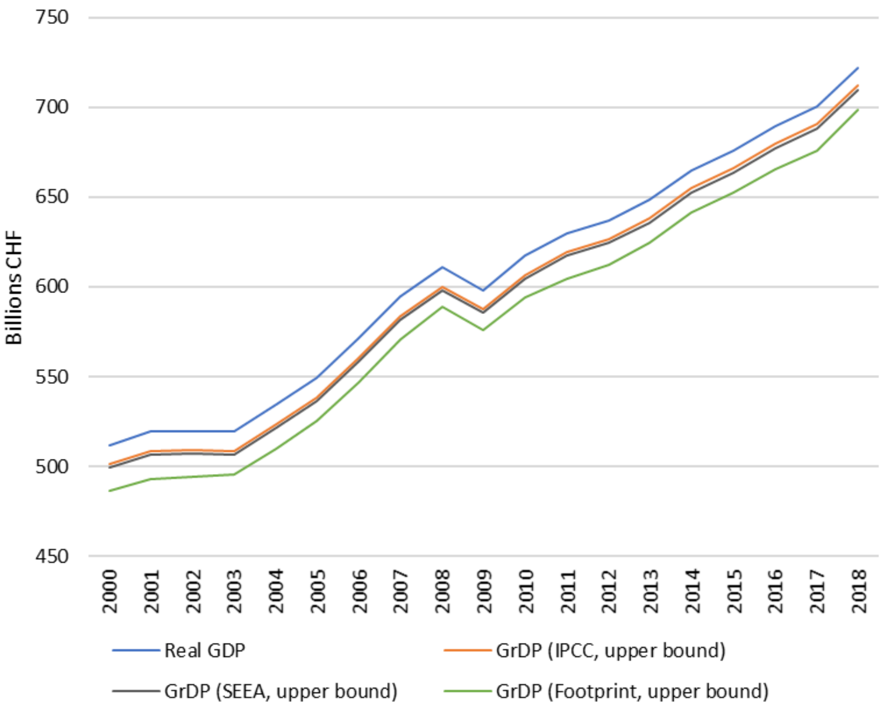

Fig. A - GDP and GrDP under different methods, using the high SCC, i.e. CHF 200 per ton

Table B - Summary Statistics of GrDP and GDP following the 3 methods with a high SCC

	GrDP - IPCC	GrDP - SEEA	GrDP - Footprint	GDP
	High SCC	**High SCC**	**High SCC**	**-**
Average annual DP Growth Rate, in %	1.984	1.984	2.047	1.938
DP Growth rate over 2000-2018, in %	42,156	42,152	43,715	41,012
	1990			
DP, in billion CHF	442.86	441.36	n/a	453.69
Value of GHG emissions, in billion CHF	10.83	12.33	n/a	n/a
DP per capita, in CHF	65,602	65,379	n/a	67,207
Amount of diminution per capita, in CHF	1,604	1,827	n/a	n/a
	2000			
DP, in billion CHF	501.08	499.12	486.26	511.73
Value of GHG emissions, in billion CHF	10.65	12.60	25.46	n/a
DP per capita, in CHF	69,555	69,284	67,498	71,033
Amount of diminution per capita, in CHF	1,478	1,749	3,535	n/a
	2018			
DP, in billion CHF	712.31	709.52	698.83	721.59
Value of GHG emissions, in billion CHF	9.28	12.08	22.76	n/a
DP per capita, in CHF	83,364	83,037	81,787	84,451
Amount of diminution per capita, in CHF	1,086	1,413	2,664	n/a