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GDP forecasting and greenhouse gas emissions – an integrated approach

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The Annual Economic Report 2022 of the German Federal Government recommends focusing more comprehensively and rigorously on the consequences of economic activity, particularly for the environment and climate. In this paper we propose a simple approach for systematically integrating the expected greenhouse gas emissions into our economic forecast for Germany. Our approach enables the greenhouse gas emissions to be expected under current conditions to be compared with the reduction targets set by policymakers. On the basis of our current GDP forecast for 2022 (+1.4%) and 2023 (-0.3%), it predicts that greenhouse gas emissions will drop this year and next, but less than intended. Thus, greenhouse gas emissions are predicted to be just under 6% higher in 2022 and a good 5% higher in 2023 than prescribed by the reduction trajectory set by policymakers. Like all forecasts, this one, too, is fraught with uncertainty. Nevertheless, based on a forecast interval derived from the historic forecast errors of our approach, the statement that the reduction targets will be missed in the forecast period appears to be empirically well validated. We plan to update this estimate periodically together with our economic forecast in the future and to report on the result in our quarterly KfW Business Cycle Compass series.

An ecological 'price tag' for GDP

Economic growth has a range of social and ecological consequences for well-being. In the past, these have usually been disregarded in the usual economic forecasts, including our own. In its Annual Economic Report 2022 the German Federal Government pointed out, for example, that macroeconomic growth, measured by the increase in gross domestic product (GDP), is a necessary but by no means sufficient prerequisite for lasting prosperity, employment, participation and social security. So a greater effort must be undertaken in the future 'to demonstrate how value added is generated in Germany and which resources are used in the process. This includes an assessment of the extent to which economic output is climate-neutral (…).'[1] Picking up on this idea, in the following we will develop a simple approach for systematically adding to our economic forecast for Germany the greenhouse gas (GHG) emissions to be expected in the forecast period. Figuratively speaking, that means we will put an ecological 'price tag' on GDP that will tell us how much the expected growth will presumably cost us as a society in the form of GHG emissions. That will sharpen our awareness of the trade-off that exists at least in the short term between more goods produced and, thus, income generated on the one hand and the use of key natural resources on the other hand.

An identity equation as a starting point

The starting point for our approach is the following identity equation, according to which total GHG emissions are the product of GDP and the emission of GHG per unit of GDP, that is, GHG intensity:

1. GHG = GDP x (GHG/GDP) = GDP x GHG intensity

Thus, the growth rates g(.) of these level variables result in the approximative equation:

2. g(GHG) = g(GDP) + g(GHG intensity)

This shows that for a typically desired positive rate of economic growth – that is, when g(GDP) > 0 – the only way for GHG emissions to drop – that is, g(GHG) < 0 –, is by realising a decline in GHG intensity that is larger than the rate of economic growth in absolute terms:

3. -g(GHG intensity) > g(GDP)

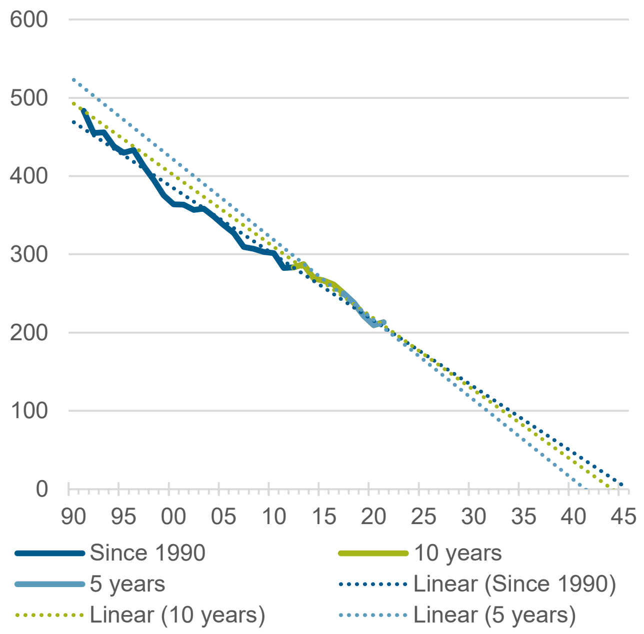
We will use these basic interrelations to make a forecast of GHG emissions to be expected in the future that are compatible with our GDP forecast. To do this we will take the GDP forecast from our quarterly updated KfW Business Cycle Compass. It currently stands at +1.4% for 2022 and -0.3% for 2023.[2] That gives us the g(GDP) from equation (2). What is still missing is the expected variation of GHG intensity, that is, g(GHG intensity). For this we can use a linear trend extrapolation.

Trend extrapolation to forecast GHG intensity

As the following Figure 1 shows, in the past the decline in GHG intensity closely followed a linear trend.[3] We will use this for the forecast by extrapolating the trend for the forecast years. In other words, we will rely on the statistical property of a linear downward trend remaining unchanged for the foreseeable future as well. An open question is how long the base period is for determining the trend in order to make as robust a forecast as possible. One obvious option is to derive the trend from the total number of available realisations, that is, since the beginning of the time series. GHG intensity has been available since the beginning of the 1990s. In the present case, however, that would mean the decommissioning of highly polluting eastern German industrial facilities after unification – particularly heavy emitters of GHG – would continue to be a factor in determining the trend. However, easily achievable GHG reduction potentials such as those realised in the 1990s have already been leveraged. Using a very short base period, on the other hand, could mean that exceptional developments in specific years greatly influence the result, such as the year 2020, during which business closures were mandated to contain the pandemic, leading to lower GHG emissions. The question about the proper base period can therefore be answered only empirically.

Figure 1: GHG intensity of GDP in Germany

In kg CO_2 equivalents per EUR 1,000 of GDP in chained prices of 2021



Source: Destatis, German Federal Environment Agency, KfW Research.

Box: Determining the suitable base period

In defining the base period, we took a pragmatic approach and determined the linear trends for the full period available at the time of the forecast, for the past ten years and for the past five years, thereby generating out-of-sample forecasts which we subsequently compared with the realised GHG intensities.

We began with a forecast for the years 2001 (one-year forecast horizon), 2002 (two-year forecast horizon) and 2003 (three-year forecast horizon) on the basis of the actual data of GHG intensity in the years 1991 to 2000 (base period ten years, initially equal to full observation period) and 1996 to 2000 (five-year base period). After that, we added a year and determined the forecasts for the ensuing three years analogously, continuing up until the year 2021, the end of the current observation period.

Subtracting the forecasts thus generated from the respective realisations allows us to determine 21 forecast errors for the one-year forecast horizon, 20 for the two-year forecast horizon and 19 for the three-year forecast horizon and to condense these into measures of forecasting quality in order to assess the forecast quality of the different base periods. To this end, we use three measures that are equal to zero in a perfect forecast:

1. Mean Error (ME). The mean error indicates whether the forecast is distorted, in other words, whether the future result is systematically underestimated or overestimated. High positive and negative deviations can be equalised in the ME.
2. Mean Absolute Error (MAE). It eliminates the sign of the deviation and thus indicates how far the forecast deviates upward or downward on average around the future result.
3. Theil's U. It is defined here as the MAE in per cent of the MAE of the naïve forecast, that is, the continuation of the last actual value over the entire forecast period. For values above 100%, the evaluated approach is poorer than the naïve forecast.

Moving 10-year base period is a good compromise

The following table illustrates that a moving ten-year period is a good compromise between a very long base period (full available observation period) and a very short base period (moving five-year period) from which to derive the linear trend on the basis of the approach described in the box and the measures of forecasting quality explained in it. Regardless of whether we look at the mean absolute error or Theil's U, both of these measures of forecasting quality are minimal in all three forecast horizons[4].

Table: Forecasting quality by base period and horizon

Forecasting horizon 1 year

Base period	Total	10 years	5 years
ME	3.3	0.2	0.3
MAE	3.7	2.7	3.0
U	147	89	100

Forecasting horizon 2 years

Base period	Total	10 years	5 years
ME	4.2	0.4	0.0
MAE	4.5	3.4	4.1
U	69	46	66

Forecasting horizon 3 years

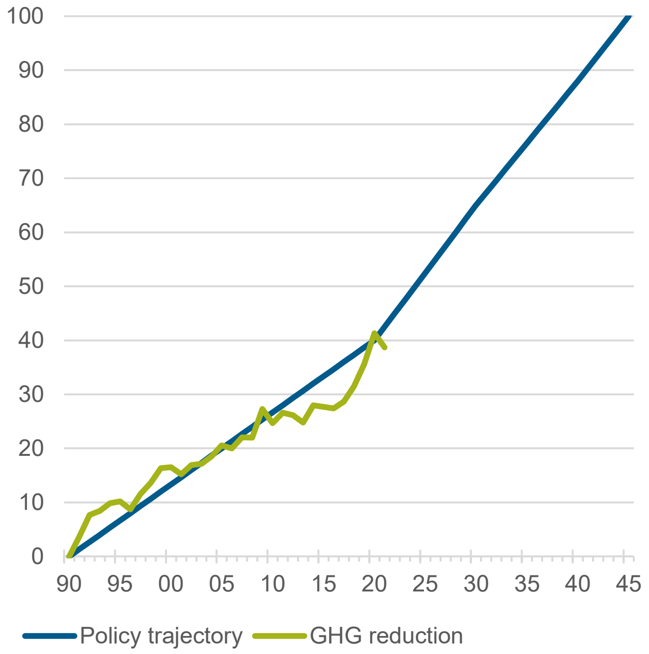
Base period	Total	10 years	5 years
ME	5.1	0.6	-0.2
MAE	5.3	4.2	5.1
U	47	33	57

Explanations: Forecast error=realisation minus forecast;
ME (mean error) mean forecast error in per cent of realisation; MAE (mean absolute error)= mean absolute forecast error in per cent of realisation; U (Theil's U)=MAE in per cent of the MAE of the naïve forecast; in regard to relative forecasting quality, the most favourable result is highlighted light blue.

Only the distortion, observable from the mean forecast error, is just slightly lower in the moving five-year period with a view to the two- and three-years ahead forecast. However, even in the ten-year period, seen individually it is low, with an over-prediction of just 0.4 and 0.6% of the realisation. Also note-worthy in the one-year forecast period is the poor result of the trend extrapolation based on the very long or very short base period in comparison with the naïve forecast, in which the last available actual value of GHG intensity is simply continued, thus following the naïve motto of 'tomorrow will be like today'. On the basis of the five-year base period, Theil's U is 100% and, if we take the relevant full observation period as the base period, significantly higher at 147%. Irrespective of this, the differences between the linear trends derived from the three base periods are rather gradual at the current margin with actual data up to the year 2021, as shown by the dotted lines in Figure 1.

Figure 2: Policy trajectory and GHG reduction

In per cent on 1990



Source: German Federal Environment Agency, KfW Research.

Politically agreed reduction targets

Policymakers have set GHG emission reduction targets. The targets are for 40% reduction by 2020, 65% by 2030, 88% by 2040 and 100% by 2045, in each case against the 1990 level of GHG emissions.[5] Figure 2 shows this policy trajectory and the GHG reductions achieved up to and including the year 2021. We have linearly interpolated the implicit target values for the periods between the years with explicit targets. The steeper angle of attack of the trajectory from 2020 is an expression of the increased level of ambition for GHG reduction, among other things in response to a ruling handed down by the German Federal Constitutional Court which led to an amendment to the Federal Climate Change Act in August 2021.[6] The GDP forecast from the KfW Business Cycle Compass and the forecast of GHG intensity for the matching time horizon from the extrapolation of the moving linear ten-year trend ultimately allows a forecast for the level and variation of GHG emissions in the forecast period to be made in line with the expected economic trend on the basis of the initially explained equations (1) and (2) and, converted to the reduction predicted with this forecast since 1990, to be compared with the GHG reduction targets established by policymakers.

GHG reduction targets for 2022 and 2023 will be missed

Figure 3 on the following page shows the result for the current forecast horizon up to the year 2023. On the basis of our current GDP forecast, our new integrated approach for the GHG forecast predicts that GHG emissions this year and next year will fall, namely from 762 million t CO_2 equivalent in 2021 to 722 million t CO_2 equivalent in 2022 and 687 million t CO_2 equivalent in 2023. The above equation (3) will therefore be fulfilled and GHG intensity is set to drop more than GDP will grow. However, the reduction target will likely be missed in the forecast period. Thus, according to our forecast, GHG emissions will likely exceed the interpolated policy trajectory set for reductions in 2022 and 2023 by 40 million t CO_2 equivalent in 2022, or nearly 6%, and by 35 million t CO_2 equivalent or a good 5% in 2023. For comparison: These additional average annual emissions of around 38 million t CO_2 equivalent above the trajectory are practically equal to the total GHG emissions of Slovakia in the year 2019.[7]

Informative value and limits of our approach

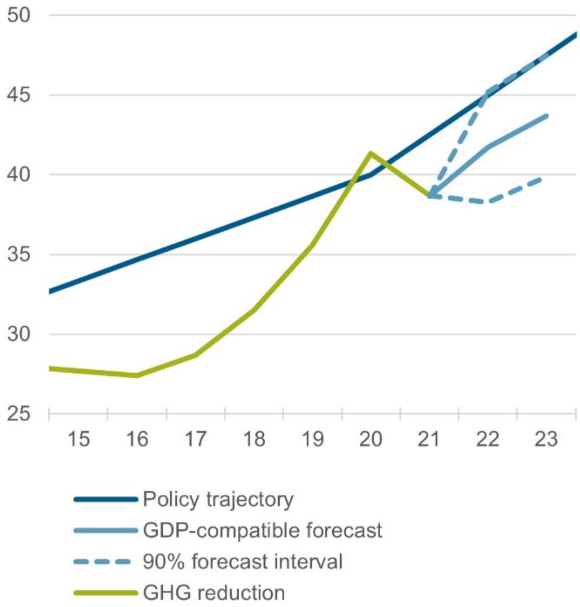
As is always the case with forecasts, the intrinsic limits of all methods must be kept in mind to appropriately assess the informative value of the forecast result. Our new approach shows what levels of GHG reduction can be expected to be achievable this year and next under the given economic forecast and statistical trend extrapolation of GHG intensity of GDP. But to what extent can the linear extrapolation of GHG intensity, chosen here mainly because of the good forecasting properties, also be interpreted materially? In essence, we see it as the summary projection of the relevant conditions from the recent past – including technological development pathways, the legal framework, seasonal temperature patterns and political ambition – into the near future. Unforeseen effects, however, are always possible and can ultimately lead to incorrect forecasts. Currently, for example, a complete stop of Russian gas supplies could create an acute gas shortage that would require the use of additional oil or coal-fired power plants with higher GHG emissions. It is also important to be mindful of the fact that outside temperatures during the heating period in winter may be exceptionally frosty or mild, for example, which would have an immediate effect on GHG emissions.

GHG forecasting risk and forecast interval

The risk of ending up being wrong is inextricably linked to the forecasting trade, as highlighted by the forecasting errors from our evaluation of the out-of-sample forecasts for GHG intensity documented in the above table. These forecasting errors can be used to construct a forecast corridor around the central forecast in which the future realisations are to be found with a certain degree of probability. In the historic distribution of forecast errors, 90% of the realisations were in an interval of around two mean absolute forecasting errors around the central forecast. This 90% forecast interval is illustrated by the dashed line around the central forecast represented by the thick light blue line in Figure 3. The upper interval limit is only minimally above the target trajectory, that is, almost the entire interval is below it. The qualitative statement that the reduction targets will be missed over the forecast period thus appears to be empirically well validated.

Figure 3: GDP-compatible forecast of GHG emissions reduction

In per cent on 1990



Source: German Federal Environment Agency, KfW Research.

GDP forecast risk was deliberately left out

Furthermore, the forecast risk about the economic development itself creates uncertainty around future GHG emissions, but this has been left out here. We clearly understand our approach as one that is integrated into the economic forecast and delivers a forecast of GHG emissions consistent with the expected growth of the economy and thus also permits a statement as to how GHG reductions in Germany are progressing under the given growth assumptions relative to the policy target – in other words, puts an ecological 'price tag' on GDP.

Self-destructing forecast is possible

Finally, there is another risk here which is characteristic of dynamic systems with social interactions, such as the economy and society. It is conceivable, for example, that the prediction of a failure to meet the target is an incentive to make significantly greater efforts, as a result of which the future outcome would be better than predicted. Conversely, however, an expected overfulfilment of the target might also cause stakeholders to slacken their efforts, leading to a poorer outcome. Either way, the forecast would destroy itself in both cases. This generally distinguishes social science forecasts from those in which a reaction by the relevant system to the forecast is generally excluded – for example in weather forecasting.

Periodic publication is planned

We plan to periodically update the estimate of GDP-compatible GHG emissions and their position relative to the reduction trajectory together with our economic forecast. We intend to report on the results in a new box in our quarterly KfW Economic Compass series, beginning with the autumn 2022 edition.

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[1] Federal Ministry for Economic Affairs and Climate Action (ed.), Annual Economic Report 2022, pages 77–78, retrieved from https://www.bmwk.de/Redaktion/EN/Publikationen/Wirtschaft/annual-economic-report-2022.pdf?__blob=publicationFile&v=2.

[2] Cf. Scheuermeyer, P. et al. (2022), KfW Business Cycle Compass August 2022 Between stagflation and recession, KfW Research.

[3] GHG emissions in the numerator of GHG intensity have been available since 1990 and published by the German Environment Agency from around mid-March up to and including the preceding year (https://www.umweltbundesamt.de/daten/umweltindikatoren/indikator-emission-von-treibhausgasen#die-wichtigsten-fakten). GDP figures for the whole of Germany have been published since 1991 and can be retrieved from the national accounts page of Destatis (https://www.destatis.de/EN/Themes/Economy/National-Accounts-Domestic-Product/_node.html). The provisional GDP result for the previous year is known from mid-January.

[4] In our quarterly economic forecast, the forecast horizon for economic growth is always two years, meaning it comprises both the current and the coming calendar year. We need the three-year forecast horizon for GHG intensity merely for our northern hemisphere winter forecast, which we always release in February. At that time, we know only the previous year's GDP but not the GHG emissions. In February, these are known only for the year before the previous year and must consequently be forecast not just for one and two years but also for a three-year period in order to match the time horizon of the GDP forecast. For our spring (May), summer (August) and autumn forecast (November), on the other hand, both figures for the previous year are known.

[5] Cf. German Federal Environment Agency (2022), Treibhausgasminderungsziele Deutschlands (*Germany's greenhouse gas reduction targets* – our title translation, in German), accessed from https://www.umweltbundesamt.de/daten/klima/treibhausgasminderungsziele-deutschlands#internationale-vereinbarungen-weisen-den-weg. The official GHG reduction goal for 2045 is for net greenhouse gas neutrality. That means inevitable residual emissions from agriculture and specific industrial sectors such as cement production are offset elsewhere, for instance through afforestation or underground carbon storage. We have approximated this with a 100% reduction target on 1990.

[6] Federal Law Gazette, year 2021 Part I No. 59, Erstes Gesetz zur Änderung des Bundes-Klimaschutzgesetzes vom 18. August 2021 (First Act to Amend the Federal Climate Change Act of 18 August 2021 – *our title translation,* in German), accessed from https://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&start=//*%5b@attr_id=%27bgbl121s3905.pdf%27%5d#__bgbl__%2F%2F*%5B%40attr_id%3D%27bgbl121s3905.pdf%27%5D__1654776756724.

[7] Cf. German Federal Environment Agency (2021) Treibhausgas-Emissionen in der Europäischen Union, (*Greenhouse gas emissions in the European Union* – our title translation, in German), accessed from https://www.umweltbundesamt.de/daten/klima/treibhausgas-emissionen-in-der-europaeischen-union#hauptverursacher.