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235 Report by Timm Bönke, Geraldine Dany-Knedlik, and Werner Roeger

Meeting climate targets can only spur on economic growth with the right combination of measures

- Study investigates growth effects of meeting emissions reduction targets
- Energy-saving technological progress results in economic growth
- Supply-side measures are important to securing economic growth

LEGAL AND EDITORIAL DETAILS



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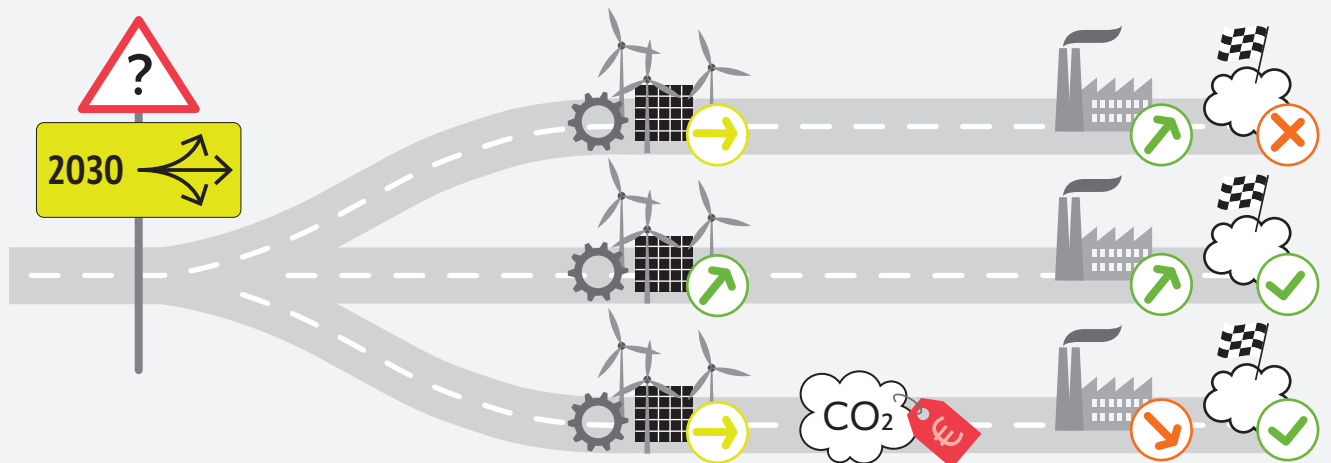
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Meeting climate targets can only spur on economic growth with the right combination of measures

By Timm Bönke, Geraldine Dany-Knedlik, and Werner Roeger

- Growth model shows possible growth trajectories of the German economy if emissions targets are met
- Emissions targets can be met through market mechanisms with energy-saving technological progress or increasing fossil fuel prices
- Energy-saving technological progress developing at a faster speed fosters economic growth
- Carbon pricing without supply-side measures dampens economic performance
- Inclusive economic growth that conforms to climate targets requires additional support of climate-friendly investments

Energy-saving technological progress developing at a faster speed allows for economic growth as well as meeting climate targets; carbon pricing on its own leads to growth losses – three scenarios



Source: Authors' depiction.

FROM THE AUTHORS

"If technological progress does not develop quickly enough, a corresponding carbon price could help save energy. To ensure economic growth, the revenue must then be used for investment measures."

— Geraldine Dany-Knedlik —

MEDIA



Audio Interview with Geraldine Dany-Knedlik (in German)
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Meeting climate targets can only spur on economic growth with the right combination of measures

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ABSTRACT

Reducing carbon emissions is essential to meeting climate targets. What is unclear, however, is which measures are required to do so and what impact they would have on economic growth. In this Weekly Report, a macroeconomic model is used to observe four scenarios in comparison to a baseline scenario without emissions reduction. It is analyzed which effects different measures, such as technological progress developing at an increased speed and/or carbon pricing, would have on economic growth and emissions targets. Assuming that energy-saving technological progress develops as it has in the past, meeting the emissions targets will require a relatively high carbon price, which has a dampening effect on economic growth. If energy-saving technological progress were to develop at a faster pace, emissions targets could be met without carbon pricing and there would be slight growth. Therefore, consideration should be given to how much accompanying economic and climate policy measures can mitigate potential growth losses and distributional effects.

As a part of the Federal Climate Change Act, the German Federal Government has pledged to achieve net greenhouse gas neutrality by 2045. Emissions must be continually decreased to reach this goal. Since 1990, total emissions have declined by 40 percent, or around 13 percent per decade. Over the next eight years, emissions must decline at twice the pace according to the emissions reduction trajectory. It is unclear if the trajectory by 2030 and the overall target by 2045 can be met without additional government measures, such as an increase in the tax rate on fossil fuels to combat carbon emissions or further regulatory measures.

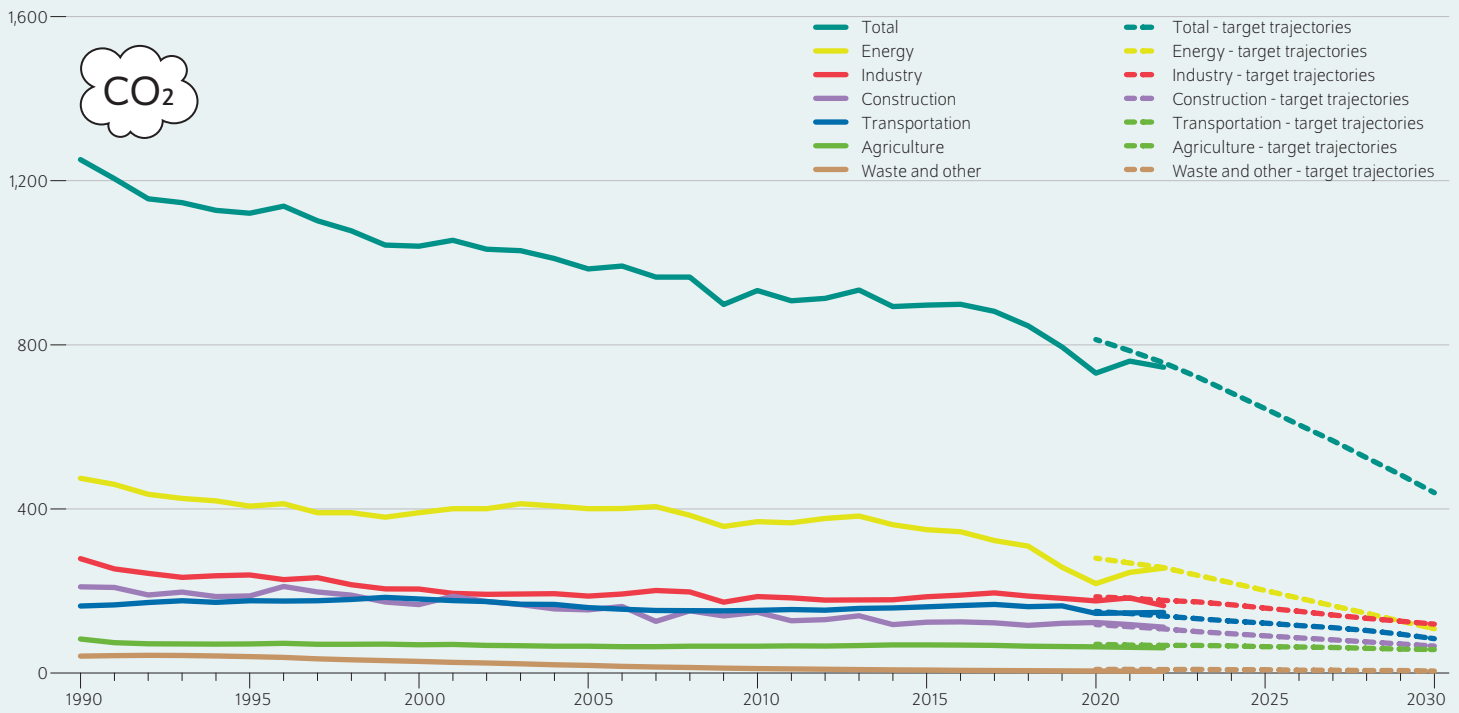
Additionally, it is unclear which effects meeting the emissions targets without additional financial policy stimuli would have on average long-term growth, which roughly corresponds to potential growth.¹ The effects depend on, on the one hand, by how much the energy intensity—the ratio from energy use to GDP—can be decreased. On the other hand, reducing carbon emissions per unit of energy (carbon intensity) is decisive.² Emissions per unit of energy are particularly high when fossil fuels are used. Significant shares of the capital utilized must be replaced by energy-efficient and carbon-efficient variants to be able to decrease both energy consumption and carbon intensity while maintaining the same production level in the manufacturing process. To reach the emissions targets by the target date, a certain share of the capital would therefore have to be amortized before the end of its useful life. Alternative investments in the decarbonization of production processes are offset, at least in part, by greater depreciation of the capital stock, which leads to economic losses in itself. These losses must be compensated for by more investments in other sectors in order to keep economic growth at a consistent level.

Using a partial macroeconomic model, this study simulates the effects of the climate targets on growth potential under various market-based conditions, thus without regulatory climate measures. Market-based mechanisms are considered to be energy-saving technological progress by itself as well

¹ Potential growth is long-term economic growth adjusted for short-term cyclical fluctuations.

² Cf. Yoichi Kaya and Keiichi Yokobori, *Environment, Energy, and Economy: Strategies for Sustainability* (United Nations University Press: 1997).

Figure 1

Development of greenhouse gas emissions and target trajectories in GermanyIn millions tons of CO₂ equivalent

Sources: Umweltbundesamt; authors' calculations.

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In the past 30 years, greenhouse gas emissions were reduced by 60 percent. To meet the target, greenhouse gas emissions must be reduced by a further 35 percent over the next eight years.

as together with carbon pricing in the form of a tax on fossil fuel use. Four scenarios are compared to a baseline scenario without emissions reductions and the effects various measures have on economic growth and the emissions targets are analyzed.

Previous studies examine energy-saving technological progress

Studies that analyze the German energy transition and possible emissions reduction scenarios usually assume a strongly positive growth trajectory for German GDP or additional investments, which are partially financed by public funds, and derive the energy demand under various assumptions about energy savings.³ Studies from the Spring 2022 and 2023 Joint Economic Forecasts (*Gemeinschaftsdiagnose*, GD) and a DIW Berlin research paper serve as the basis of this

Weekly Report.⁴ The GD studies investigate to what extent meeting the emissions targets impacts the production potential—long-term possible growth—in Germany. A partial macroeconomic model in which energy, capital, and labor are considered as additional production factors is used. The studies assume an exogenous decline in primary energy consumption by roughly 50 percent to reach the emissions targets. The effect of the energy transition on economic output is modeled in different scenarios. Various assumptions are made about the expansion of renewable energy sources and the speed at which energy-saving technological progress develops. For this purpose, future price trends for fossil fuels and renewable energy sources as well as for carbon are assumed exogenously. Assuming that energy-saving technological progress develops at triple the speed in the future and the expansion of renewable energy sources takes place slowly, the results of the 2023 GD study show that German economic output would increase by seven percent by 2030 if adhering to the emissions targets. Germany would thus

³ Cf. for example Gunnar Luderer et al., *Ergänzende Daten zum Ariadne Report Deutschland auf dem Weg zur Klimaneutralität 2045-Szenarien und Pfade im Modellvergleich* (2021) (in German; available online. Accessed on August 22, 2023. This applies to all other online sources in this report unless stated otherwise); also cf. Manfred Fischedick et al., *Chancen durch Klimaschutz. Kurzbericht Bundesministeriums für Umwelt, Naturschutz und nukleare Sicherheit* (2019) (in German).

⁴ Cf. *Gemeinschaftsdiagnose, Von der Pandemie zur Energiekrise – Wirtschaft und Politik im Dauerstress* (2022) (in German) as well as *Gemeinschaftsdiagnose, Inflation im Kern hoch – Angebotskräfte jetzt stärken* (2023) (in German); Geraldine Dany-Knedlik und Werner Roeger, "Growth effects of decarbonisation under different policies: a macroeconomic perspective," *DIW Discussion Paper* (forthcoming).

Box

Model of long-term growth including the energy transition

The model used in this study is based on the GD model and was developed further at DIW Berlin.¹ It is a common, partial macroeconomic model for estimating long-term growth. Aggregate output Y is represented by labor L , capital K , and energy E in the context of a CES function:

$$Y_t = \left[s^V \frac{1}{\sigma} V_t^{\frac{\sigma-1}{\sigma}} + s^E \frac{1}{\sigma} (T_t^E E_t)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \quad (1)$$

The production function (1a) characterizes to what extent the energy aggregate is complementary to the use of labor and capital ($\sigma < 1$). Energy-saving technological progress is also considered T^E . Assuming that fossil fuels are imported, the variable V indicates domestic value added:

$$V_t = T_t L_t^\alpha K_t^{1-\alpha} \quad (2)$$

The value added is characterized by a Cobb-Douglas production function of labor and capital as well as a neutral technological progress term T . The energy aggregate E is described with elasticity of substitution μ by a CES function from fossil fuel and renewable energy inputs.

$$E_t = \left[s^F \frac{1}{\mu} F_t^{\frac{\mu-1}{\mu}} + s^R \frac{1}{\mu} (R_t)^{\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}} \quad (3)$$

Assuming that households and businesses make cost-minimizing investment and employment decisions, demand for labor, capital, and energy—differentiated between fossil fuels and renewable energy—can be derived as a function of aggregate demand and relative factor prices.

For factor prices, it is assumed that the real capital utilization prices do not change over time and are unaffected by the energy transition. The real energy prices before taxes are also assumed to be constant. A constant labor force participation rate is assumed for the labor market. This implies that the real wages change across the individual scenarios.

Due to adaptation costs, it is unrealistic to assume the capital stock will immediately be adjusted when energy prices change. Therefore, it is assumed, consistent with the macroeconomic investment literature,² that the private sector distributes investments over time to minimize the adaptation costs. This results in three transmission channels of the energy transition to investment:

Capital costs: This transmission channel is presumably switched off.

Capital intensity of production: Capital intensity of production decreases when energy consumption decreases, as long as the decrease in consumption is not due to energy-saving technological progress.

Macroeconomic output: Macroeconomic output decreases with consistent employment, reduced energy consumption, and the related decrease in the capital intensity of production. This results in a decline in investment that is greater than the decline in value added.

Calibration

In the production function, the energy share parameter s^E is fixed at 0.023, corresponding to the share of energy in aggregate income. For the elasticity of substitution between energy and labor as well as capital σ , the values 0.02 and 0.2 are used to depict the spectrum of common values.³ The output elasticity of the labor factor α is set to 0.65, corresponding to the wage share of GDP. For aggregate total factor productivity growth, the value of 0.5 percent per year projected by the modified EU method⁴ in the medium term is used. For the growth rate of energy-saving technical progress, the value of 2.7 percent per year determined in the GD 2022 is continued. By disaggregating the energy into renewable and fossil fuel sources and by using a CES function for the energy aggregate, two additional parameters are introduced into the model: A share parameter for renewable energy sources s^R and the elasticity of substitution between fossil and renewable energy sources μ . The share parameter is set at 0.2, corresponding to the most recent share of renewable energy sources. For the elasticity of substitution between fossil fuels and renewable energy sources, values between 0.4 and 0.7 are permitted. These parameter values were determined in a way that the model in Scenarios 3 and 4 can generate an increase in renewable energy sources of around 50 percent.⁵

¹ Geraldine Dany-Knedlik and Werner Roeger, "Growth effects of decarbonisation under different policies: a macroeconomic perspective," *DIW Discussion Paper* (forthcoming).

² Cf. Frank Smets and Raf Wouters, "An Estimated Stochastic General Equilibrium Model of the Euro Area," *Journal of the European Economic Association* 1, no. 5 (2003): 1123–1175; Deutsche Bundesbank, *Entwicklung und Anwendung von DSGE-Modellen für die deutsche Volkswirtschaft* (2008) (in German).

³ Xavier Labandeira, José M. Labeaga, and Xiral Lopez-Otero, "A meta-analysis on the price elasticity of energy demand," *Energy Policy* 102 (2017): 549–568.

⁴ This is based on the EU model for Potentialschätzung that was modified by the GD, compare to Projektgruppe Gemeinschaftsdiagnose, *Aufschwung bleibt moderat – Wirtschaftspolitik wenig wachstumsorientiert* (2016) (in German).

⁵ Acemoglu et al. use elasticities that are significantly greater than one. However, such values would lead to expansion rates for renewable energy sources that would far exceed an increase in renewable energy sources of about 50 percent by 2030, see Daron Acemoglu et al., "The environment and directed technical change," *American Economic Review* 102, no. 1 (2012): 131–166.

continue to have potential growth of around 0.8 percent per year. However, if technological progress continues to develop at the historically observed speed, a roughly 14-percent decline in German GDP is expected. This decline is mainly due to the fact that compliance with the emissions targets can only be achieved by foregoing economic output in the model used by the study.

Forecast model of long-term growth including the energy transition

The model used here is a common partial macroeconomic model for estimating long-term growth (Box). While the GD studies assume the 48 percent decline in primary energy consumption is exogenous, this model focuses on the market-based conditions necessary for meeting emissions targets. To this end, two important components are added to the GD analyses: First, fossil fuels and renewable energy sources are modeled separately. This makes it possible to analyze effects of changes in the fossil fuel and renewable energy prices. Second, additional effects of changes in the energy share of production on capital stock are considered. For this purpose, the investment decisions of the private sector are explicitly modeled. Investments depend significantly on the expected demand and the effects of a change in energy intensity on capital productivity. The explicit modeling of the investments is relevant to depict important transmission channels. If there is slower growth due to the energy transition, investments will also decline. In addition to this main channel, a decreasing energy-to-production ratio also lowers production per unit of capital, which leads to an additional decline in investments.

Energy-saving technological progress supports economic growth, carbon pricing dampens it

Four scenarios are simulated using the model. The first two scenarios were constructed for comparison with the GD results. In these scenarios, it is investigated to what extent the emissions targets can be achieved by 2030 solely through energy-saving technological progress. In the model used, this summarizes the changes in overall economic output and production processes in practice. This does not only refer to switching from energy-intensive to less energy-intensive production processes; it also involves switching from private, high-emissions vehicles to public transportation or reducing the amount of energy required to heat buildings through energy-efficient renovation.

It is unclear how energy-saving technological progress will develop in the future. If the average growth rates of the past are extrapolated into the future, this results in an annual growth rate of 2.7 percent. In light of its past development, which has shown no strong fluctuations over the past 50 years, this seems to be a likely assumption about its future development. However, a credible announcement of emissions targets could provide special incentives that lead to a surge in the development of energy-saving production processes and goods, resulting in energy-saving technological

progress developing much more dynamically in the future. The latter is taken into account in Scenario 2.

Scenarios 1 and 2

Based on the 2023 GD scenarios, technological progress resulting in energy savings of 2.7 percent per year is assumed. This is an energy savings per unit of GDP of about 2.7 percent per year, which decreases energy consumption by around 20 percent by 2030. As in the 2022 GD, an elasticity of substitution of 0.02 is assumed for the possibility of substituting energy in the production process with the other production factors, capital and labor.⁵

In the second scenario, technological progress resulting in energy savings of 4.6 percent per year is assumed, which decreases energy consumption by 33 percent. It is assumed that the elasticity of substitution of capital, labor, and energy is 0.02.

The results for Scenario 1 show a slight overall increase in economic output of 0.9 percent by 2030 (Figure 2). However, primary energy consumption only decreases by 20 percent by 2030. This decline is achieved by reducing fossil fuels as well as renewable energy sources, although the share of renewable energy sources remains constant. This seems high considering the fact that carbon emissions have only been reduced by around 40 percent since 1990. However, it must be noted that the average GDP growth rate between 1990 and 2020 was almost twice as high as in the forecast period and there was, accordingly, a greater reduction potential.

In the second scenario, the growth effects of significantly greater energy-saving technological progress are simulated. By nearly doubling the annual growth of energy-saving technological progress, energy consumption is reduced by 33 percent. The simulation results show that the modifications introduced here deliver comparable results under similar assumptions as in the 2022 and 2023 GD analyses: Long-term growth increases by nearly 0.15 percent by 2030. Additionally, the results show that investments in the next seven years will be 0.9 percent higher than in the baseline scenario, causing the capital stock to increase by 0.3 percent.

Both scenarios show that introducing fossil fuels and renewable energy sources into the model and the modeling of the adaptation costs for investments barely affects the correlation between energy-saving technological progress, energy reduction, and economic growth. This seems plausible because the ratio of fossil fuels and renewable energy sources as well as the effective energy input remain the same due to the increase in energy-saving technological progress and the (marginal) productivity⁶ of capital does not change.

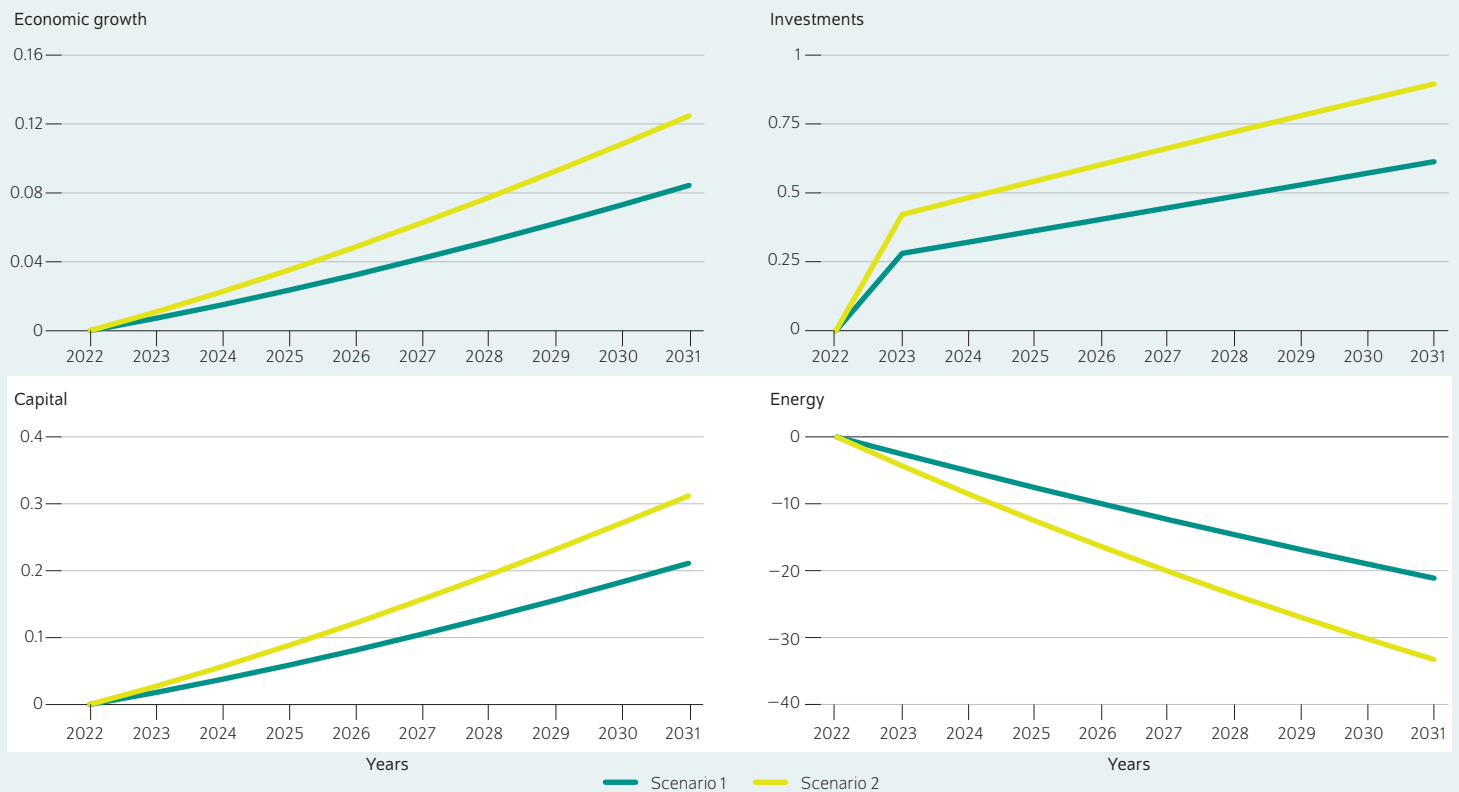
⁵ The elasticity of substitution between energy and the other production factors describes how much energy is saved in relative terms when the use of other production factors, labor and capital, increases by one percent.

⁶ The marginal productivity of capital corresponds to the additional units of GDP that an additional unit of capital can produce.

Figure 2

Simulation results for Scenarios 1 and 2

Percentage deviation from long-term trend



Source: Authors' calculations.

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Climate targets can only be approximately met if energy-saving technological progress develops at twice the speed.

In addition, the first two scenarios show that the emissions targets can only be achieved if the development of energy-saving technological progress speeds up. However, because a rapid near doubling of the speed of development of technological progress is uncertain, its relatively constant development over the last decade is observed. Therefore, this Weekly Report assumes that the emissions reduction target must be met through economic policy measures in addition to energy-saving technological progress. Furthermore, the assumed elasticity of substitution between energy and the other production factors, capital and labor, is decisive. In the GD studies, it is assumed that the elasticity of substitution is 0.02, and energy can thus hardly be substituted by capital and labor.⁷ There has previously been no consensus in the literature on the value of this elasticity.⁸ As the studies use a

value significantly higher than in the GD studies on average, a higher elasticity of substitution is assumed in Scenario 4.

Scenarios 3 and 4

It is assumed that the energy-saving technological progress, similar to in the past, grows by 2.7 percent annually. In addition, it is assumed that carbon pricing in the form of a tax on fossil fuel use will be introduced. Taxing fossil fuels leads to them being replaced by renewable energy sources. The use of renewable energy sources increases by about 50 percent, as is planned in the energy transition. It is assumed that the elasticity of substitution of capital, labor, and energy is 0.02.

In Scenario 4, the elasticity of substitution is increased to 0.2. All other assumptions are the same as in Scenario 3.

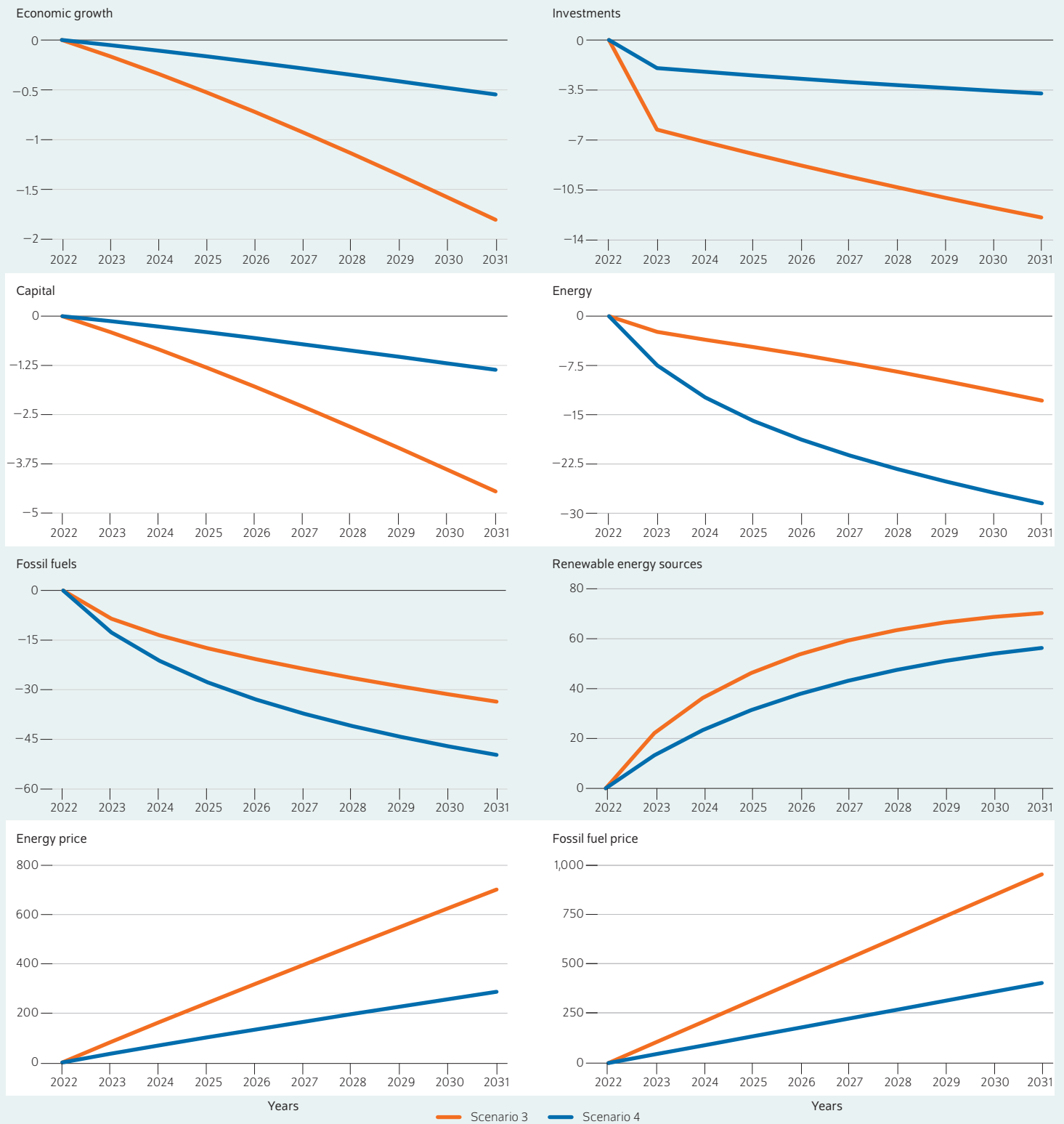
With a low elasticity of substitution between energy and the other factors of production of 0.02 (Scenario 3), even if the fossil fuel price were to increase by just under 1,000 percent in 2023, the carbon reduction target would not be met by 2030 because fossil fuel use would only fall by around 33 percent by 2030 (see Scenario 1). In this scenario, the emissions

⁷ Cf. John Hassler, Per Krusell, and Conny Olovsson, "Directed Technical Change as a Response to Natural-resource Scarcity," *Journal of Political Economy*, vol. 129, no. 11 (2021): 3039–3072.

⁸ Xavier Labandeira, José M. Labeaga, and Xiral Lopez-Otero, "A meta-analysis on the price elasticity of energy demand," *Energy Policy* 102 (2017): 549–568; Toon Vandyck et al., "Climate policy design, competitiveness and income distribution: A macro-micro assessment for 11 EU countries," *Energy Economics* 103 (2021); Rüdiger Bachmann et al., "How it can be done," *ECONtribute Policy Briefs*, no. 34 (2022).

Figure 3

Simulation results of Scenarios 3 and 4 Percentage deviation from long-term trend



Source: Authors' calculations.

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The climate targets could be met if fossil fuel prices were increased by around 400 percent (Scenario 4). However, long-term growth would decline by around 0.5 percent.

reduction target cannot be reached under the assumed carbon price because overall energy consumption declines by less than 15 percent, which is also due to the increase in the use of renewable energy. The macroeconomic output decreases in Scenario 3 compared to the baseline scenario without the energy transition by around two percent in the next eight years (Figure 3). The impact on investments and capital stock at the end of the eight years are, with declines of 12 and 4.5 percent, respectively, relatively high. This is due to the increase in the energy price, which leads to a decline in capital intensity, or the ratio from utilized capital to GDP. The adjustment dynamics can be described as follows: The increase in the energy price reduces energy-intensive production together with a decline in demand for capital and labor. A decrease in real wages relative to the capital costs stabilizes employment in these scenarios. This leads to lower capital intensity. The lower the elasticity of substitution between energy and the other production factors, the stronger the effect mechanism.

With a higher elasticity of substitution in Scenario 4, it appears that an increase in the fossil fuel prices of about 400 percent by 2030 could reduce fossil fuel use by nearly 50 percent. This is an increase in the overall energy price of around 300 percent. In this scenario, renewable energy use would increase by 50 percent over the next eight years, as is planned in the energy transition, and total energy consumption would decrease by 33 percent. Compared to the baseline scenario without the energy transition, the impact on economic growth would be lower, with an around 0.5 percent loss in GDP by 2030. However, it is also true in this scenario that the energy transition would be associated with a decline in investment and the capital stock of around 3.5 and 1.4 percent, respectively, by 2030 due to an increase in fossil fuel prices.

Because the model used in the analysis does not consider the shares of individual energy sources in the overall use of fossil fuels, the tax introduced on fossil fuel use cannot be readily converted into a carbon price in euros per ton of CO₂ emitted. It is also unclear at which actual annual rate energy-saving technological progress will develop over the next years. Moreover, the model does not take into account any other climate policy instruments that have already been adopted in the climate change policy instrument mix. For these reasons, the simulated increase in fossil fuel prices in Scenarios 3 and 4 are not suitable for assessing the German government's planned carbon pricing.

Conclusion: use income from carbon pricing to fund growth and investment measures

The simulation analyses of the long-term growth model including the energy transition show that energy-saving technological progress must develop more quickly to meet the emissions targets if no other additional climate policy measures are introduced. If energy-saving technological progress develops more quickly for the next eight years, not only will the emissions targets be reached by 2030, but the German economy will also likely experience slight growth due to the energy transition. If technological progress will develop more quickly is uncertain, however, especially considering its relatively constant development over the past years.⁹ Assuming energy-saving technological progress develops as it has in the past, the emissions target could be reached by 2030 via a high carbon price in the form of a tax on fossil fuel use. With a high elasticity of substitution, this would mean a small loss of growth of around 0.5 percent, with losses in investment and the capital stock of 3.5 and 1.4 percent, respectively, over the next eight years compared to the baseline scenario without the energy transition. The losses can be explained by the decline in energy-intensive production due to higher energy prices.

It is therefore necessary to consider the extent to which further accompanying economic and climate policy measures can mitigate potential losses and promote inclusive climate-neutral growth. In the analyses presented here, revenue from the tax on fossil fuel use is not returned to the private sector. To mitigate distributional effects and promote investment, the German government plans to use the increasing revenues from the gradual rise in carbon pricing via a climate fund. For example, there are plans to partially return the revenue to households through a climate dividend (*Klimageld*) and investments to transform the economy are already being promoted in many sectors, such as renewable energy, insulation, and production.¹⁰ The model mechanisms suggest that financing investment measures has significant effects on long-term growth.

⁹ Cf. Gemeinschaftsdiagnose, *Von der Pandemie zur Energiekrise*.

¹⁰ For more on the duties, revenue, and expenses of the Klimatransformationfonds, cf. information in the Federal Government's finance plan for 2022 to 2026 (in German; available online). For more on distribution/distributive effects and the design of a *Klimageld*, see Stefan Bach et al., "Facilitating the Transport and Heating Transition: Strengthen Carbon Pricing, Introduce a Climate Dividend, and Reduce Adaptation Costs," *DIW Weekly Report*, no. 23 (2023): 273–280 (available online); Matthias Kalkuhl et al., *Optionen zur Verwendung der Einnahmen aus der CO₂-Bepreisung* (Potsdam: 2022: Kopernikus-Projekt Ariadne) (in German; available online).

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