FRANKFURT UNIVERSITY OF APPLIED SCIENCES

Environmental Assessment

Fachbereich 2 Informatik und Ingenieurwissenschaften

Development of emission intensities

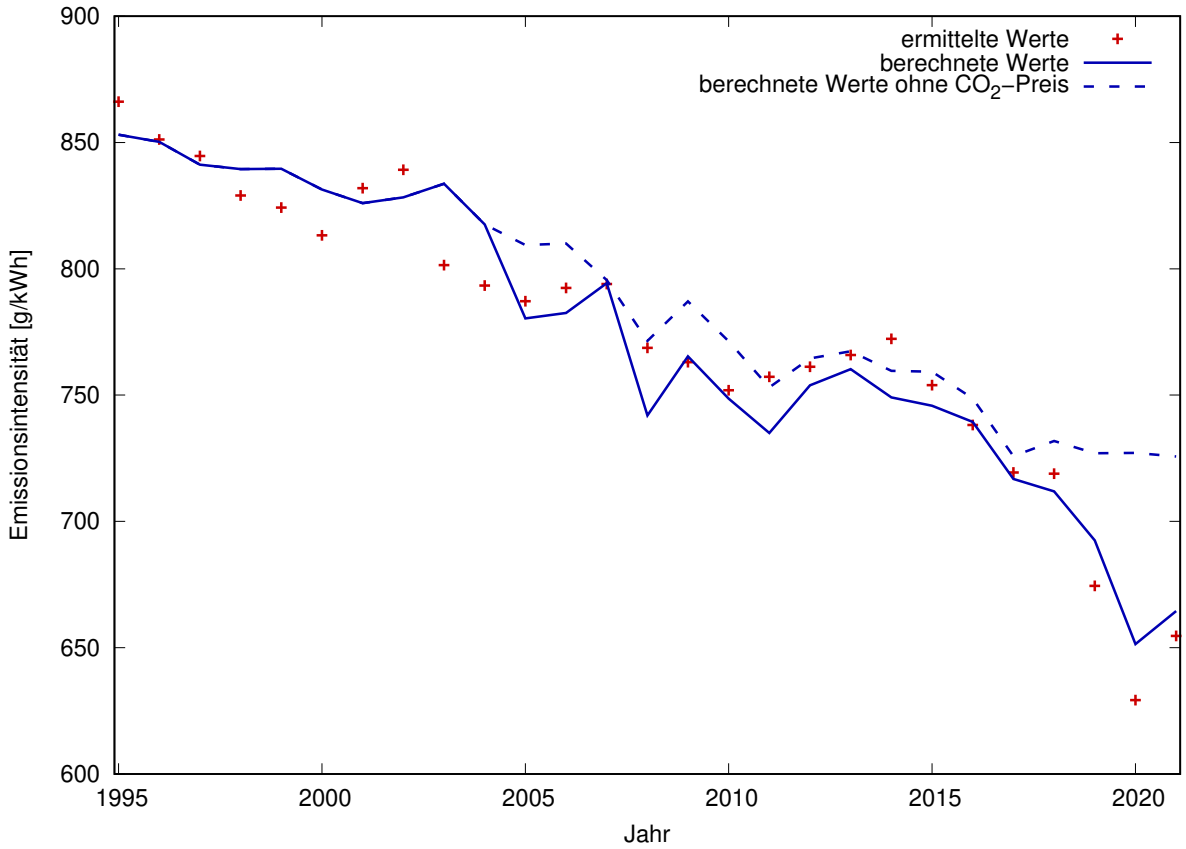

Figure: Development of real and calculated emission intensities in the German electricity sector between 1995 – 2021 together with counterfactual scenario without ETS; own illustration.

Comparison of CO_2 reductions

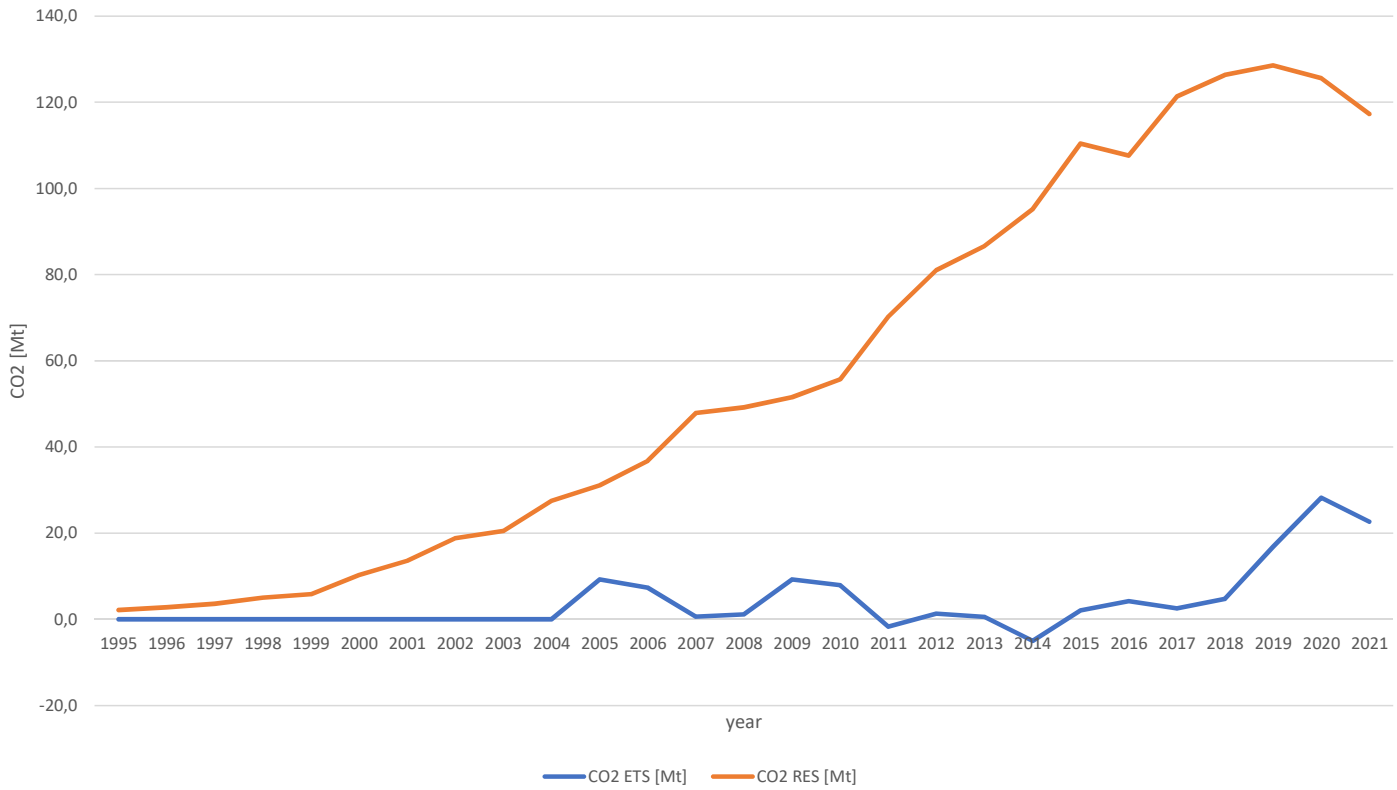

Figure: Development of CO_2 reduction assigned to the ETS and subsidies for RES from 1995 – 2021. The reduction assigned to the ETS is based on the counterfactual scenario developed above. The reduction assigned to subsidized RES is based on the product of emission intensity and electricity generated by RES with a discount of 10 % for fossil power plants on standby.

Choice of policy instruments

- Which policy instrument to choose with respect to

→ efficiency

→ innovation incentives

→ accuracy

→ additionally to consider: **effectiveness**

Policy instruments – ranking

- ETS and emission tax have advantages with respect to efficiency when compared to obligations
- without adjustments innovation incentives are highest for the emission tax
- accuracy is highest for obligations and the ETS
- investment incentives are best for an emission tax

$\Rightarrow$ close to E^* the emission tax is superior to the other policy instruments while later the ETS is superior

- **What about subsidies for RES?**

History of electricity generation with RES

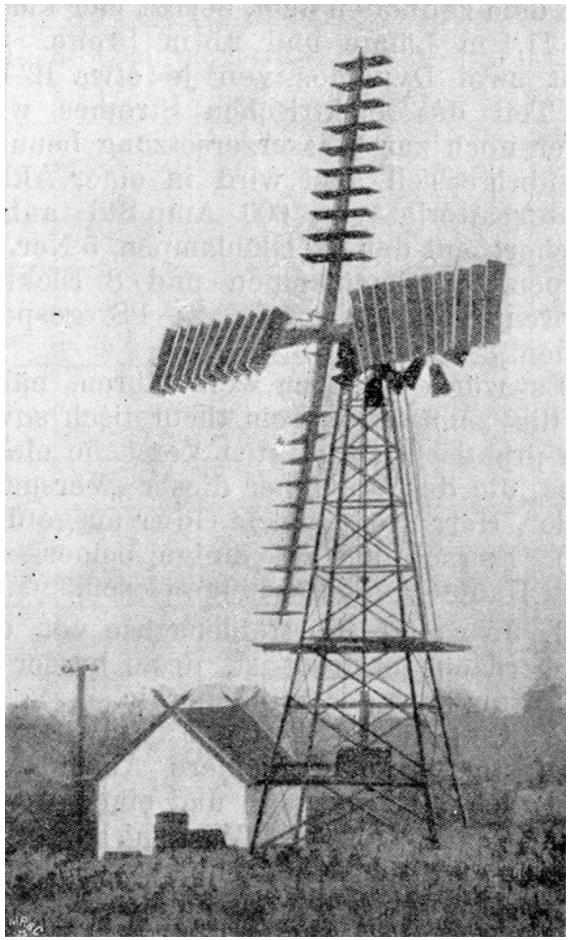

Figure: Wind turbine in 1907 designed by Paul la Cour; source: Wikipedia

- wind mills are already known since ancient times
- first wind turbines already used in the 19th century (Kaldellis and Zafirakis, 2011; Viollet, 2017)

→ Paul la Cour is seen as a pioneer for wind turbines

History of electricity generation with RES

- photovoltaics attracted broad attention when it was used for satellites in the late 1950s (Perlin, 2002)
- oil price shocks in 1973 and 1979/80 called for alternatives to fossil-based electricity generation

→ additionally a debate about environmental issues in electricity generation started

⇒ several counties (e.g. Denmark, Germany, USA) started research projects on the use of renewable energy (Lucas, 1985).

The GROWIAN project

Figure: GROWIAN in 1984; source: Wikipedia

- German government started the development of a wind turbine called GROWIAN (Große Windenergieanlage – “large wind turbine”) in 1976

→ 150 m total height

→ 100,4 m rotor diameter

→ 3 MW generator output

⇒ largest wind turbine in the world at that time(Heymann, 1995, p. 369–378)

GROWIAN – a failure

- operation started on July 6, 1983

→ operation time only 420 hours during 4 years of operation (Heymann, 1995, p. 378 – 380)

⇒ in 1988 it was dismantled

- Hans Matthöfer who, as former minister for research and development, enabled the start of the project announced on February 28, 1982 with respect to GROWIAN:

  "*We know that it does not make sense. We still carry it out to prove supporters of wind energy that it will not work.*" (Heymann, 1995, p. 373)

GROWIAN – a failure

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→ operation time only 420 hours during 4 years of operation (Heymann, 1995, p. 378 – 380)

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- Hans Matthöfer who, as former minister for research and development, enabled the start of the project announced on February 28, 1982 with respect to GROWIAN:

  Wir wissen, daß es uns nichts bringt. Aber wir machen es, um den Befürwortern der Windenergie zu beweisen, daß es nicht geht.(Heymann, 1995, p. 373)

Introduction of RES in Germany

- The Intergovernmental Panel on Climate Change (IPCC) was founded in 1988
- first assessment report published in 1990

$\Rightarrow$ RES-based electricity generation came into the focus

$\Rightarrow$ Germany introduced subsidies for RES-based electricity generation already in 1991 (Electricity Feeding Act, 1990).

- The explanatory memorandum of the law explicitly referred to climate protection (Federal Government, 1990)

Growing RES-based electricity generation

- Renewable Energies Act in 2000 increased the use of RES (Renewable Energies Act, 2000)

→ in 2017 179 countries subsidized RES

→ 113 used a system of FiTs similar to the German Renewable Energies Act of the year 2000 (Sawin *et al.*, 2018, p. 19)

- Today it is clear that at least a part of fossil electricity generation has to be substituted by RES in the future (e.g. Sanden and Azar, 2005; De Jonghe *et al.*, 2009)

Figure: Commercial from 1993; source: Süddeutsche Zeitung 152

World electricity generation

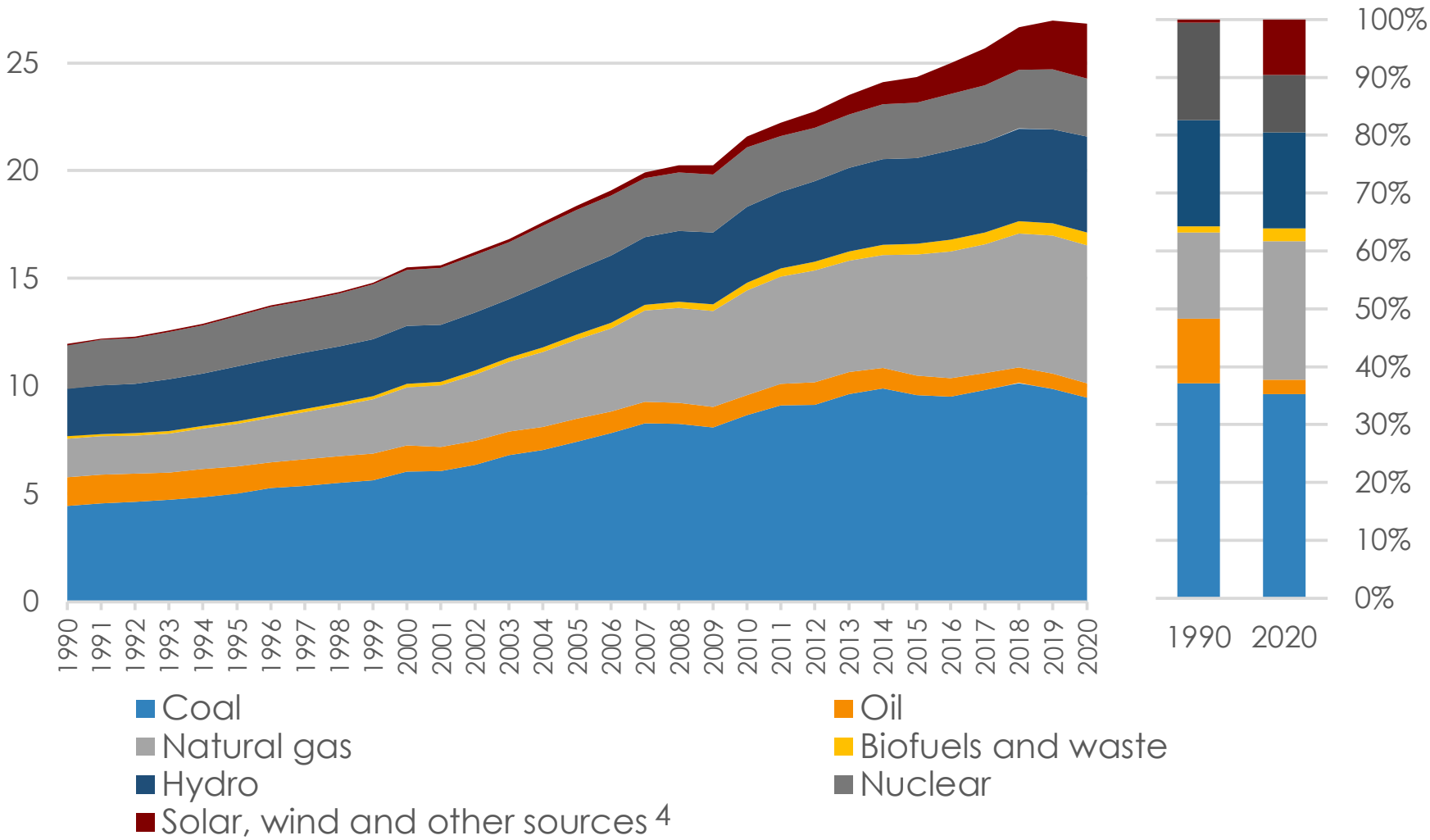

Figure: World electricity generation by source, 1990-2020; source: United Nations (2023).

Worldwide RES-based electricity generation

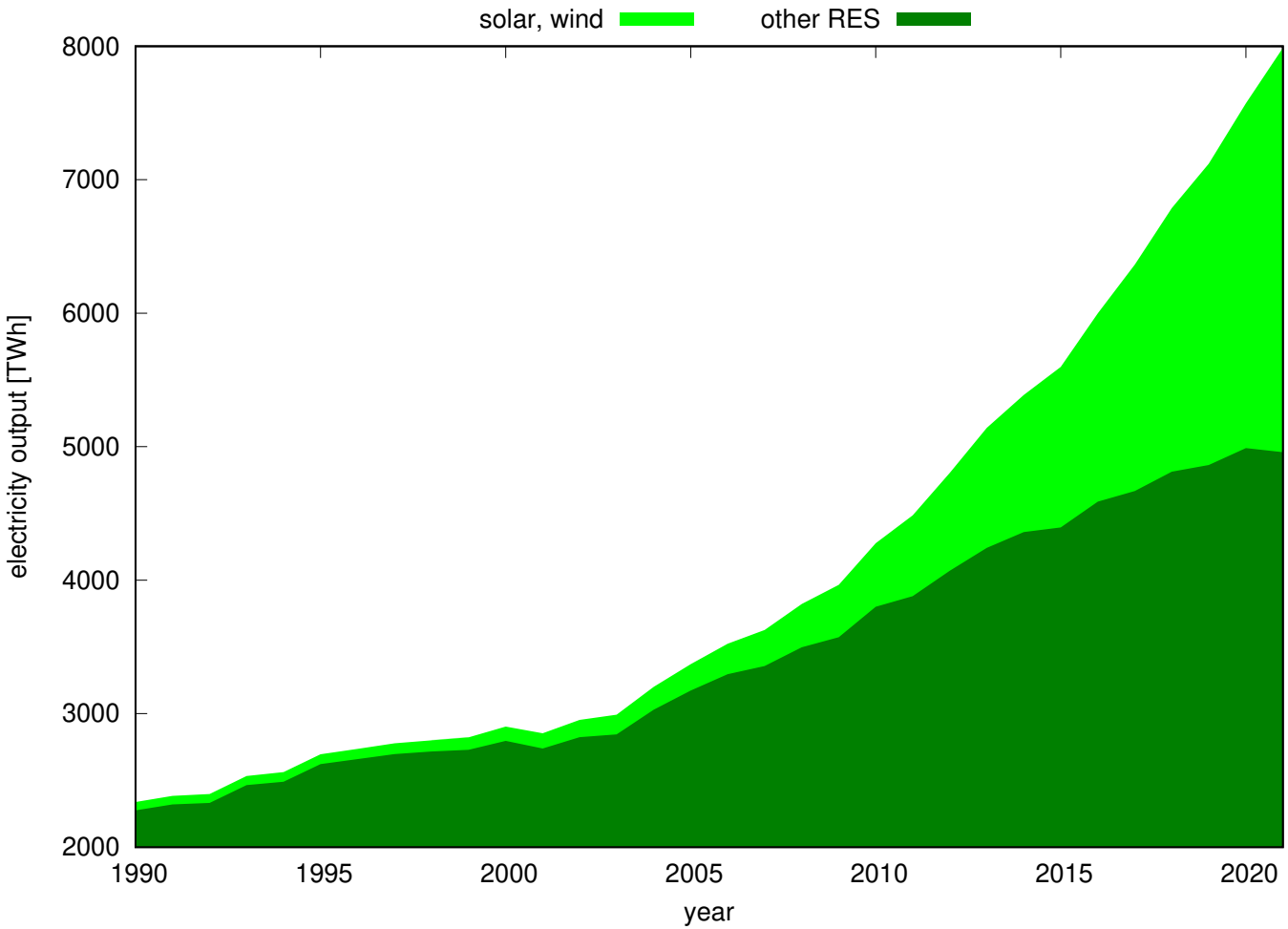

Figure: Stacked area chart illustrating the development of electricity generation based on wind and solar power plants and remaining renewable energy sources from 1990 until 2021; own illustration based on data provided by Enerdata (2018), Working Group on Energy Balances (2018).

Worldwide wind- and solar-based electricity generation

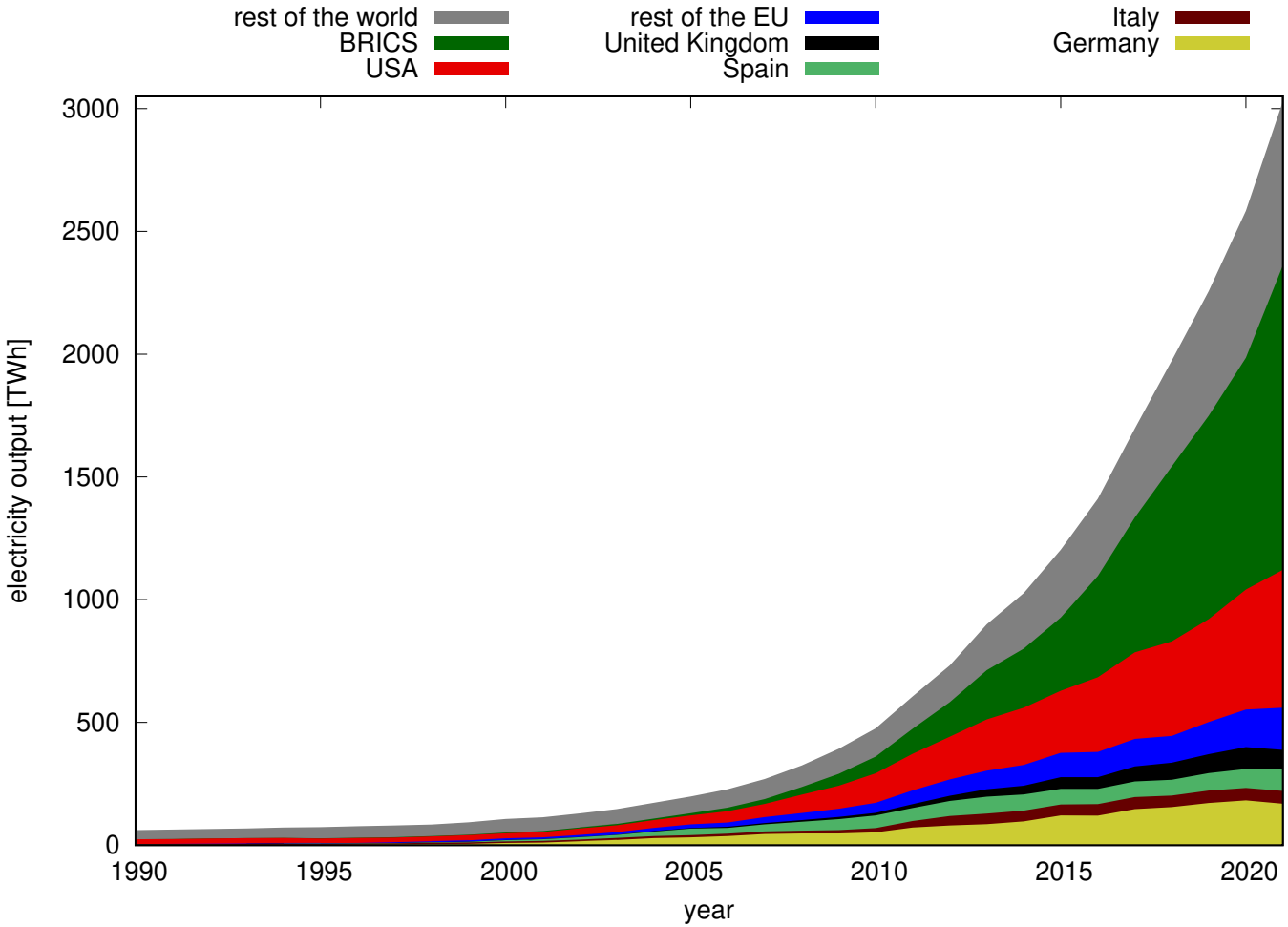

Figure: Stacked area chart illustrating the development of electricity generation based on wind and solar power plants in selected countries and worldwide from 1990 until 2021; own illustration based on data provided by Enerdata (2018), Working Group on Energy Balances (2018).

Electricity generation in Germany

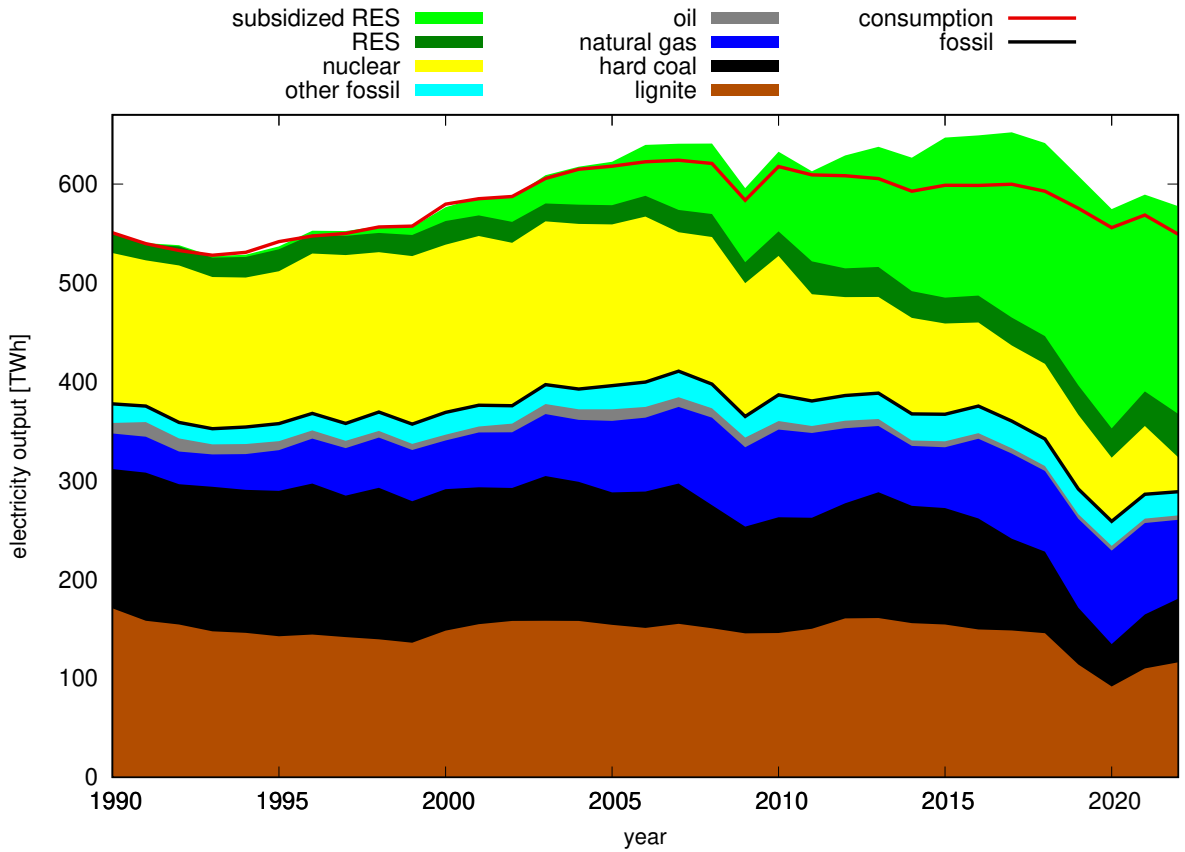

Figure: Stacked area chart illustrating the development of gross electricity output with respect to different energy sources in Germany between 1990 and 2022. The difference between gross electricity generation and gross electricity consumption (red line in the graph) corresponds to electricity exports; own illustration based on data provided by Working Group on Energy Balances (2018), Information Platform of the German Transmission System Operators (2018)

Promotion of RES

- **feed in tariff (FIT)**

  fixed price paid for electricity from RES connected with an **acceptance obligation** for generated electricity

- **feed in premium (FIP)**

  electricity from promoted RES is regularly sold at the market but the seller in addition receives a **premium**

⇒ a **fixed FIP** shifts risks from the regulator to the power plant operator

⇒ a **sliding FIP** acts like a more market-based FIT

- How a sliding FIP changes the operator's behavior when compared to an FIT?

Promotion of RES

- **contracts for differences CFDs**

  the subsidized power plant operator receives/pays the difference between the market price and a predefined strike price

→ operator receives money for market prices below the strike price

→ operator has to pay if market prices are above the strike price

- What are advantages/disadvantages from the perspective of the regulator and the power plant operator?

Subsidies for RES-based electricity generation

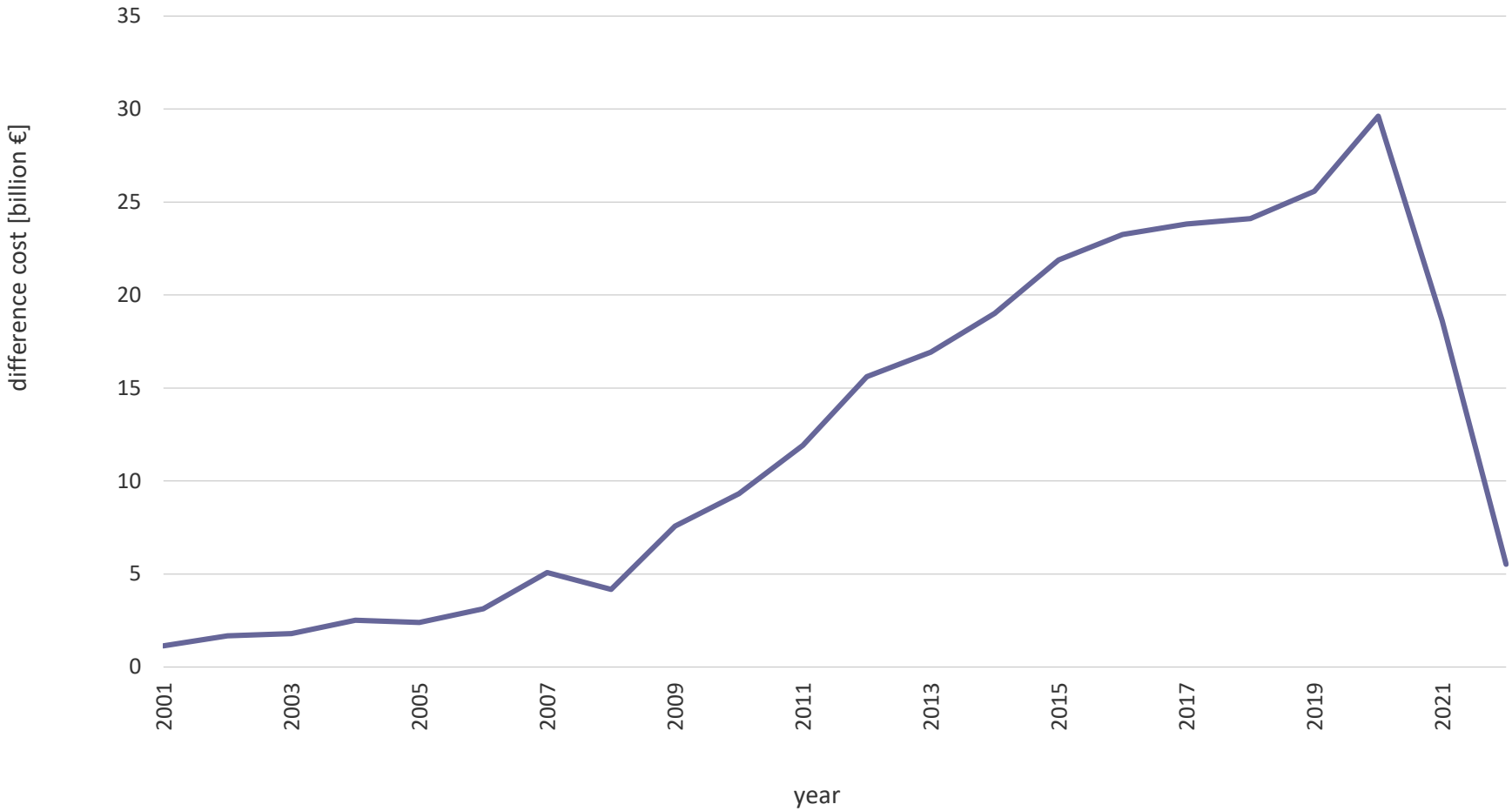

Figure: Difference costs induced by subsidies for electricity generation by RES in Germany. Own illustration based on data provided by Information Platform of the German Transmission System Operators (2018,b).

Marginal abatement cost of RES – exercise

- Which data is necessary to calculate marginal abatement cost of RES-based electricity generation?
- Calculate the marginal abatement cost of electricity generation with RES
- Compare it to the price of certificates for the EU ETS

Marginal abatement cost of RES – exercise

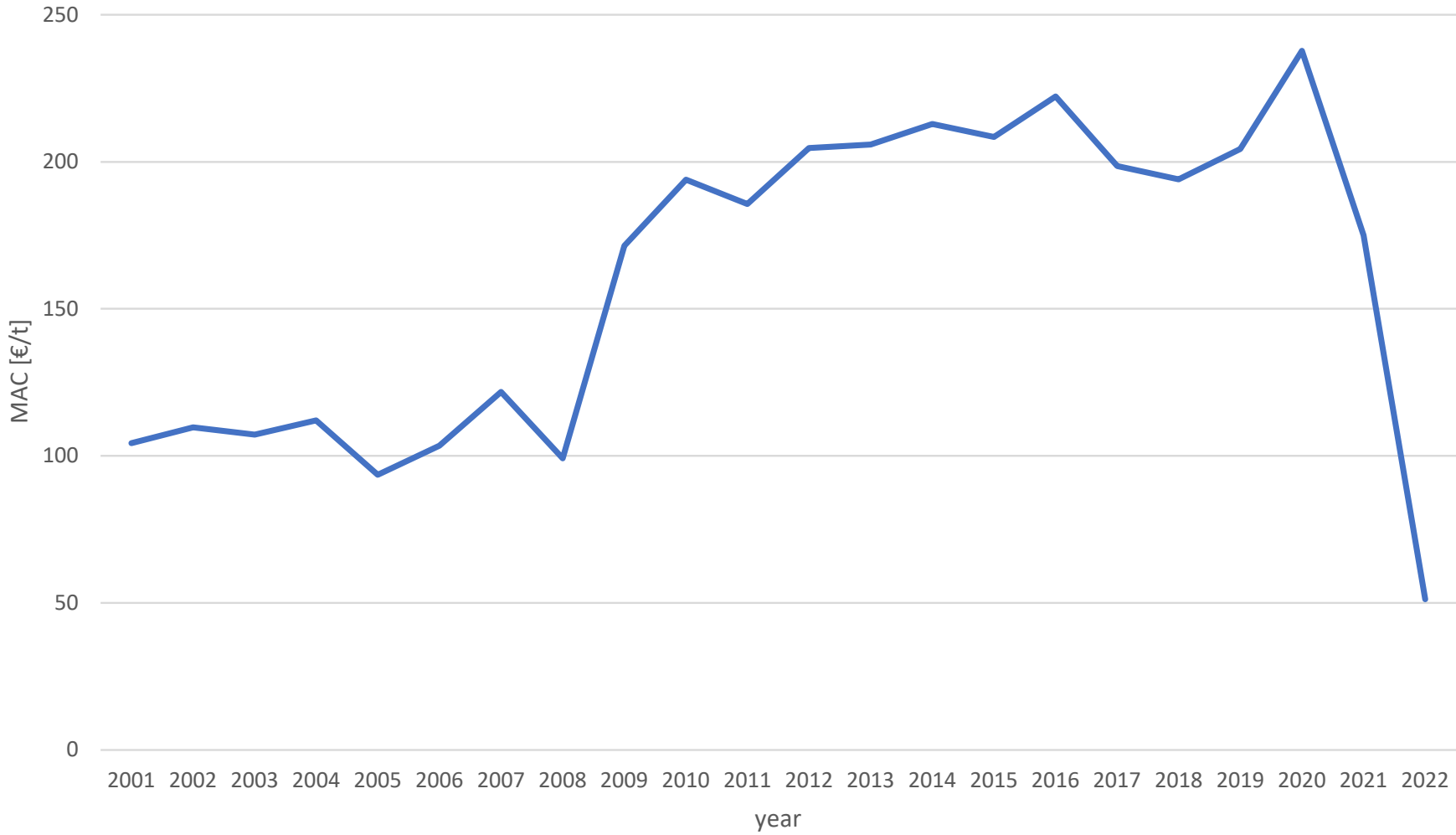

Figure: Development of abatement cost of RES-based electricity generation in Germany. Own illustration based on data provided by Information Platform of the German Transmission System Operators (2018,b).

EUA price development

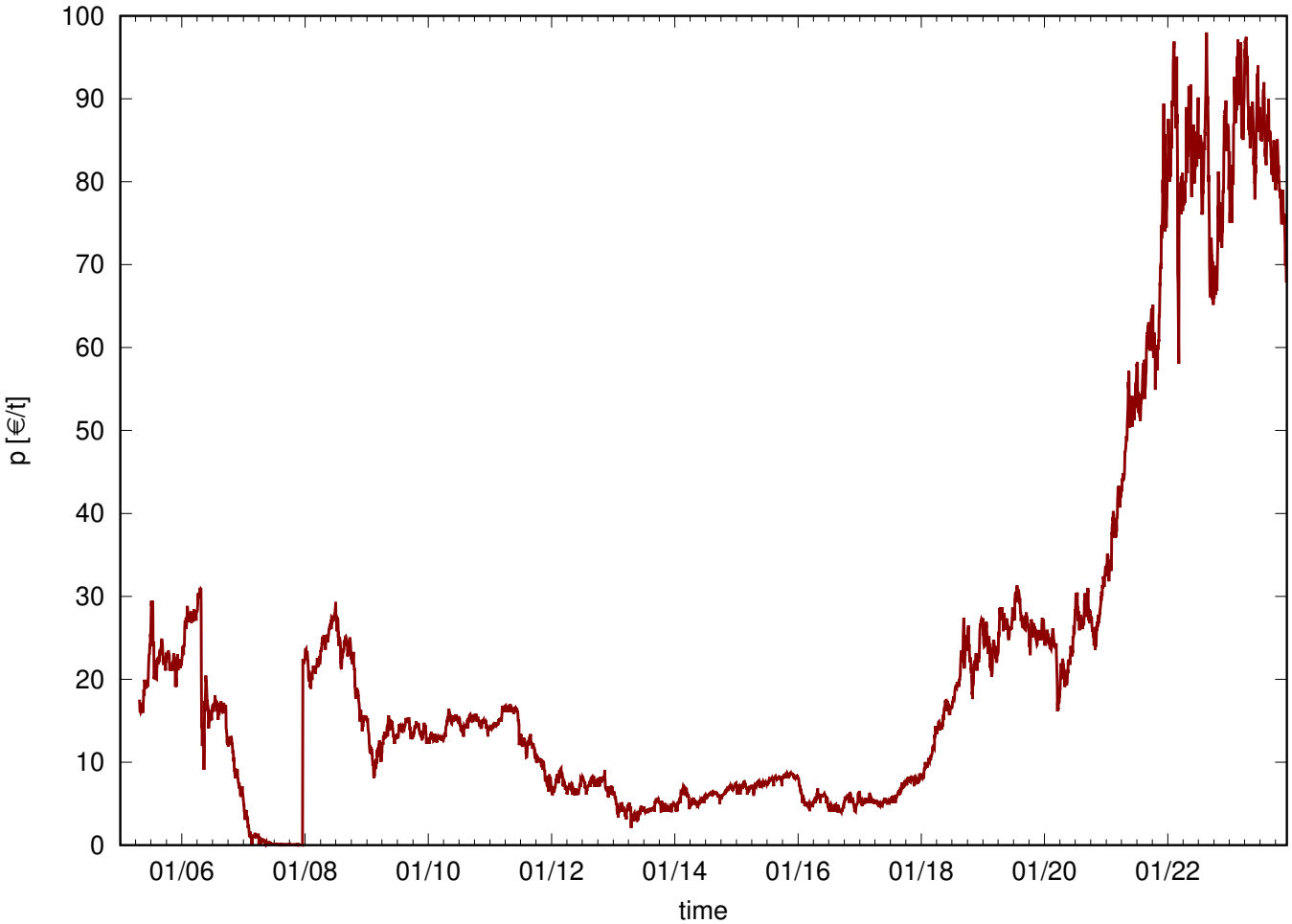

Figure: Development of the allowance price of the EU ETS between April 25, 2005 and December 6, 2023. Own illustration based on investing.com (2023).

Abatement cost of RES – exercise

Figure: Development of the average day-ahead prices for electricity in Germany on a monthly basis between 2006 and 2022; source: energy-charts.info.

The merit order effect of RES

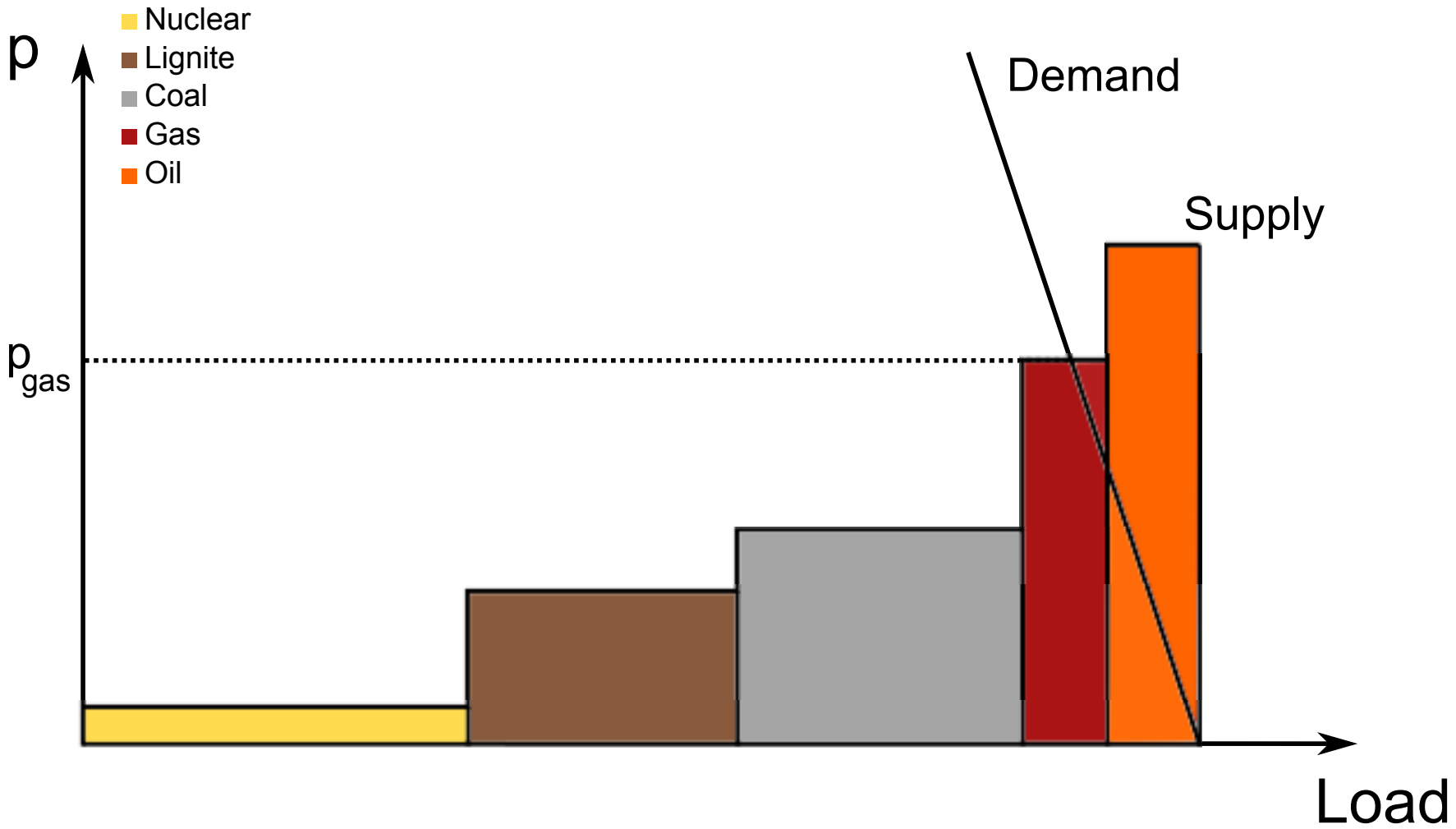

Figure: Schematic illustration of the merit order effect of RES as described by De Miera *et al.* (2008); Sensfuß *et al.* (2008); own illustration.

The merit order effect of RES

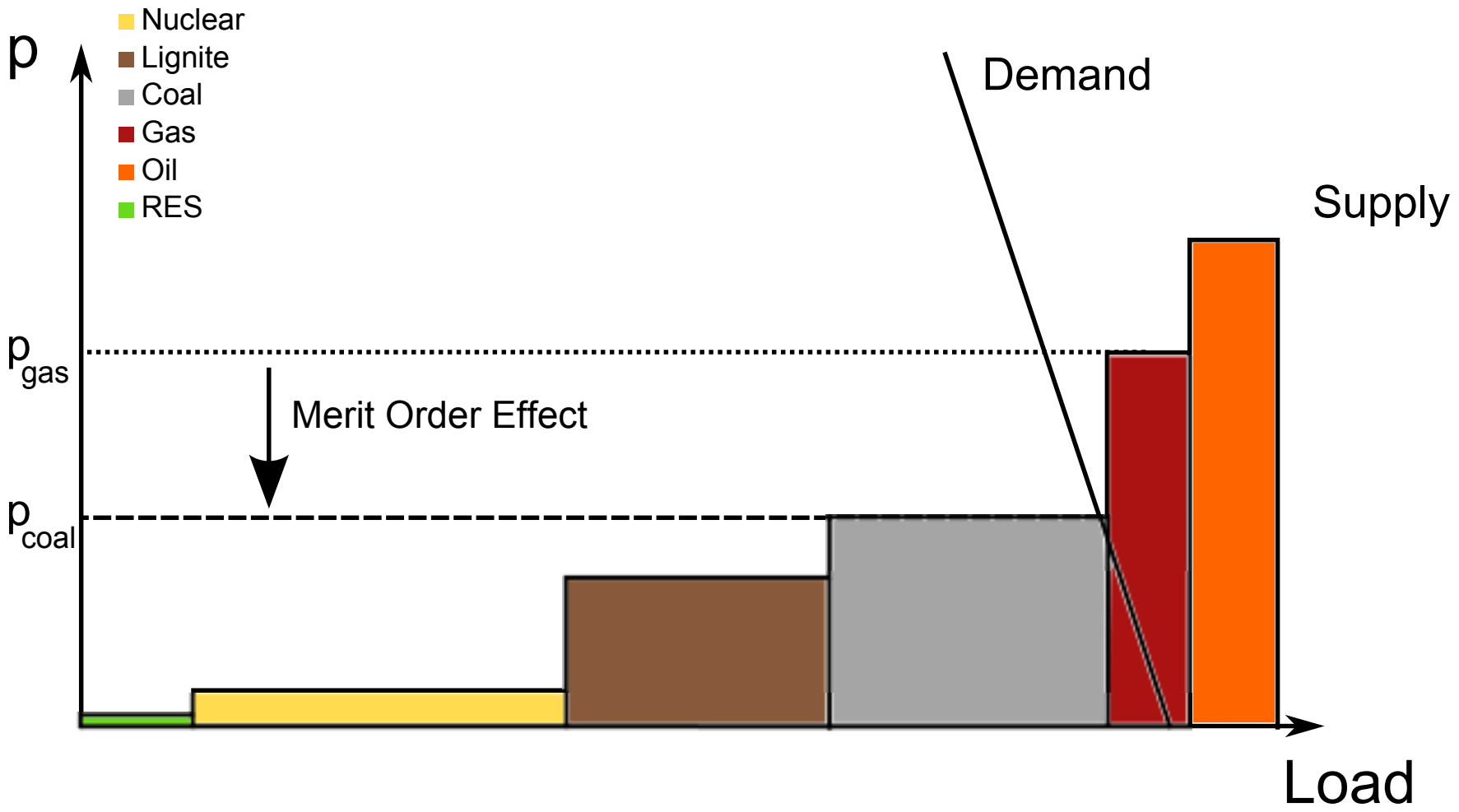

Figure: Schematic illustration of the merit order effect of RES as described by De Miera *et al.* (2008); Sensfuß *et al.* (2008); own illustration.

Promotion of RES

- regulator's assumption: subsidies for RES are "too high"

→ reducing power plant operators' profits

→ increase **efficiency** without deteriorating **effectiveness**

- reverse auctions for RES

⇒ shift from price-based promotion scheme to a quantity-based promotion scheme

Auctions

- usual auction

→ the auctioneer wants to sell a good for the highest price possible

→ the bidder wants to buy the good as cheap as possible

→ efficiency is achieved if the bidder with the highest willingness to pay acquires the good

- reverse auction

→ the auctioneer wants to buy a good for the lowest price possible

→ the bidder wants to sell the good as expensive as possible

→ efficiency is achieved if the bidder with lowest cost sells the good

- In a reverse auction the roles of bidder and auctioneer are reversed

References I

De Jonghe, C., Delarue, E., Belmans, R. and D'haeseler, W. (2009). Interactions between measures for the support of electricity from renewable energy sources and CO_2 mitigation. *Energy Policy*, **39**, 4743–4752.

De Miera, G. S., del Rio Gonzalez, P. and Vizcaino, I. (2008). Analysing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain. *Energy Policy*, **36** (9), 3345–3359.

Electricity Feeding Act (Stromeinspeisungsgesetz) (1990). Gesetz über die Einspeisung von Strom aus erneuerbaren Energien in das öffentliche Netz. Available at: `http://www.bundesgerichtshof.de/SharedDocs/Downloads/DE/Bibliothek/Gesetzesmaterialien/11_wp/StromeinspeisungsG/bgbl.pdf?__blob=publicationFile`, accessed August 27, 2018.

Enerdata (2018). Global energy statistical yearbook. Available at: `https://yearbook.enerdata.net/`, accessed September 4, 2018.

Erneuerbare-Energien-Gesetz – EEG (2000). Gesetz für den Vorrang Erneuerbarer Energien (Erneuerbare-Energien-Gesetz – EEG) sowie zur Änderung des Energiewirtschaftsgesetzes und des Mineralölsteuergesetzes. Available at: `https://www.bgbl.de/xaver/bgbl/start.xav#__bgbl__%2F%2F*%5B%40attr_id%3D%27bgbl100s0305.pdf%27%5D__1537220013385`, accessed September 17, 2018.

Federal Government (Bundesregierung) (1990). Bundestag Drucksache 11/7971 – Gesetzesentwurf der Bundesregierung: Entwurf eines Gesetzes über die Einspeisung von Strom aus erneuerbaren Energien in das öffentliche Netz (Stromeinspeisungsgesetz). Available at: `http://dipbt.bundestag.de/doc/btd/11/079/1107971.pdf`, accessed September 17, 2018.

Federal Ministry for Economic Afairs and Energy (2017). State Secretary Baake: "Citizens' energy wins first onshore wind auction". Available at: `https://www.bmwi.de/Redaktion/EN/Pressemitteilungen/2017/20170519-staatssekretaer-baake-buergerernergie-gro%C3%9Fe-gewinner-der-ersten-ausschreibungsrunde-wind-an-land.html`, accessed August 31, 2018.

Heymann, M. (1995). *Die Geschichte der Windenergienutzung*. Frankfurt and New York: Campus.

Information Platform of the German Transmission System Operators (Informationsplattform der deutschen Übertragungsnetzbetreiber – netztransparenz.de) (2018). EEG-Jahresabrechnungen. Available at: `https://www.netztransparenz.de/EEG/Jahresabrechnungen`, accessed April 1, 2018.

References II

INVESTING.COM (2023). Commodity prices. Avaialable at: https://www.investing.com/currencies/xbr-usd-historical-data, accessed January 8, 2023.

KALDELLIS, J. K. and ZAFIRAKIS, D. (2011). The wind energy (r)evolution: A short review of a long history. *Renewable Energy*, **36**, 1887 – 1901.

LUCAS, N. J. D. (1985). *Western European Energy Policies: A Comparative Study of the Influence of Institutional Structure on Technical Change*. Oxford: Clarendon.

PERLIN, J. (2002). *From space to earth: The story solar electricity*. Cambridge: Harvard University Press.

SANDEN, B. A. and AZAR, C. (2005). Near-term technology policies for long-term climate targets – economy wide versus technology specific approaches. *Energy Policy*, **33**, 1557–1576.

SAWIN, J. L., RUTOWITZ, J., SVERRISSON, F., ABERG, E., ADIB, R., APPAVOU, F., BROWN, A., SCOTT DWYER, EPP, B., GUERRA, F., KONDEV, B., MURDOCK, H. E., MUSOLINO, E., SEYBOTH, K., SKEEN, J., TESKE, S. and WUESTER, S. W. H. (2018). Renewables 2018: Global Status Report. Available at: http://www.ren21.net/wp-content/uploads/2018/06/17-8652_GSR2018_FullReport_web_final_.pdf, accessed August 31, 2018.

SENSFUSS, F., RAGWITZ, M. and GENOESE, M. (2008). The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany. *Energy Policy*, **36** (8).

UNITED NATIONS (2023). Energy statistics pocketbook 2023. Available at: https://unstats.un.org/unsd/energystats/pubs/documents/2023pb-web.pdf, acessed April 15, 2023.

VIOLLET, P.-L. (2017). From the water wheel to turbines and hydroelectricity. technological evolution and revolutions. *Comptes Rendus Mécanique*, **345**, 570–580.

WORKING GROUP ON ENERGY BALANCES (ARBEITSGEMEINSCHAFT ENERGIEBILANZEN E.V) (2018). Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern. Available at: https://ag-energiebilanzen.de/index.php?article_id=29&fileName=20171221_brd_stromerzeugung1990-2017.xlsx, accessed September 4, 2018.