**Supplementary Material**

**Appendix A: Constructing Natural Capital Accounts for the**

**Hambach Opencast Mine and Forest Across Alternative Scenarios**

This Appendix provides supplementary materials detailing how the nature capital accounts in Section 5 were computed. The underlying model and data forming the basis of the analysis is available upon request.

**Scenarios**

The natural capital accounts calculate the value of ecosystem services and environmental damages across three plausible scenarios at the Hambach mine. Parameter values such as price of carbon and the discount rate are assumed to be constant across scenarios. The only changing variables across scenarios are: the size of the forest and the amount of lignite excavation and combustion.

In scenario 1 (baseline), Hambach forest is 1 km2. Excavation and combustion occur up until 2038, after which all remaining lignite is stranded. We assume some sort of ‘compromise’ between the federal government and RWE is the most likely trajectory given the current political situation and, hence, call this scenario our baseline.

In scenario 2 (high emissions) the forest is 0 km2 and excavation and combustion continue until all lignite reserves are exhausted. This is RWE’s preference.

In scenario 3 (climate action) the forest is 5 km2, which is its present-day size, and there is an immediate cessation of all mining activities. This is the demand of environmental NGOs and civil society groups.

All figures are in 2019 euros, adjusted for inflation.

**Carbon Sequestration**

Biophysical data on the type of tree species in the forest, their average spacing, age and yield class is used to determine the carbon sequestration rate of the forest. A comprehensive mapping from these biophysical characteristics to the carbon sequestration rate can be found in Woodland Carbon Code (2019) look-up tables. Since Hambach is an oak-hornbeam forest, we use oak as the representative species and assume the yield class is 4, the spacing is 1.2 meters. We assume a standard distribution of tree ages which implies the average carbon sequestration rate is around 7.5 tCO2/ha/year. Peak sequestration can be as much as 34 tCO2/ha/year while minimum sequestration is close to 0 (see Figure 3).

Figure 6: Sequestration Rates for Oak Trees

Source: Woodland Carbon Code (2019)

This representative sequestration rate is multiplied by the size of Hambach forest across alternative scenarios to obtain the total sequestration per year, which is then multiplied by the price of carbon which is EUR 30/tCO2. The value for each year is summed up across the 34 years and discounted using a constant discount rate of 3.4% to produce the net present value of carbon sequestration across different scenarios.

**Pollination and Recreation**

We obtain data on the value of the ecosystem service per hectare of the habitat (*valib*). The subscripts *i* and *b* denote the ecosystem service and habitat respectively. We then calculate value of the ecosystem service per year by multiplying the unit value (*valib*) by the hectarage of Hambach forest across different scenarios (*habitats*) and the discount factor for each year (*discount\_factort*) which is based on a constant discount rate of 3.5%. The calculation is as follows: *valib \*habitats*\**discount\_factort*.The net present value of the ecosystem service is calculated for by summing up all of the annual values for each scenario across the 34 years. All unit values are obtained from the TEEB Valuation database which lists several studies from which unit values can be chosen. Specifically, for pollination services *valib* is obtained from Brenner-Guillermo (2007) who uses a benefit transfer method to infer the value of pollination services for a temperate forest. For recreation, *valib* was obtained from Cruz and Benedicto (2009) where it is calculated based on a travel cost method.

**Air Pollution**

A host of rich literature has shown that the combustion of coal is associated with particulate matter pollution which endangers human health. Lignite that is excavated at Hambach open-cast mine is combusted locally. Some epidemiological studies have already linked Hambach mine to premature deaths (Fearnehough *et al*. 2018).

We calculate the cost of air pollution by performing the following calculation: *vali \* emissionss*\**discount\_factort*.Data on the cost of air pollution (PM2.5 damages) per tonne of emitted CO2-equivalent (*vali*) for Germany is obtained from Hamilton *et al*. (2017) who do a meta-analysis of modelling studies that estimate the benefits from avoided PM2.5 damages for each tonne of abated CO2. From RWE’s website we get the annual figure for metric tonnes of excavated lignite and multiply this by the Rhineland-specific emissions factor for lignite (1.03 kgCO2/kg, as in Juhrich (2016)) to calculate the quantity of CO2 emissions across each scenario (*emissionss*). We assume that the amount of lignite excavated in any given year is also combusted that year. Finally, the net present value of air pollution is calculated by summing up all of the annual values for each scenario over the34 years.

It is important to note that this calculation specifically looks at the *particulate matter* damage from coal combustion and is separate from the social cost of carbon which looks at the economic damages from *increased CO2 concentrations* due to coal combustion.

**Social Cost of Carbon**

We calculate the social cost of carbon (SCC) by performing the following calculation: *social cost per tonne CO2 \* emissionss*\**discount\_factort* (€).The SCC used is €30/tCO2, although Pindyck (2019) presents a comprehensive expert elicitation and shows it can be as high as €70-270/tCO2e. This implies our estimate is conservative. The net present value is calculated by summing up all of the annual values for each scenario for the34-years.

**Market Value of Lignite**

We calculate the revenue from lignite sales by performing the following calculation: *price\* lignites*\**discount\_factort* (€).Data on the latest price of lignite: *price* (€/tonne) is obtained from Wronski and Fleet (2018). The market price of lignite is assumed to be constant over all periods. From RWE, we obtained the annual figure for metric tonnes of excavated lignite (*lignites*). The net present value is calculated by summing up all of the annual values for each scenario for the34-years. Since this calculation ignores excavation and other costs, it is most likely an upper bound. Furthermore, as parts of RWE’s lignite operations close, as is expected under the coal phase-out plan, then the fixed costs are spread over less production implying that lignite is likely to become even less economical.

**Increased Electricity Cost**

We calculate the amount of electricity that is produced from the lignite excavated at Hambach. To do this we multiply the average energy density of lignite with the tonnage of excavated lignite scaled by the efficiency of German power plants, the latter based on values in CIRAIG (2016). Then we check how much more expensive it would be if the same amount of electricity were generated from renewable energy instead of lignite by comparing the levelized cost of electricity in Germany. Since lignite provides baseload power, we assume the replacement will be solar photovoltaic cells plus batteries. If the replacement were to be solar PV alone (without battery storage), then transitioning to renewables reduces total electricity costs. However, pairing solar PV with battery storage units helps address the intermittency problem of renewable power and could play an important role in grid stability. Assuming solar PV plus battery storage substitutes all of the lignite-generated electricity, overall system costs increase. Our estimate of increased electricity costs is likely to be an upper bound for several reasons: first, we only assume learning and cost reductions up to 2030 for renewable energy, but it is probable that there will be further cost reductions as break-through technologies are discovered. Second, it is not necessarily the case that all lignite has to be substituted with solar PV plus batteries. Some portion can likely be substituted with just solar PV and Germany could use demand-side management to handle a portion of the intermittency problem. Data on the levelized costs of each electricity source used in this analysis are specific to Germany and obtained from Kost *et al*. (2018).

**References for Appendix A**

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