Decarbonization in the Non-ETS with sector coupling via input-output linkages

Insights from the project ELECTRO_COUP

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Kurt Kratena (CESAR)

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CESAR
Centre of Economic Scenario Analysis and Research

Research questions

- **Sector coupling and the ETS/Non-ETS link in Europe**: carbon reduced in one part of the system (Non-ETS) → higher emissions in another part (ETS) = **Sector coupling → linkages** between different sectors.

- **IO linkages with fully integrated energy system**: (i) input-output (IO) linkages in production and (ii) energy demand linkages between ETS and non ETS.

- **The IO linkages**: quantity and price linkages, energy linkages (final → transformation), special case: electricity price (merit order model & IO price model) and CO_2 prices

The macroeconomic IO model

- **IO model based on SUT**:
- **Supply** (industries * goods) **V** with column sum = output by goods, **q**(**g**), row sum = output by industries, **q**
- **Domestic Use/intermediate** (goods * industries) $\mathbf{U}^{d}$ and **imported Use/intermediate** (goods * industries) $\mathbf{U}^{im}$
- **Final demand** $\mathbf{F}^{d}$ and $\mathbf{F}^{im}$ (goods * final demand components), **domestic (d)** and **imported (im)** goods.
- Two main equations (solution in a loop): $\mathbf{q} = \mathbf{D}\,\mathbf{q}(\mathbf{g})$ and $\mathbf{q}(\mathbf{g}) = \mathbf{B}^{\mathrm{d}}\mathbf{q} + \mathbf{cp}^{\mathrm{d}} + \mathbf{cf}^{\mathrm{d}} + \mathbf{f}^{*\mathrm{d}}$, with technical coefficients $\mathbf{B}^{d}$, private consumption $\mathbf{cp}^{\mathrm{d}}$, gross capital formation $\mathbf{cf}^{\mathrm{d}}$, and other final demand $\mathbf{f}^{*\mathrm{d}}$.

The macroeconomic IO model

- **IO model for energy system**:
- **SUT framework**, where the '***industries***' are the eight **transformation processes *t*** and the goods are the 26 types of energy *k*
- Main equations for **output, supply and use**:
- $\mathbf{q} = \mathbf{D}(\mathbf{k})\,\mathbf{q}(\mathbf{k},\mathbf{T}),\qquad \mathbf{x}(\mathbf{k}) = \mathbf{B}_{\mathrm{k},\tau}\mathbf{q} + \mathbf{fe} + \mathbf{ex} + \mathbf{f}^{*,\mathrm{k}}$ and
- $\mathbf{q}(\mathbf{k}) = \mathbf{x}(\mathbf{k}) - \mathbf{im}\quad ;\quad \mathbf{q}(\mathbf{k},\mathbf{T}) = \mathbf{T}_{\mathrm{P,T}}\,\mathbf{q}(\mathbf{k})$
- Total **use/supply of *k*** $\mathbf{q}(\mathbf{k})$, output ($\mathbf{k}$) from **transformation** $\mathbf{q}(\mathbf{k},\mathbf{T})$, and output by **process *t***, **q**.
- **Final** energy **fe** and $\mathbf{f}^{*,\mathrm{k}}$ (transport losses, stock changes, non-energetic use)

The macroeconomic IO model

- **Production costs and prices of output q** with inputs of capital (***K***), labour (***L***) and intermediates (***M***), and exogenous import prices (***p***(***im***)), ***L*** and ***K*** can be substituted (CES in **composite LK**), plus a trend for ***M*** + mark-up and net indirect taxes→ output prices, ***p***.

- $\mathbf{p}' = [(\mathbf{p}_{\mathrm{L}}' \frac{\widehat{\mathbf{L}}}{\mathbf{Q}} + \mathbf{p}_{\mathrm{K}}' \frac{\widehat{\mathbf{K}}}{\mathbf{Q}} + \mathbf{p}^{\mathrm{d}\prime}\mathbf{B}^{\mathrm{d}} + \mathbf{p}^{\mathrm{im}\prime}\mathbf{B}^{\mathrm{im}})(1 + \mu)] + \mathbf{t}_{\mathrm{q}}'$

- **IO technical coefficients** for non-energy goods in $\mathbf{B}^{\mathrm{d}}$ and $\mathbf{B}^{\mathrm{im}}$ are the product of $\frac{\widehat{\mathbf{M}}}{\mathbf{Q}}$ and fixed matrices (**Leontief technology**) within $\frac{\widehat{\mathbf{M}}}{\mathbf{Q}}$.

The macroeconomic IO model

- **Capital income coefficient** per unit of output is derived as the difference between the output price and marginal cost, plus indirect taxes.
- Wages = nominal labour coefficients/net of taxes * output
- Profits = nominal capital income coefficients/net of taxes * output
- **Primary household net income** with t_Y as net tax rate and s_Y as profit share of households: $\mathbf{y}' = [\lambda(1 - t_Y)]'\hat{\mathbf{q}} + [s_Y\kappa(1 - t_Y)]'\hat{\mathbf{q}}$
- **Disposable household income** with Y_p as other income (property, etc.): $YD = \mathbf{y}'\mathbf{i} + Y_p$

The macroeconomic IO model

- **Consumer price index (PC)**: aggregate **Divisia price index** of expenditures: (i) **energy *en*** (heating), (ii) **personal transport *tr***, and (iii) **non-energy consumption *nen***:
$\ln(PC) = w_{en,cp}\ln\left(p_{en,cp}\right) + w_{tr,cp}\ln\left(p_{tr,cp}\right) + w_{nen,cp}\ln\left(p_{nen,cp}\right)$

- **Aggregate real private consumption**: with c_Y as the **average propensity of consumption**: $CP = c_Y\left[\mathbf{y}'\mathbf{i} + Y_p\right]/PC$

- **Full separability** between energy/transport consumption and non-energy consumption → non-energy consumption as the difference: $CP_{nen} = CP - CP_{en} - CP_{tr}$

- **Cobb-Douglas preferences** with constant budget shares

The macroeconomic IO model

- **Final energy demand of households, heating**: part of final energy **fe** → monetary expenditure (IO classification) with ***'implicit prices'*** → part of $\boldsymbol{CP_{en}}$ (+ heating appliances, investment in thermal insulation)

- **Final energy demand of households, transport**: total **person-km** by households → **total** expenditure on **transport**, CP_{tr} plus purchases of **vehicles** (total), by **drive** (discrete choice models) and **energy** use (fleet efficiency and behaviour)

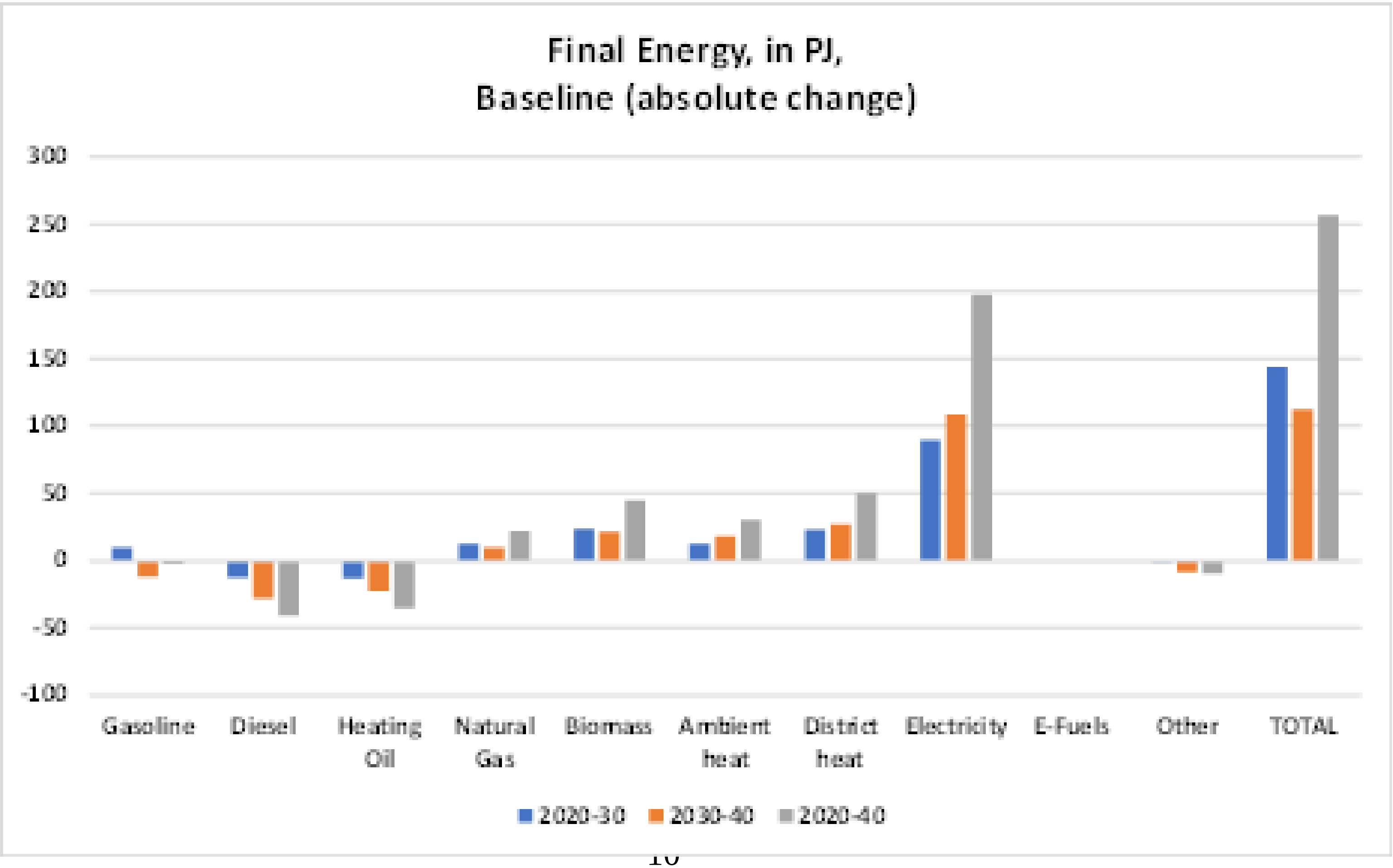
- **Final energy demand**: output (***Q***) demand and energy (***En***) by energy type (*k*), **Kaya-identity**: $(En_k/Q) = (En_k/Q_k) * (Q_k/Q)$, En_k/Q_k **= efficiency** in process *k*, and Q_k/Q = **output share** of process *k* in total output **Q**. En_k/Q → monetary units

The macroeconomic IO model

- **Energy transformation**: fixed technical coefficients for energy inputs (*f*) for **coke oven, refinery, blast furnace**
- **Energy transformation in electricity and steam**: technical coefficients for energy inputs (*k*) = ($\boldsymbol{E_k}$/$\boldsymbol{Q_k}$) * ($\boldsymbol{Q_k}$ /$\boldsymbol{Q}$), the product of **fixed technologies by *k*** and **output shares by *k*** (e.g.: electricity produced out of *k*)
- **Input of *L* and *K***: fixed coefficients for coke oven, refinery, blast furnace and technology specific (*k*) for electricity and steam.
- **Prices of electricity**: cost shares, mark-up plus (additional) **ETS permit costs**

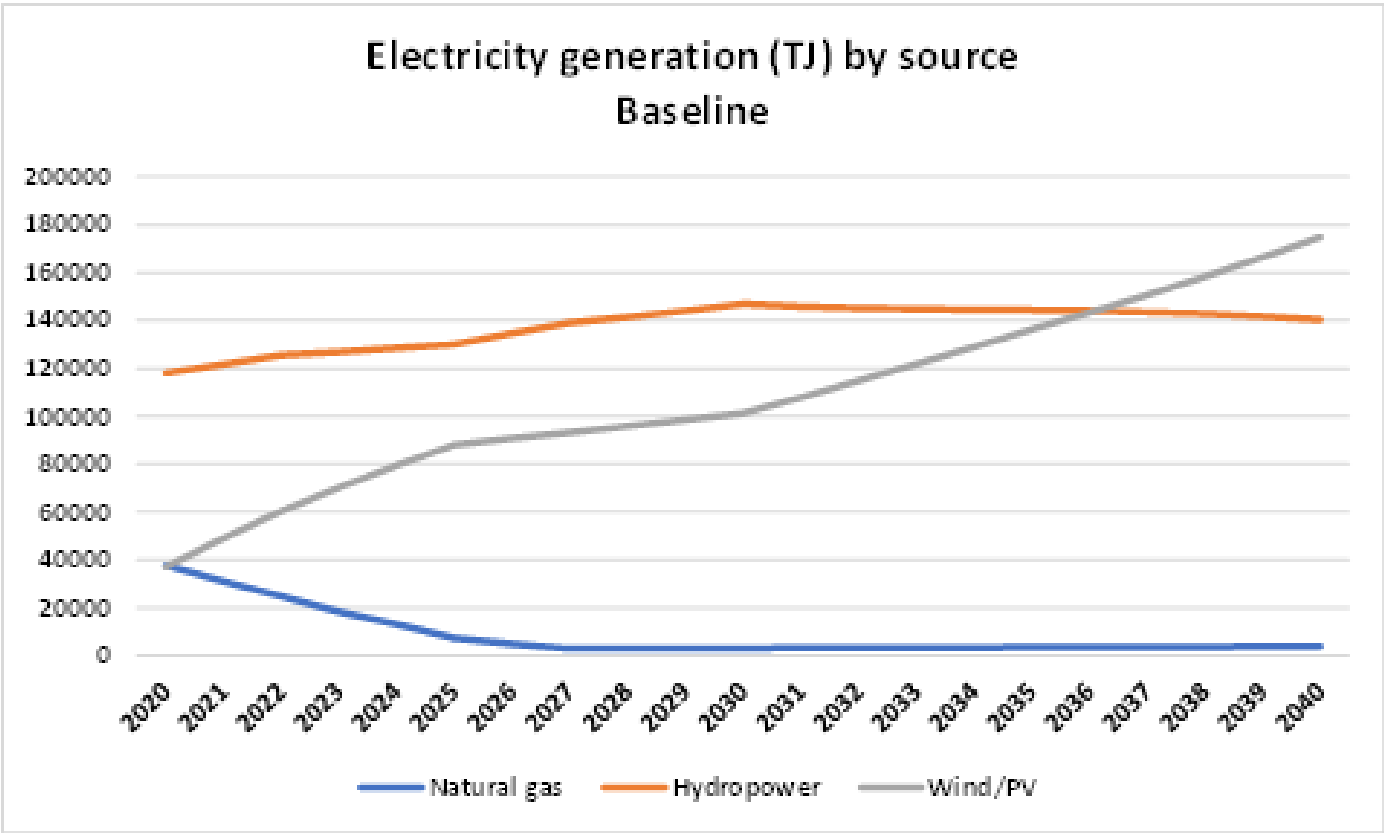
Baseline

- Final energy (change in PJ) by type of energy, 2022 - 40 in "Base"



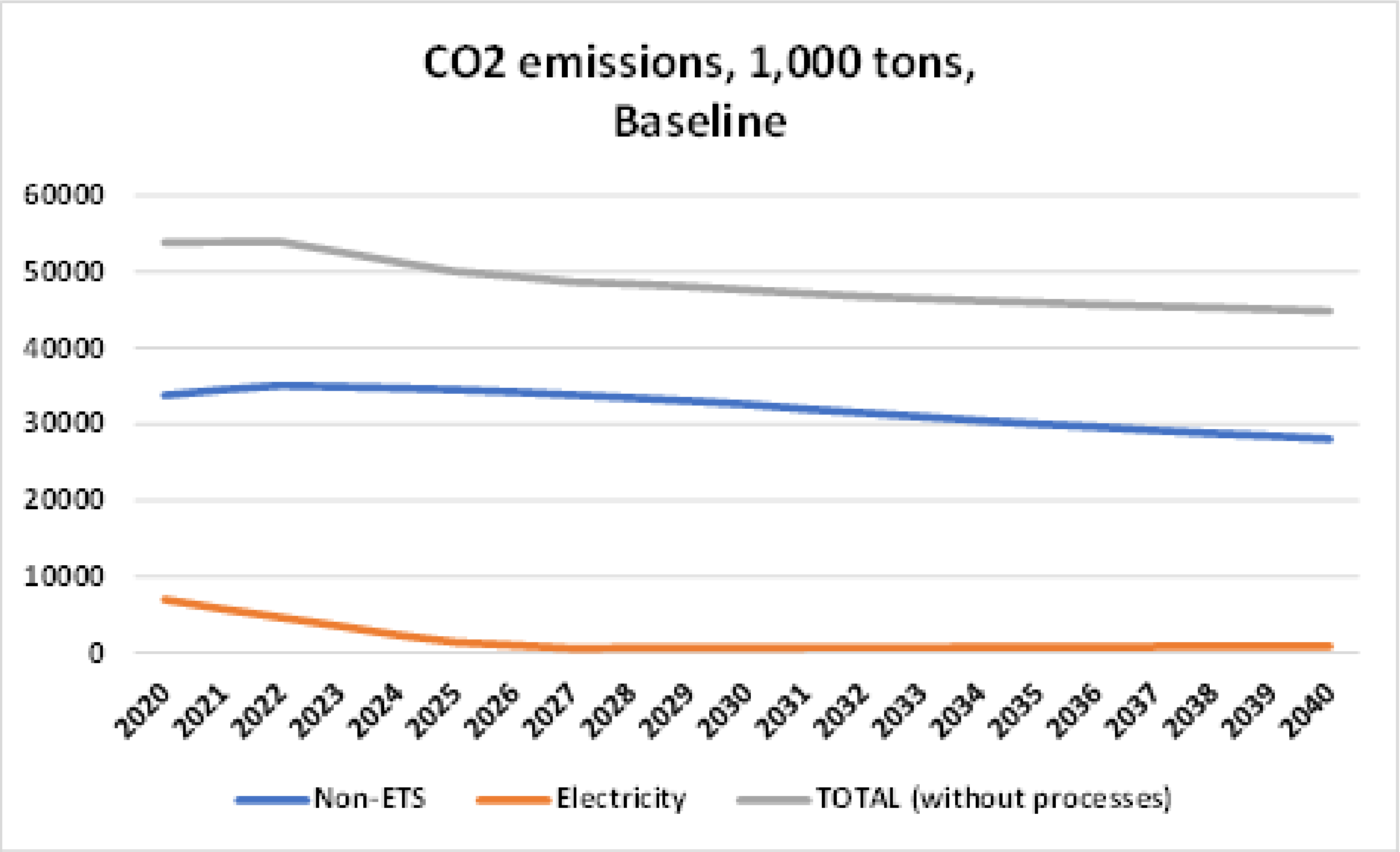
Baseline

- Electricity generation (in TJ) by main sources, 2022 - 40 in "Base"



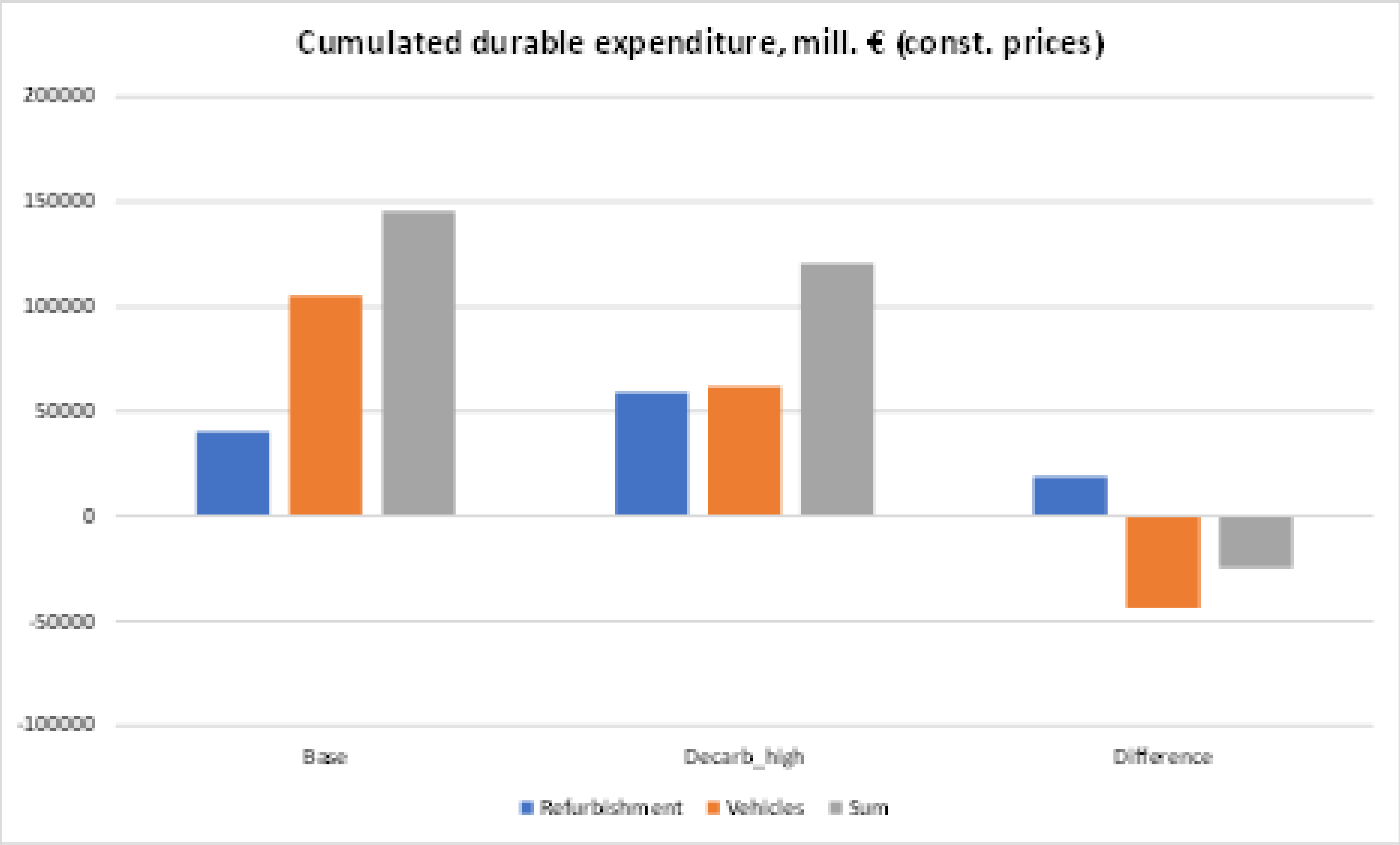
Baseline

- CO_2 emissions (in 1,000 t), 2022 - 40 in “Base”



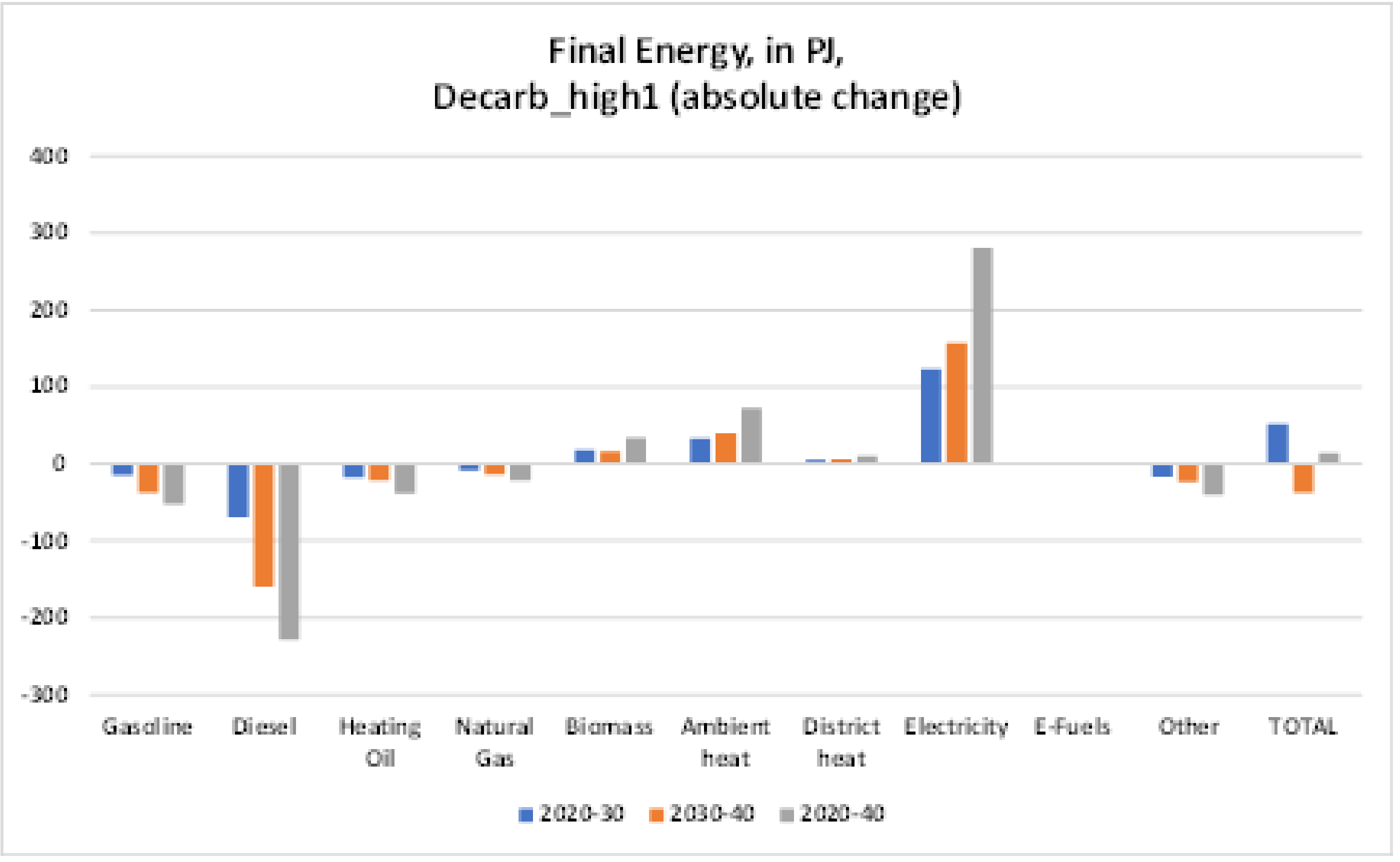
Scenario “Decarbonization 2040 –high system efficiency”

- Household durable expenditure (in mill €, const. prices), 2022 - 40 in “Decarb_high”



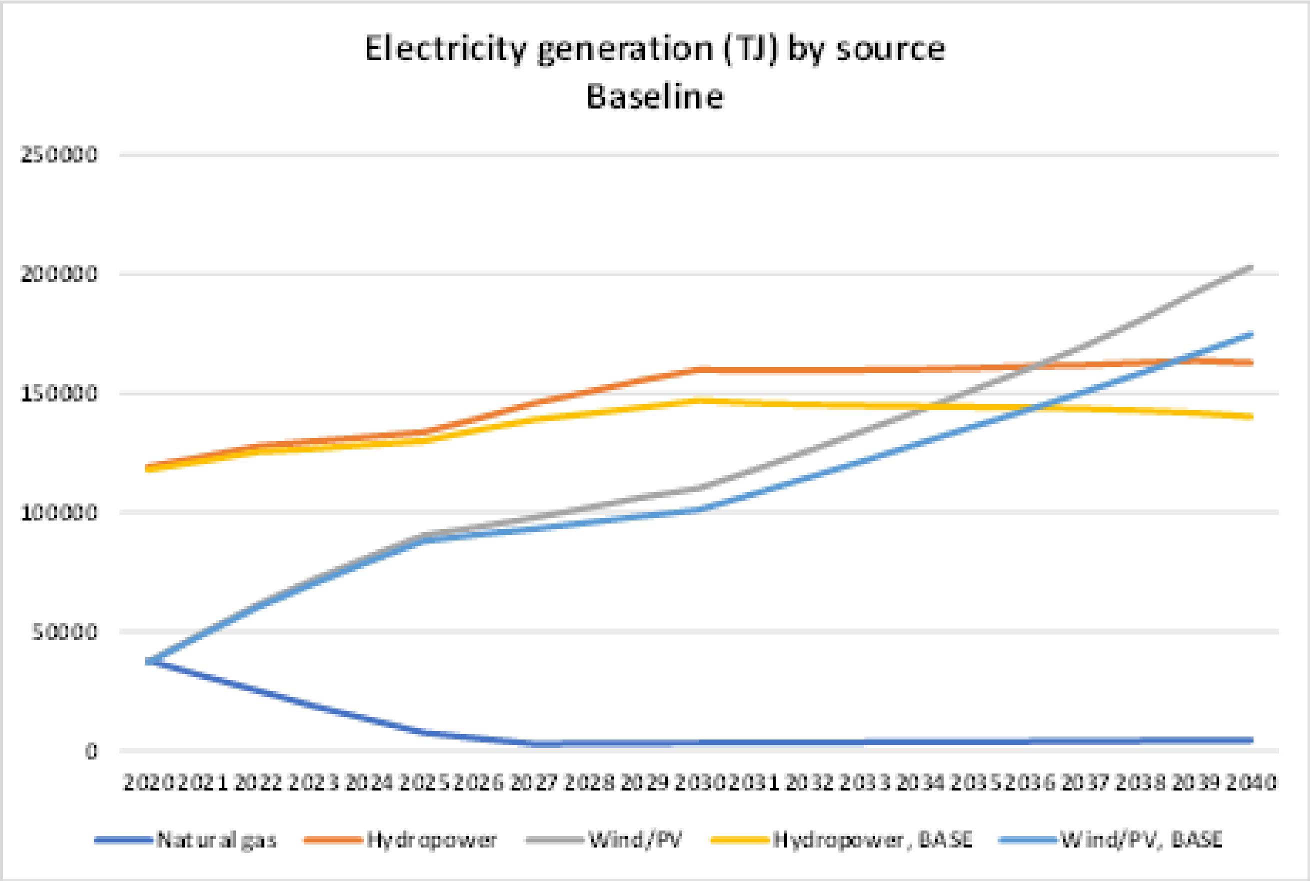
Scenario “Decarbonization 2040 –high system efficiency”

- Final energy (change in PJ) by type of energy, 2022 - 40 in “Decarb_high”



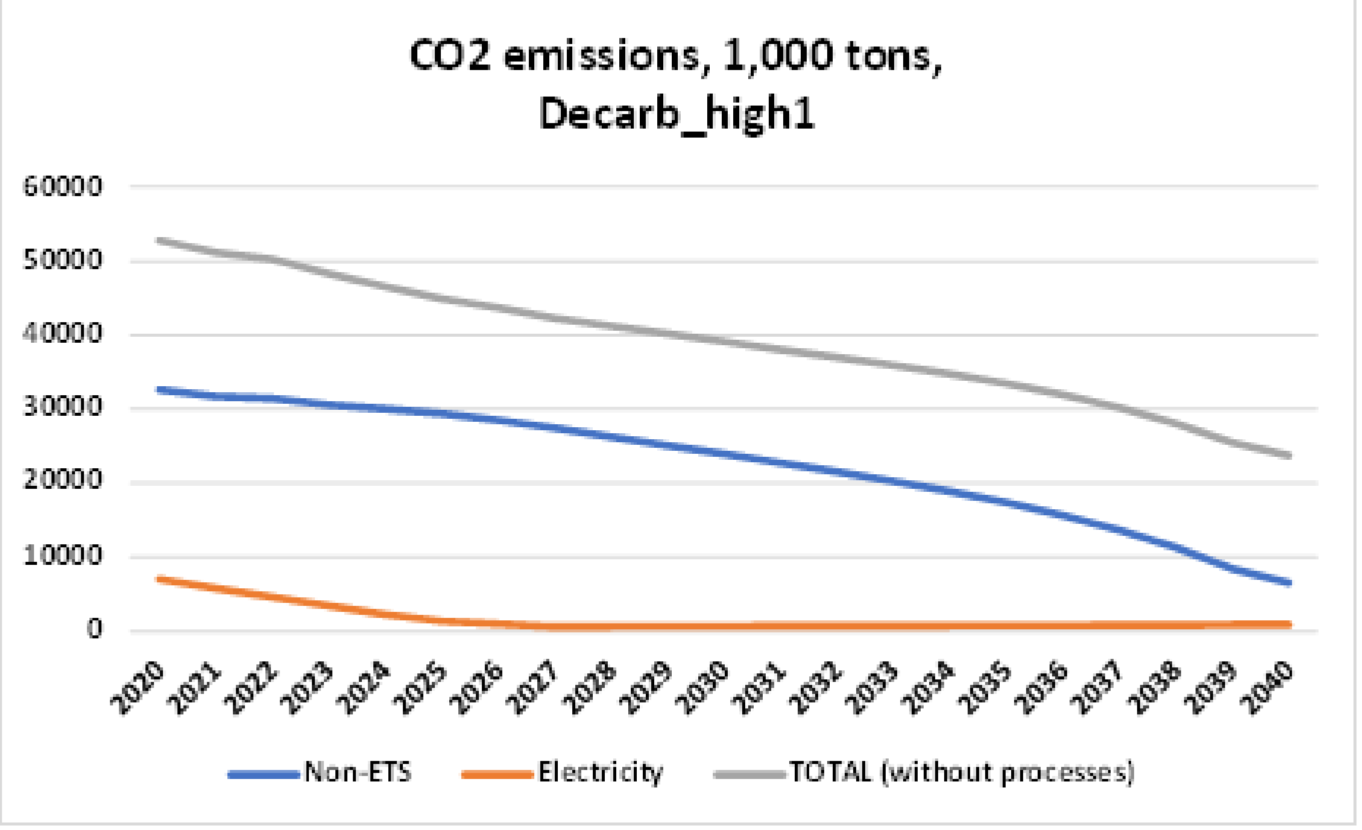
Scenario "Decarbonization 2040 –high system efficiency"

- Electricity generation (in TJ) by main sources, 2022 - 40 in "Base" and "Decarb_high1"



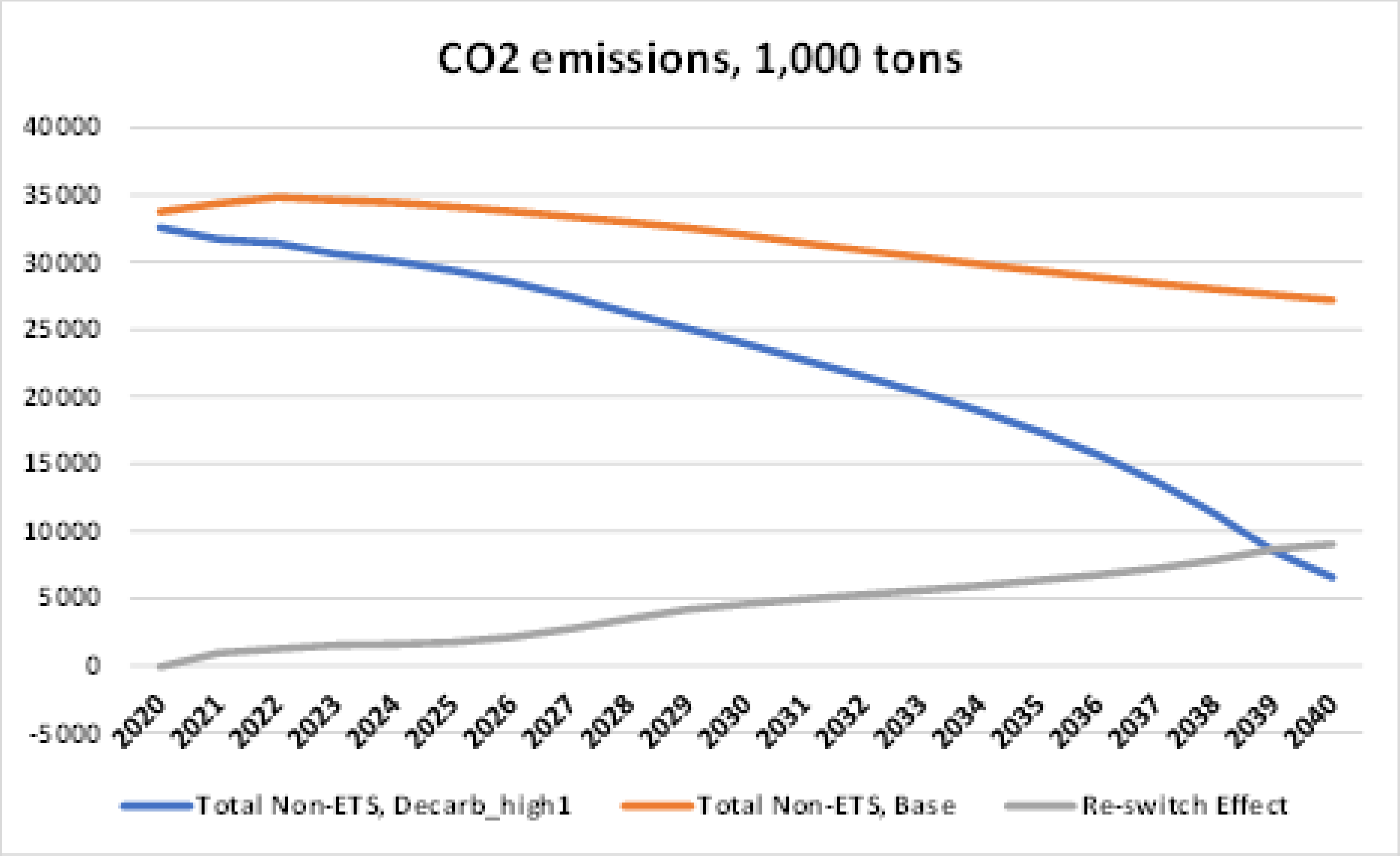
Scenario “Decarbonization 2040 –high system efficiency”

- CO_2 emissions (in 1,000 t), 2022 - 40 in “Decarb_high1”



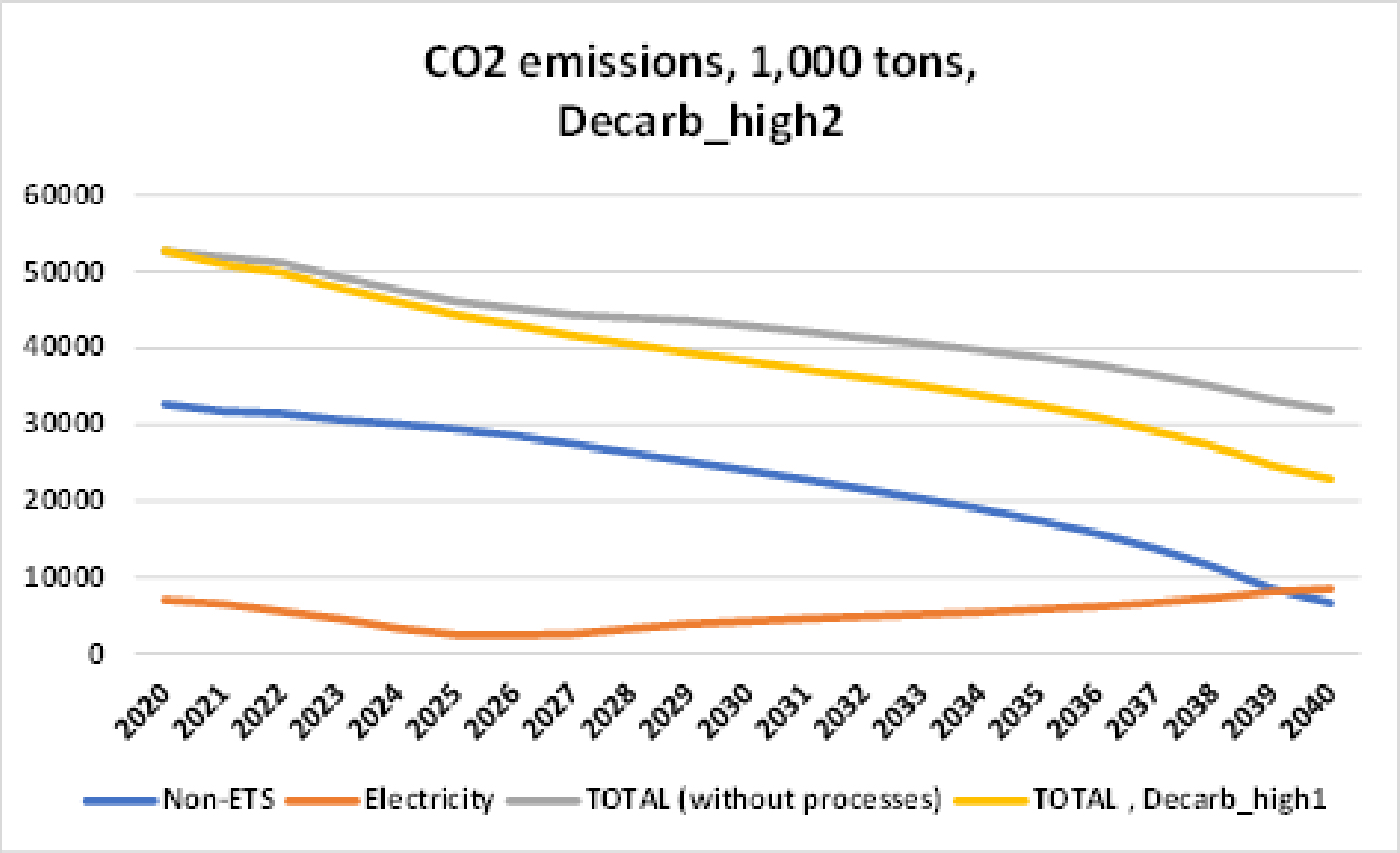
Scenario “Decarbonization 2040 –high system efficiency”

- CO_2 emissions (in 1,000 t), 2022 – 40, the **‘re-switch’ effect** in “Decarb_high2”



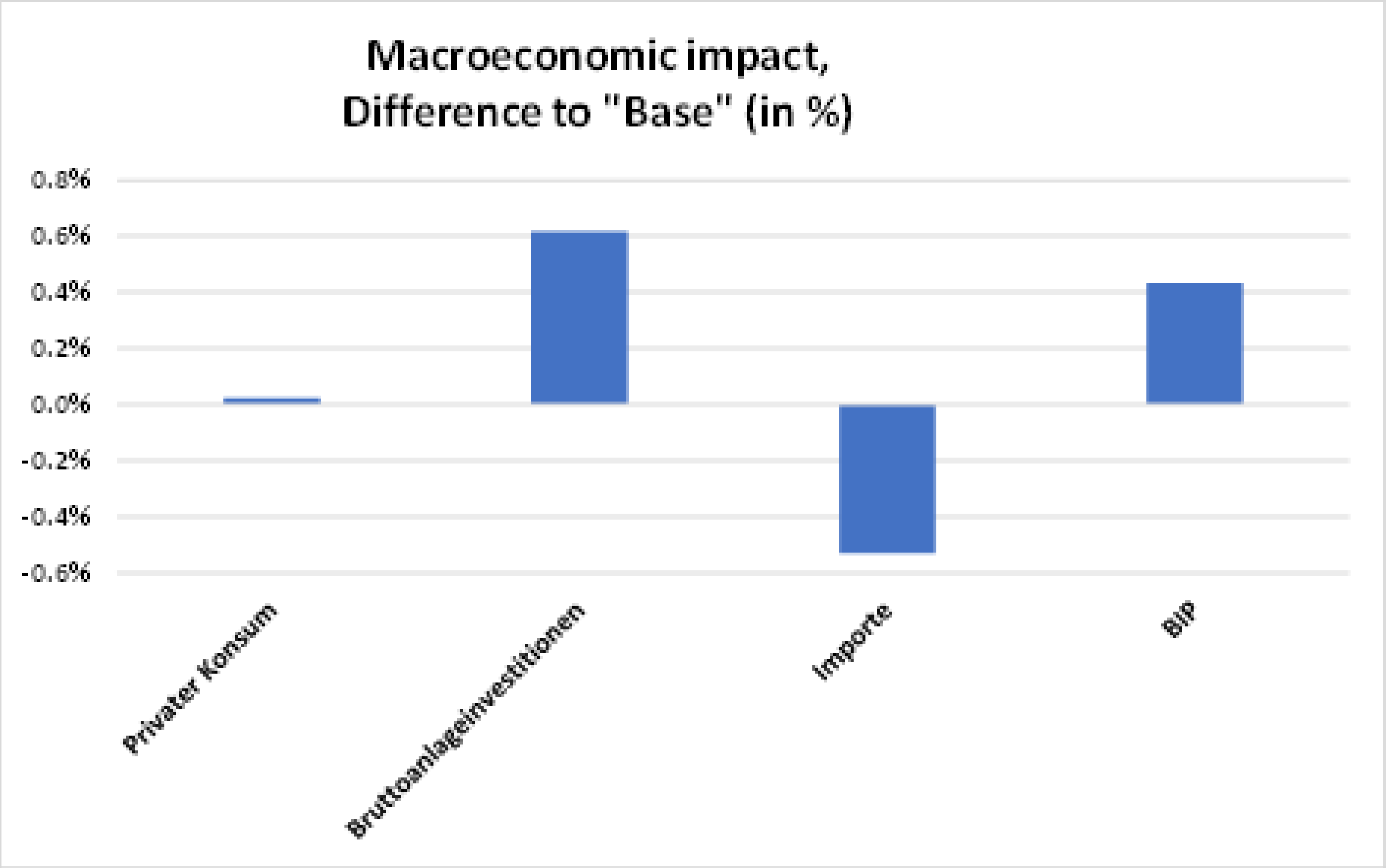
Scenario “Decarbonization 2040 –high system efficiency”

- Total CO_2 emissions (in 1,000 t), 2022 - 40 in “Decarb_high2”



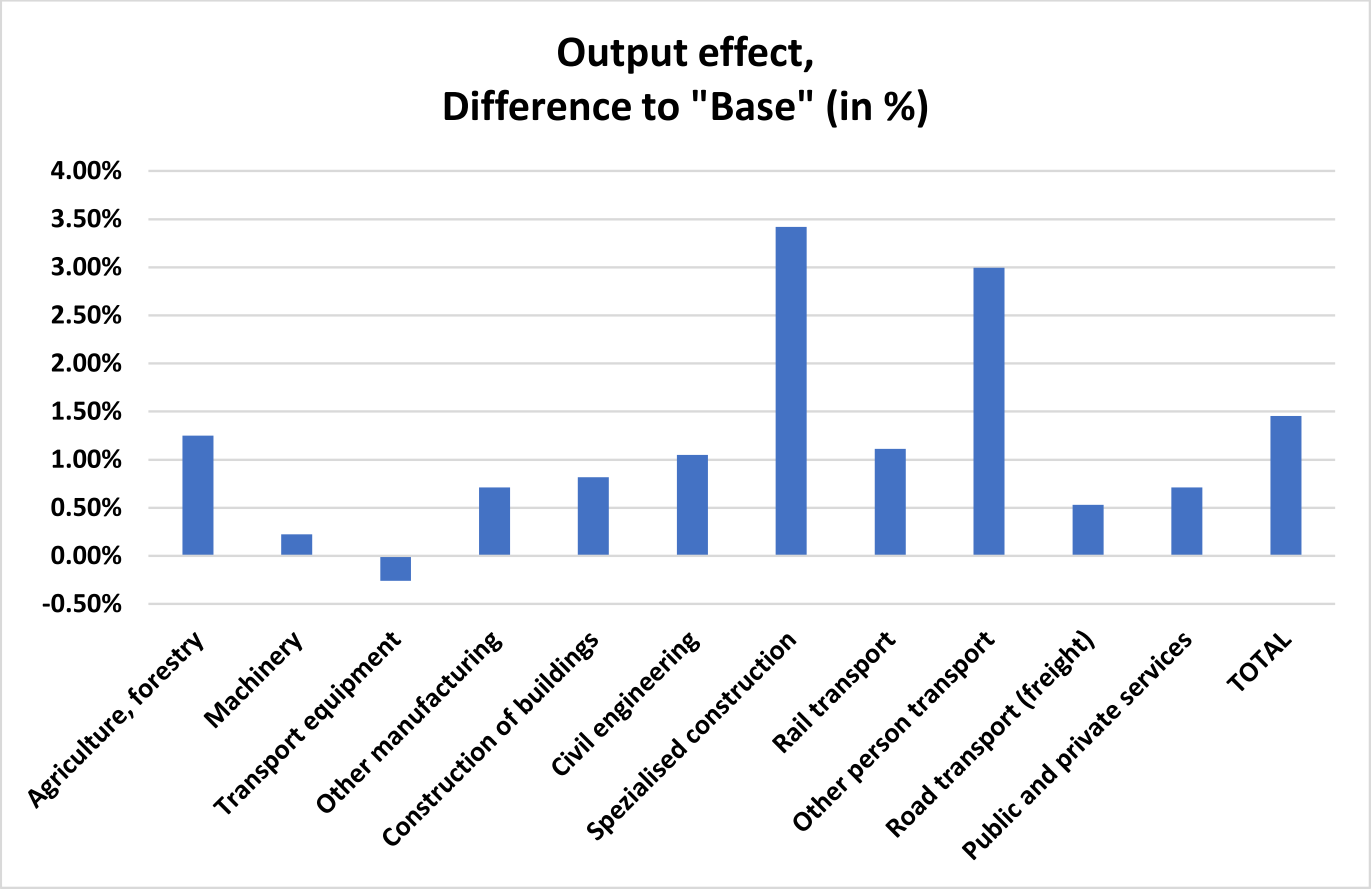
Scenario “Decarbonization 2040 –high system efficiency”

- Macroeconomic impact (in %), ‘Decarb_high2’ compared to ‘Base’



Scenario "Decarbonization 2040 –high system efficiency"

- Gross output impact (in %), 'Decarb_high2' compared to 'Base'



Scenario “Decarbonization 2040 –high system efficiency”

- Gross employment impact (in persons, FTE), ‘Decarb_high2’ compared to ‘Base’