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Life Cycle Assessment of substitute natural gas production from biomass and electrolytic hydrogen

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1. Abstract

In this work six different layouts for the production of a substitute of natural gas (SNG) and electricity from biomass and fluctuating electricity are compared from the environmental point of view by means of Life Cycle Assessment (LCA) methodology. Two different functional units are chosen: 1 kg of SNG produced and 1 MJ of output energy (SNG + electricity). Global Warming Potential (GWP), Cumulative Energy Demand (CED) and Acidification Potential (AP) are selected as impact indicators for this analysis.

2. Introduction

In recent years, renewable energies are increasingly gaining relevance towards the achievement of environmental, economic and political objectives and for a diversification of the energy mix. Nevertheless, one of the main problems in the integration of renewable sources into the energy sector lies in the need for a reliable large-scale energy storage system that can decouple production from energy demand, especially for those non-programmable sources. Generally, due to the use of a significant amount of power, electrolysis is an expensive process, but it could become cost-competitive and environmentally sustainable when powered by surplus electricity from renewable energy sources. Such a surplus could occur either because the grid is not demanding for additional power or because it could create grid instability.

In a previous paper different layouts were analysed to evaluate the energy balance of the production of SNG starting from biomass and electrolytic hydrogen. Two alternative scenarios were considered: (i) only the SNG is produced (Fig.1) and (ii) SNG and power are cogenerated (Fig. 2). The efficiencies of the different analysed layouts range from 52.4% to 73.8% with chemical power (fuel) accounting for 75-100% of the total output. Different power units define different sub-scenarios:
(i) gas turbine (**GT**);
(ii) steam injected gas turbine (**STIG**);
(iii) internal combustion engine (**ICE**);
(iv) solid oxide fuel cell (SOFC) fed by syngas at 6 bar (**SOFC6**);
(v) SOFC fed by syngas at 30 bar (**SOFC30**).
(vi) the case of hydrogasification (**HG**) that does not involve the co-production of power.
In the layouts with cogeneration of SNG and electricity (Fig. 2) electrolytic oxygen is used in the gasifier and the power unit to separate carbon dioxide from exhaust gases easier. Whereas in the previous paper an energy analysis was carried out, in this paper the layouts are compared from the environmental point of view by means of LCA.

Fig. 1

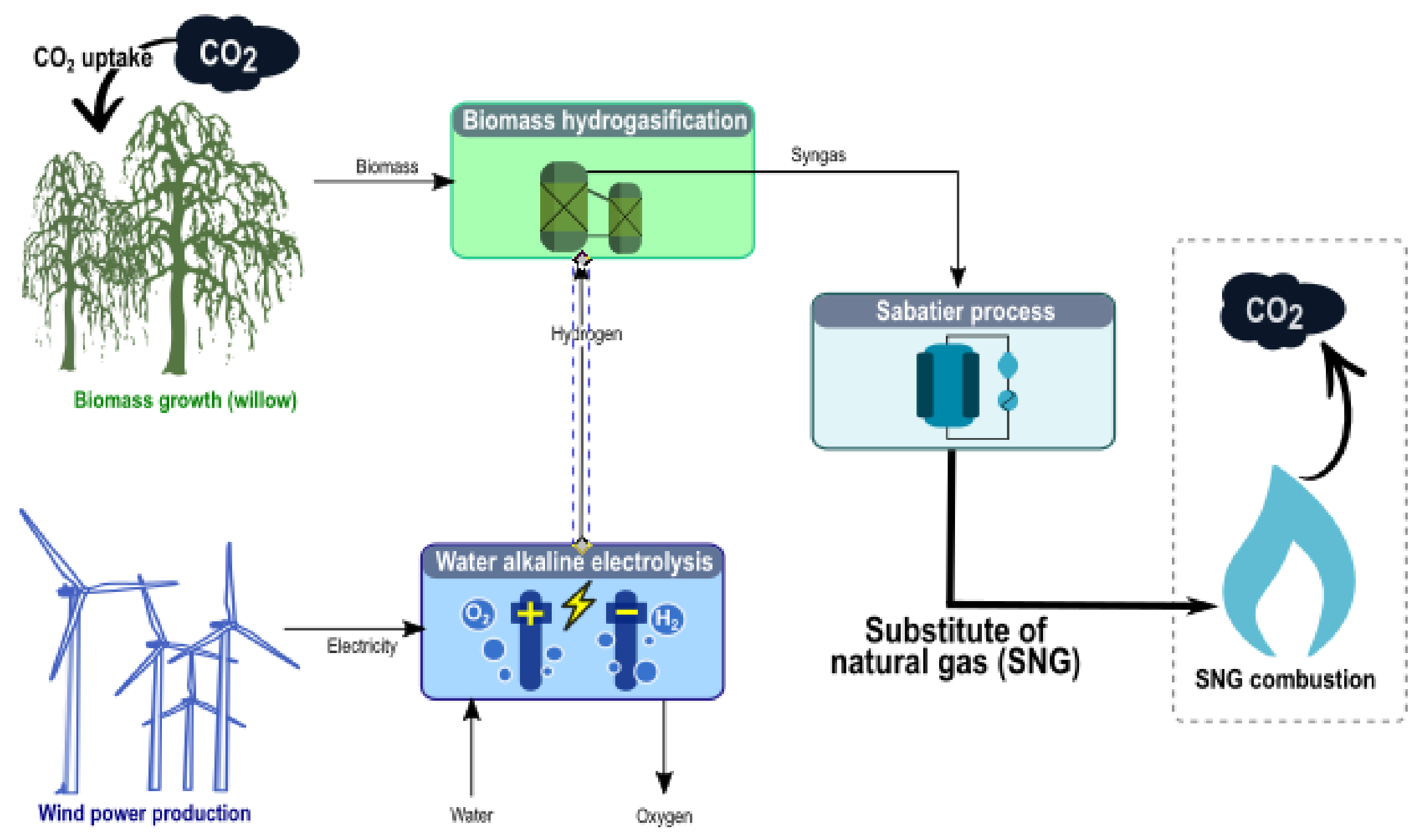
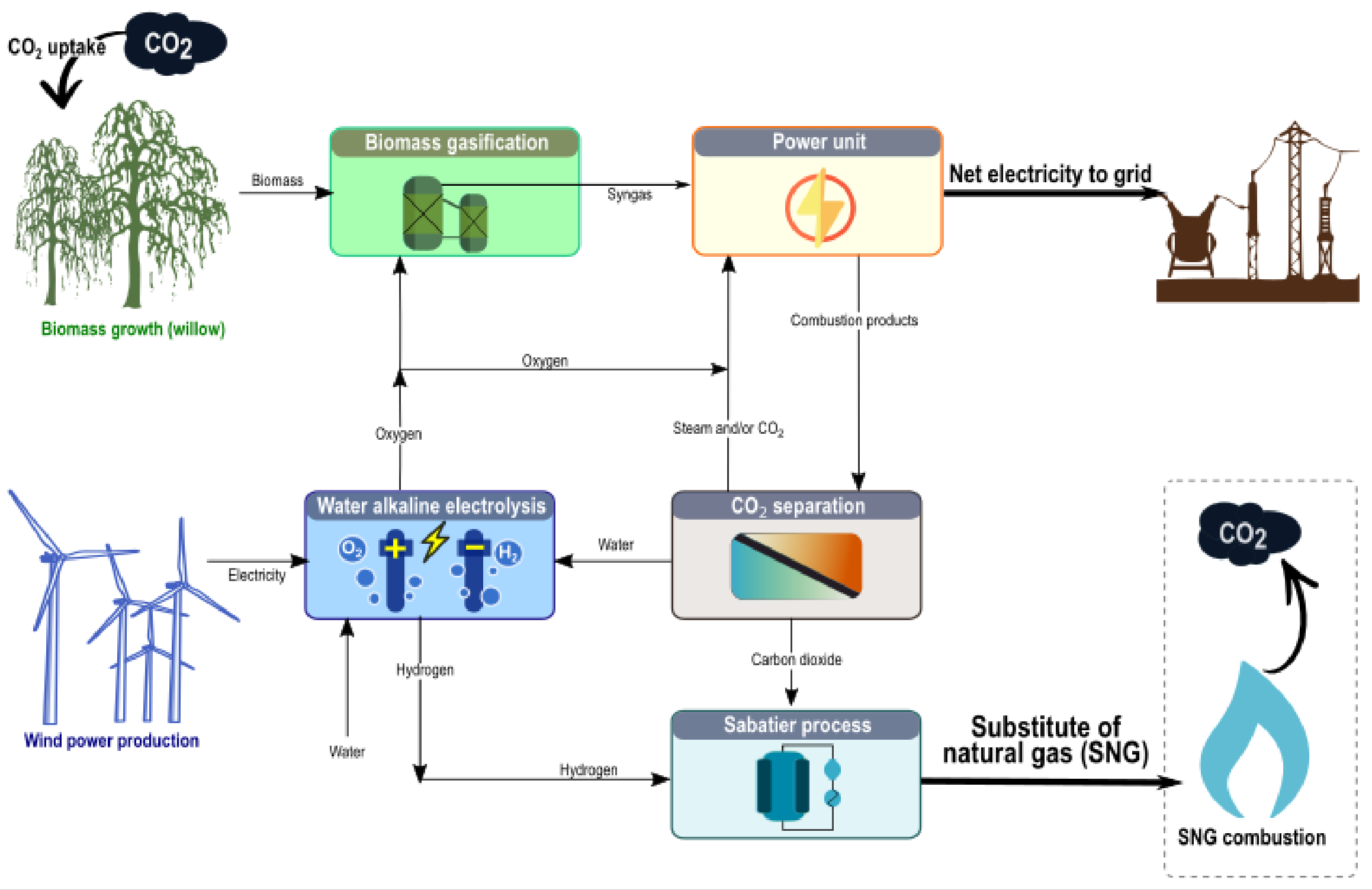


Fig. 2



3. Methodology

In this work an *attributional LCA* was performed, according to the ISO 14040 and 14044 guidelines. The inventories data are obtained from Aspen Plus simulations and modelled in the software SimaPro 8 using ecoinvent 3.5 for background data. The life cycle environmental performance are characterised by quantifying the environmental impacts of global warming potential 100 year horizon (GWP), cumulative energy demand (CEDnr) and acidification potential (AP) by employing the impacts assessment methods of IPCC 2013, VDI and CML-IA baseline, respectively. The electricity used inside the plant is renewable (from *wind power*), while the electricity fed into the grid is assumed from a *2030 Italian scenario*. The assessment was performed exploring the effect different methodological assumptions. In particular different functional units (1 kg SNG, 1 MJ of total energy produced) and the *approaches followed to deal with multifunctionality* (avoided burdens, energy allocation). The combustion of SNG is also involved into the system boundaries (Cradle-to-Grave approach).

4. Results and discussion

The results of the six layouts are reported in this section in addition with the environmental characterization of conventional natural gas (production plus combustion).

SNG mass as functional unit *(Fig. 3):* the layouts that have the lowest GWP and CEDnr are the SOFC30, SOFC6 and the STIG, while the lowest AP is for the HG case.

Energy output as functional unit *(Fig. 4):* the layout that implies the lowest GWP, AP and CED is the one with hydrogasification **(HG)**. The second lowest GWP is with the ICE layout, which on the other hand gives the highest impacts in terms of AP and CEDnr. The SOFC30, SOFC6 and STIG layouts report similar impacts on all the considered indicators, slightly lower than the GT layout. The same conclusions apply also to the case study with the **SNG mass as functional unit and energy allocation** *(Fig. 5)* among the products.

Conventional natural gas has higher impacts than the proposed layouts in terms of GWP and CEDnr, but outperforms SNG in terms of AP. This found to be closely linked to the use of fertilisers and pesticides in the biomass growth stage in the six layouts producing SNG.

Impact breakdown *(Fig. 6-8):*

- *Carbon footprint (Fig. 6)*: in all layouts the major impact is given by the SNG combustion, while the higher credit is given by the CO_2 uptake from the atmosphere by the biomass.
- *Acidification footprint (Fig. 7)*: the biggest impact is ascribable to the electrolyzer infrastructure. The electricity fed to the grid in the cogenerative layouts reports a significant negative contribution.
- *Non-renewable energy footprint (Fig. 8):* The major (negative) contribution is given by the electricity credits for the cogenerative layouts, while the most significant positive contribution is ascribable to electricity production from wind power.

Fig. 3

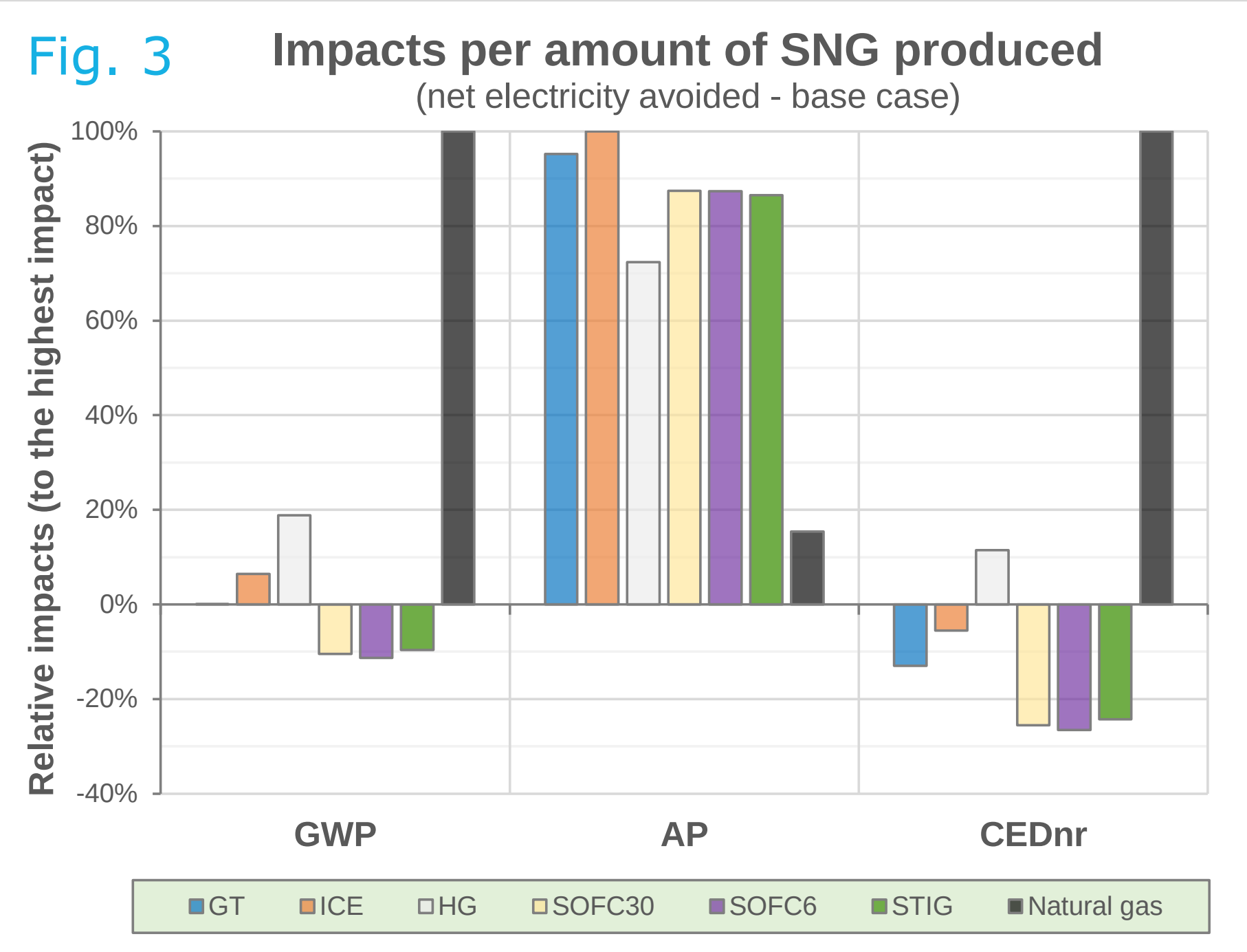


Fig. 4

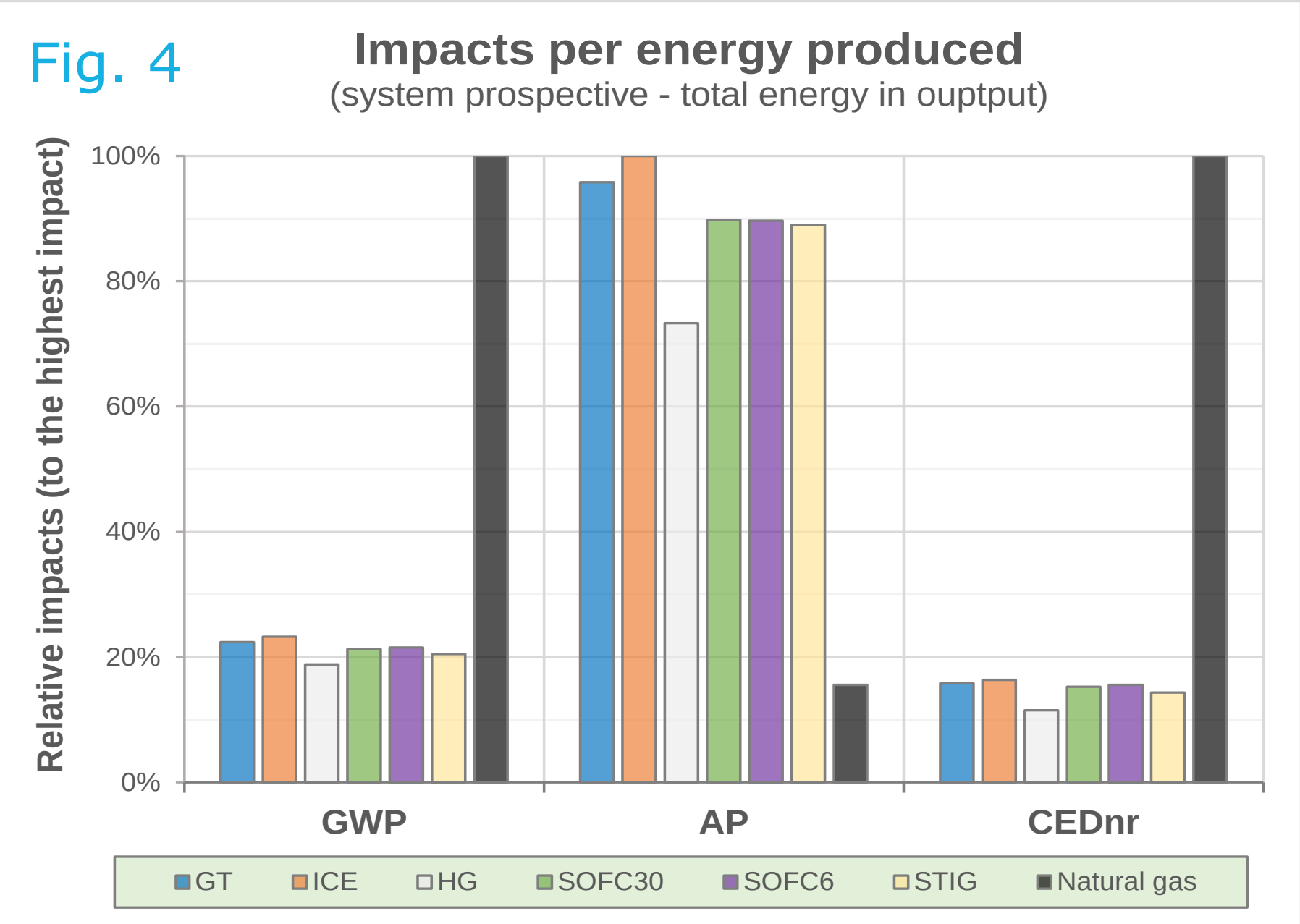


Fig. 5

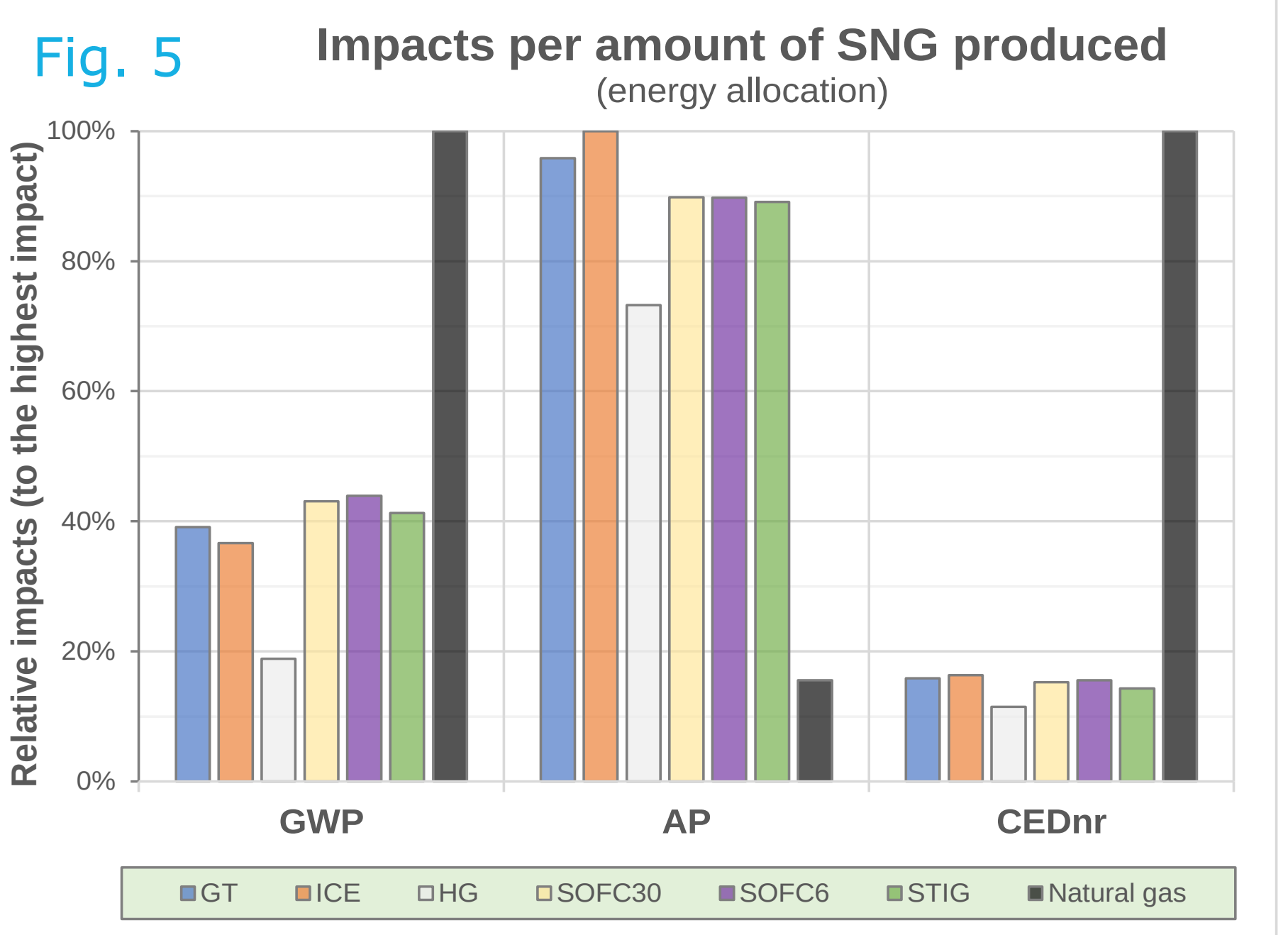


Fig. 6

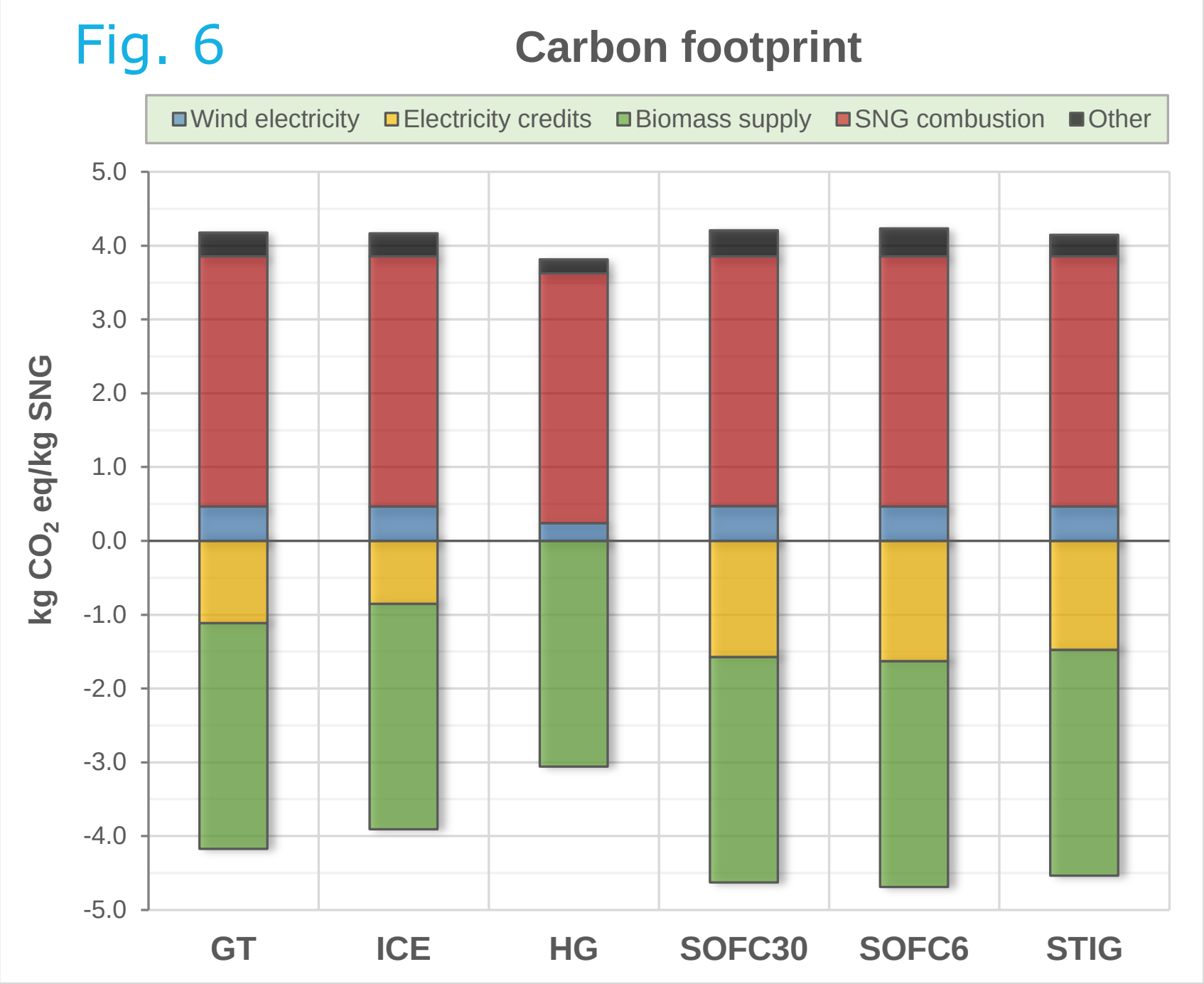


Fig. 7

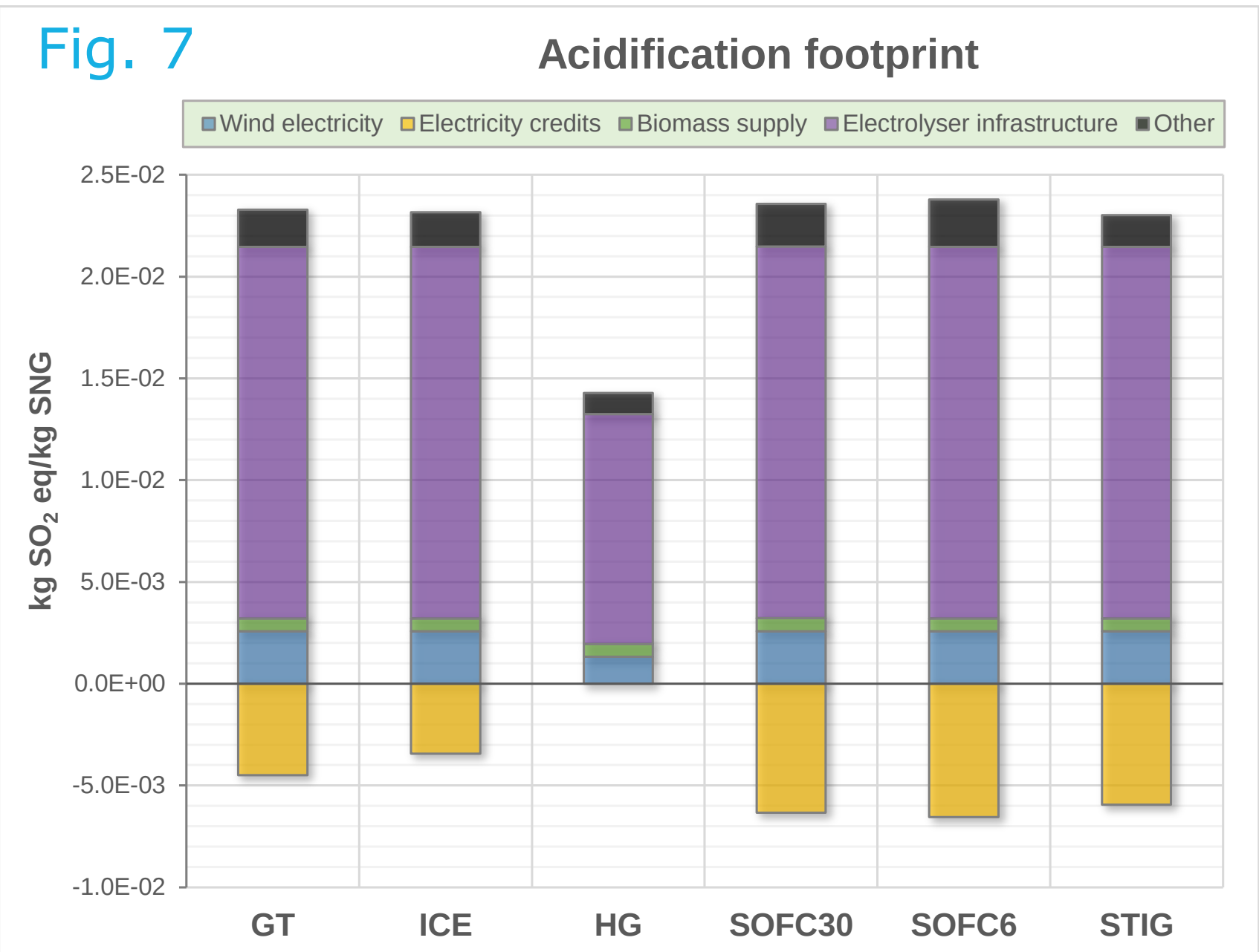
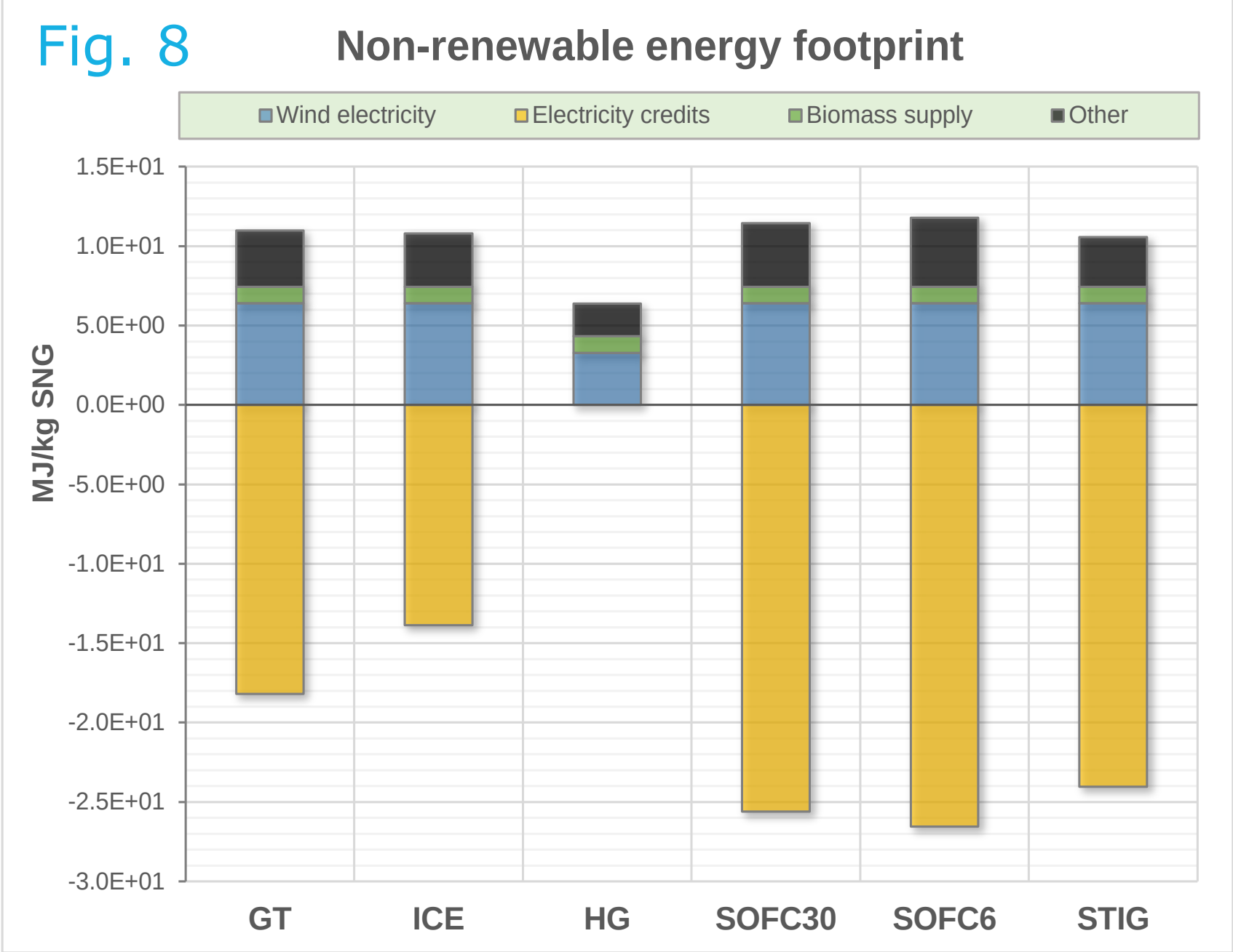


Fig. 8



5. Conclusions and outlook

In the present paper the LCA of six different layouts for the production of SNG from biomass and electrolytic hydrogen is performed according to three impact indicators (GWP, AP, CED), and compared with the natural gas impacts. The analysis is performed with different functional units and with two different approaches to deal with multifunctionality. The results show that the layout based on hydrogasification has the lowest impacts on all of the considered cases a part from the GWP and the CED with SNG mass as functional unit and the avoided burden approach. The proposed layouts have lower impacts than natural gas production in terms of GWP and CEDnr, higher impacts on AP. The impact breakdown shows that the major impacts on GWP, AP and CEDnr are ascribable to SNG combustion, electrolyzer infrastructure and electricity production from wind energy, respectively. When applying avoided burdens approach, the credits for the electricity fed to the grid is relevant, although related to the energy mix chosen (Italian 2030 energy mix).