PLANETS
Probabilistic Long-term Assessment of New Energy Technology Scenarios

# Assessment of energy technologies based on carbon price developments

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# The background

The aim of the paper is to assess energy technologies in power and transport sectors. The main tasks are to develop the framework for comparative assessment of energy technologies based on future carbon prices imposed on economy by post-Kyoto climate change mitigation regimes.

The proposed assessment framework allows to compare power generation and transport technologies in terms of their environmental and economic impacts.

The main indicators selected for technologies assessment are: private costs and external costs of GHG emissions. The ranking of energy technologies based on total social costs allows to identify the most perspective technologies in future taking into account international climate change mitigation constraints and to promote these technologies by policy tools.

The main results presented in this paper were obtained during EU financed Framework 7 project “PLANETS”

# Technologies assessment framework

- The main indicators for energy technologies assessment are private costs and external costs of GHG emissions. The life cycle GHG emissions indicator reflects the potential negative impacts of the global climate change caused by emissions of greenhouse gases for the production of 1 kWh of electricity or ride of 1 vehicle km.
- Seeking to integrate long-term technology assessment with results of long-term policy scenarios run in assessing the main relevant power and transport technologies the carbon price obtained by various policy scenarios runs was used in the calculation of the GHG emission externalities of selected energy technologies in power and transport sectors. These two main fossil fuel burning sectors were selected based on IPCC methodology as they are the major sources of GHG emission from this GHG emission sector.

# Life cycle GHG emissions in power sector

| Fuel or energy type | Direct $CO_2$ emissions from combustion | | Life cycle $CO_2$ emissions | | Average value, of life cycle GHG emissions, kg/MWh |
|---|---|---|---|---|---|
| | kg/GJ | kg/MWh | kg/GJ | kg/MWh | |
| Nuclear | 2.5÷30.3 | 9÷110 | 2.8÷35.9 | 10÷130 | 65 |
| Oil | 126.9÷300.7 | 460÷1090 | 137.9÷331.0 | 500÷1200 | 850 |
| Natural gas | 96.6÷179.31 | 350÷650 | 110.3÷215.2 | 400÷780 | 590 |
| Hard coal | 193.1÷262.1 | 700÷950 | 206.9÷344.8 | 750÷1250 | 1000 |
| *Hard coal IGCC with CCS* | *52.4÷60.7* | *190÷220* | *38.6÷46.9* | *140÷170* | *155* |
| Large scale wood chips combustion | - | - | 21.0÷23.0 | 76.0÷83.3 | 79.6 |
| Large scale wood chips gasification | - | - | 6.0÷8.0 | 21.6÷29.0 | 25.3 |
| *Biomass IGCC with CCS* | *-139.4÷-143.5* | *-505÷-520* | *-35.9÷-41.4* | *-130÷-150* | *-140* |
| Large scale straw combustion | - | - | 62.0÷70.0 | 223.2÷252.0 | 237.6 |
| Wood chips CHP large scale | - | - | 6÷10 | 21.6÷36.0 | 28.8 |
| Wood chips gasification CHP small scale | - | - | 3÷6 | 10.8÷21.6 | 16.2 |

# Long-term private costs of power generation technologies, EUR/MWh

| Fuel or energy type | Costs, EUR/MWh | | Average private costs, EUR/MWh |
|---|---|---|---|
| | Min | Max | |
| Nuclear | 24 | 42 | 33 |
| Oil | 79 | 100 | 90 |
| Natural gas | 53 | 60 | 57 |
| Hard coal | 21 | 44 | 33 |
| *Hard coal IGCC with CCS* | *40* | *43* | *42* |
| Large scale wood chips combustion | 35 | 38 | 37 |
| Large scale wood chips gasification | 42 | 49 | 46 |
| *Biomass IGCC with CCS* | *57* | *60* | *59* |
| Large scale straw combustion | 44 | 48 | 46 |
| Biomass (wood chips) CHP large scale | 37 | 60 | 49 |
| Biomass (wood chips gasification) CHP small scale | 37 | 60 | 49 |

# Life cycle GHG emissions in transport

| Fuel | Life cycle GHG emissions, $CO_2$ eq | | | | | Average life cycle GHG emissions g/vehicle km |
|---|---|---|---|---|---|---|
| | g/litre | kg/gal | g/MJ | g/mile at 4.5 MJ/mile | g/vehicle km | |
| Petrol | 2600 | 11.8 | 81-110 | 366-495 | 227.4-307.6 | 268 |
| Diesel | 3128 | 14.2 | 87-90 | 391-405 | 243.0-251.7 | 247 |
| Bioethanol from sugar beet | 724 | 3.3 | 37-43 | 166.5-193.5 | 103.5-120.2 | 112 |
| Bioethanol from wheat | 511 | 2.3 | 27-31 | 121.5-139.5 | 75.5-86.7 | 81 |
| Biodiesel from rapeseed | 1334 | 6.1 | 39-43 | 175.5-193.5 | 109.1-120.2 | 115 |
| Biodiesel from waste vegetable oil | 437 | 2.0 | 11-15 | 49.5-67.5 | 30.8-41.9 | 36 |

# Long –term private costs of transport technologies, EURcnt/vehicle km

| Fuel | Private costs | | | | | Average private costs, EURcnt/ vehicle km |
|---|---|---|---|---|---|---|
| | EURcnt/ litre | Energy density MJ/litre | EURcnt/ MJ | EURcnt/mile at 4.5 MJ/vehicle mile | EURcnt/ vehicle km | |
| Petrol | 27.6-47.3 | 32 | 0.86-1.08 | 3.87-4.86 | 2.41-3.02 | 2.72 |
| Diesel | 27.6-47.3 | 36 | 0.77-1.31 | 3.47-5.90 | 2.16-3.67 | 2.92 |
| Bioethanol from sugar beet | 31.5-47.3 | 21 | 1.50-2.25 | 6.75-10.13 | 4.20-6.30 | 5.25 |
| Bioethanol from wheat | 53.4-51.2 | 21 | 2.54-2.44 | 11.43-10.98 | 7.10-6.80 | 6.95 |
| Biodiesel from rapeseed | 31.5-59.4 | 33 | 0.95-1.80 | 4.28-8.10 | 2.70-5.00 | 3.85 |
| Biodiesel from waste vegetable oil | 51.5-59.1 | 33 | 1.56-1.79 | 7.02-8.06 | 4.30-5.00 | 4.65 |

# Climate change mitigation policy scenarios

- 2 First best scenarios: FB-3p2 and FB-3p5 setting alternative targets after 2050: 3.2 W/m2 and 3.5 W/m2.

- 4 Second best policy scenarios: SC1-3p2 –To reach commitments indicated in Table for SC1 linearly declining from business as usual from start date. The target after 2050: 3.2 W/m2;

- SC1-3p5- To reach commitments indicated in Table for SC1 linearly declining from business as usual from start date. The target after 2050: 3.5 W/m2

- SC2-3p2- To reach commitments indicated in Table for SC2 linearly declining from business as usual from start date. The target after 2050: 3.2 W/m2

- SC2-3p5 - To reach commitments indicated in Table for SC2 linearly declining from business as usual from start date. The target after 2050: 3.5 W/m2.

- 4 variant second best policy scenarios are the same as for 4 second best scenarios, but with a limitation on the purchasing of carbon permits between 2020 and 2050, during which period at least 80% of abatement has be undertaken domestically by each region, and at most 20% of the abatement can be done with international offsets.

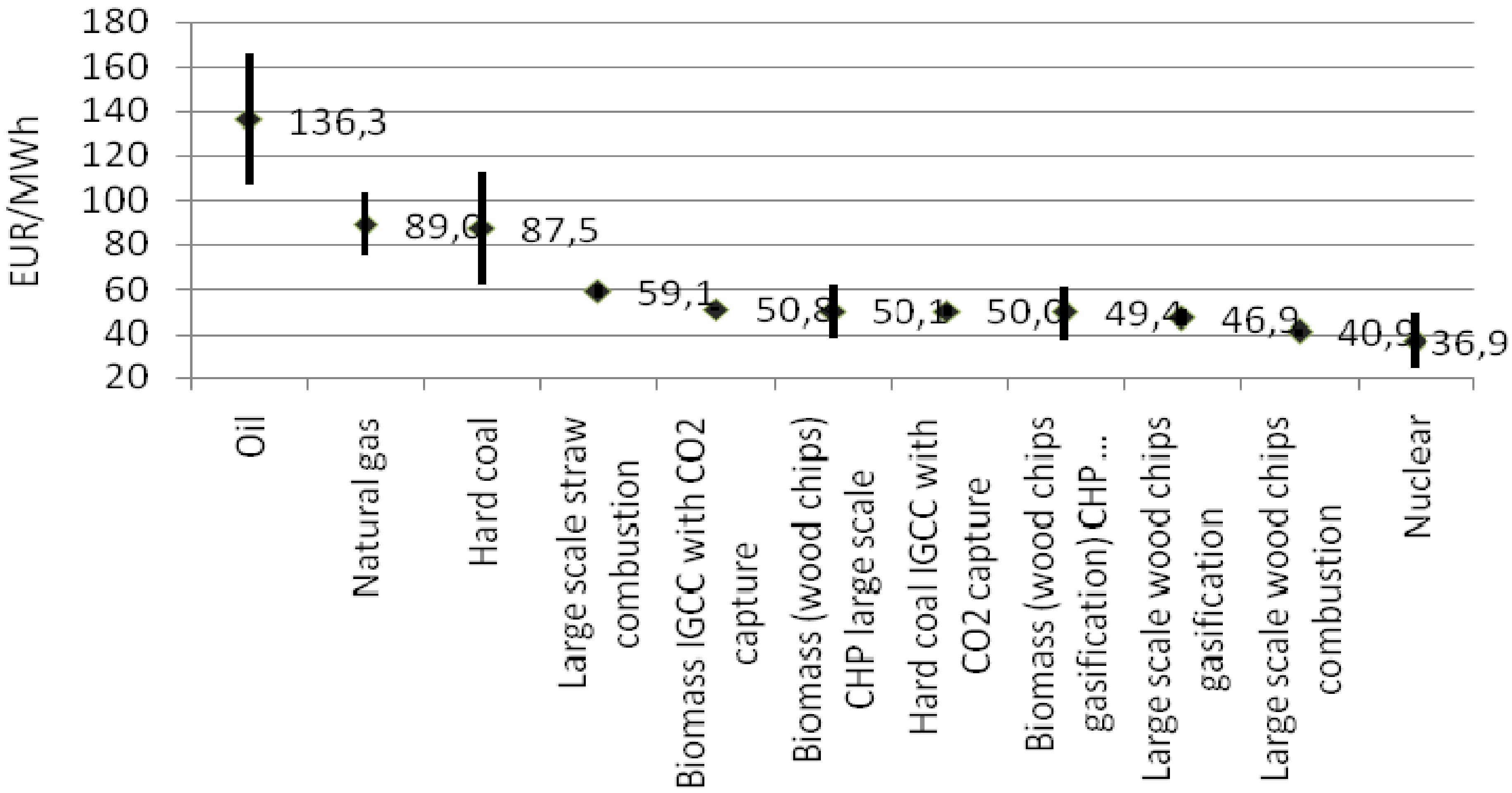
# GHG reduction commitments

| Regions | Starting date of commit-ments | Commitments SC1 in 2050 comparing with year 2005 | Commitments SC2 in 2050 comparing with year 2005 |
|---|---|---|---|
| OECD | 2015 | -80% | -90% |
| ENERGY EXPORTING (EEX) | 2025 | -50% | 0% |
| DEVELOPING ASIA (Dev. Asia) | 2025 | +25% | 0% |
| REST OF THE WORLD (ROW) | 2025 | +55% | +100% |
| WORLD | | -28% | -26% |

# Carbon prices

| Fuel or energy type | 2020 | | | | | 2050 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Global | OECD | EEX | DEV Asia | ROW | Global | OECD | EEX | DEV Asia | ROW |
| REF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| FB-3p2 scenario | 21-89 | 21-48 | 21-48 | 21-48 | 21-48 | 176-573 | 195-573 | 195-573 | 195-573 | 195-573 |
| FB-3p5 scenario | 13-52 | 13-48 | 13-48 | 13-48 | 13-48 | 89-297 | 195-297 | 195-297 | 195-297 | 195-297 |
| SC1-3p2 scenario | 3-21 | 3-21 | 3-21 | 3-21 | 3-21 | 107-248 | 107-248 | 107-248 | 107-248 | 3-107 |
| SC1-3p5 scenario | 3-44 | 3-13 | 3-13 | 3-13 | 3-13 | 110-289 | 110-289 | 110-289 | 110-289 | 110-289 |
| SC2-3p2 scenario | 3-14 | 3-14 | 3-14 | 3-14 | 3-14 | 110-229 | 110-229 | 110-229 | 110-229 | 110-229 |
| SC2-3p5 scenario | 3-13 | 3-13 | 3-13 | 3-13 | 3-13 | 110-268 | 110-268 | 110-268 | 110-268 | 110-268 |
| VAR1-3p2scenario | 0-14 | 0-14 | 0-17 | 0-12 | 0-12 | 111-192 | 113-192 | 125-192 | 103-192 | 103-192 |
| VAR1-3p5 scenario | 3-13 | 3-14 | 3-15 | 3-11 | 3-11 | 110-238 | 114-238 | 120-238 | 103-238 | 103-238 |
| VAR2-3p2 scenario | 0-13 | 0-15 | 0-12 | 0-12 | 0-12 | 105-164 | 115-164 | 101-164 | 101-164 | 101-164 |
| VAR2-3p5 scenario | 3-11 | 3-15 | 3-10 | 3-10 | 3-10 | 105-203 | 114-203 | 101-203 | 101-203 | 101-203 |

# The range of social costs of electricity generation in 2020 for FB-3p2



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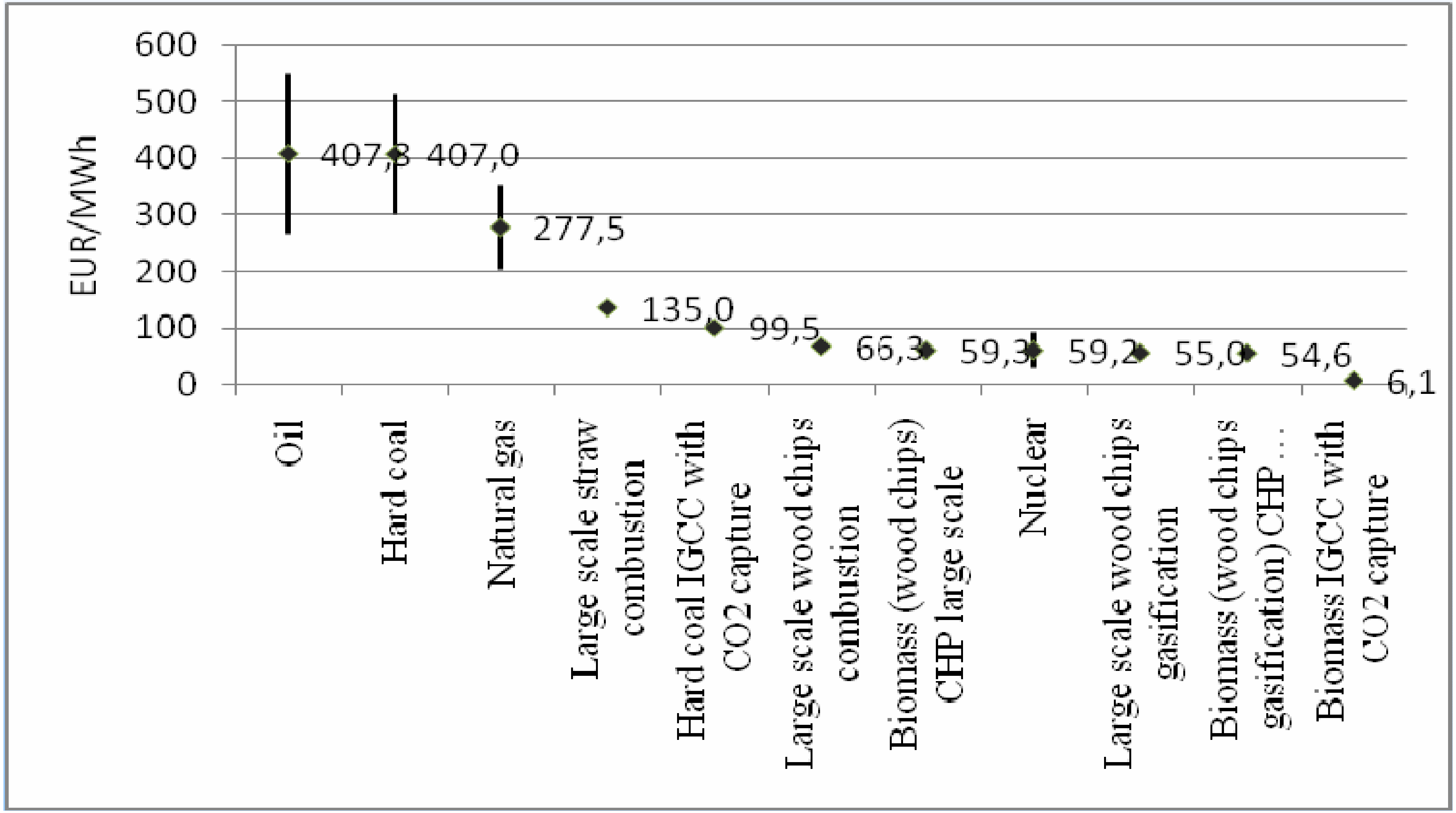
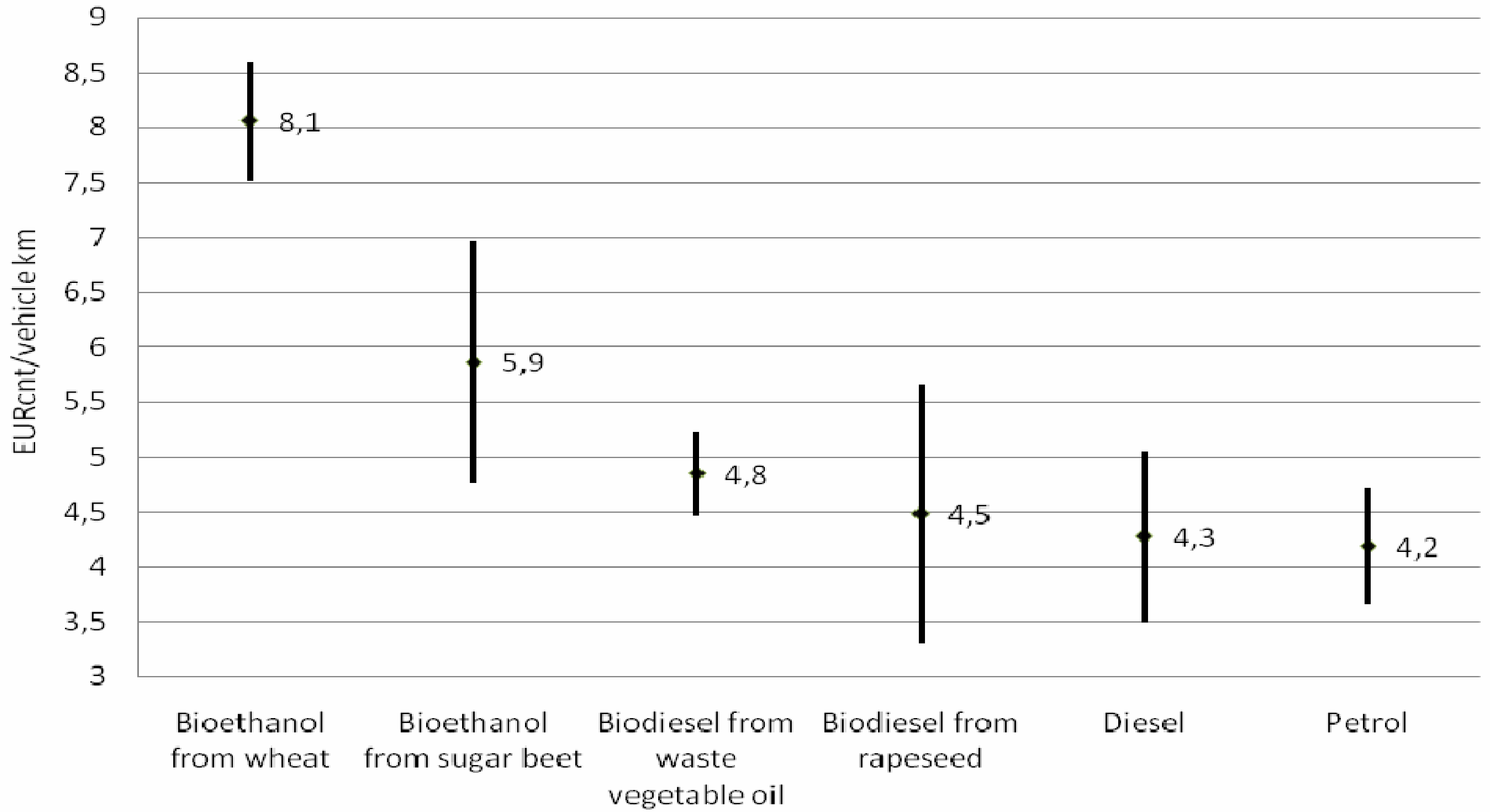
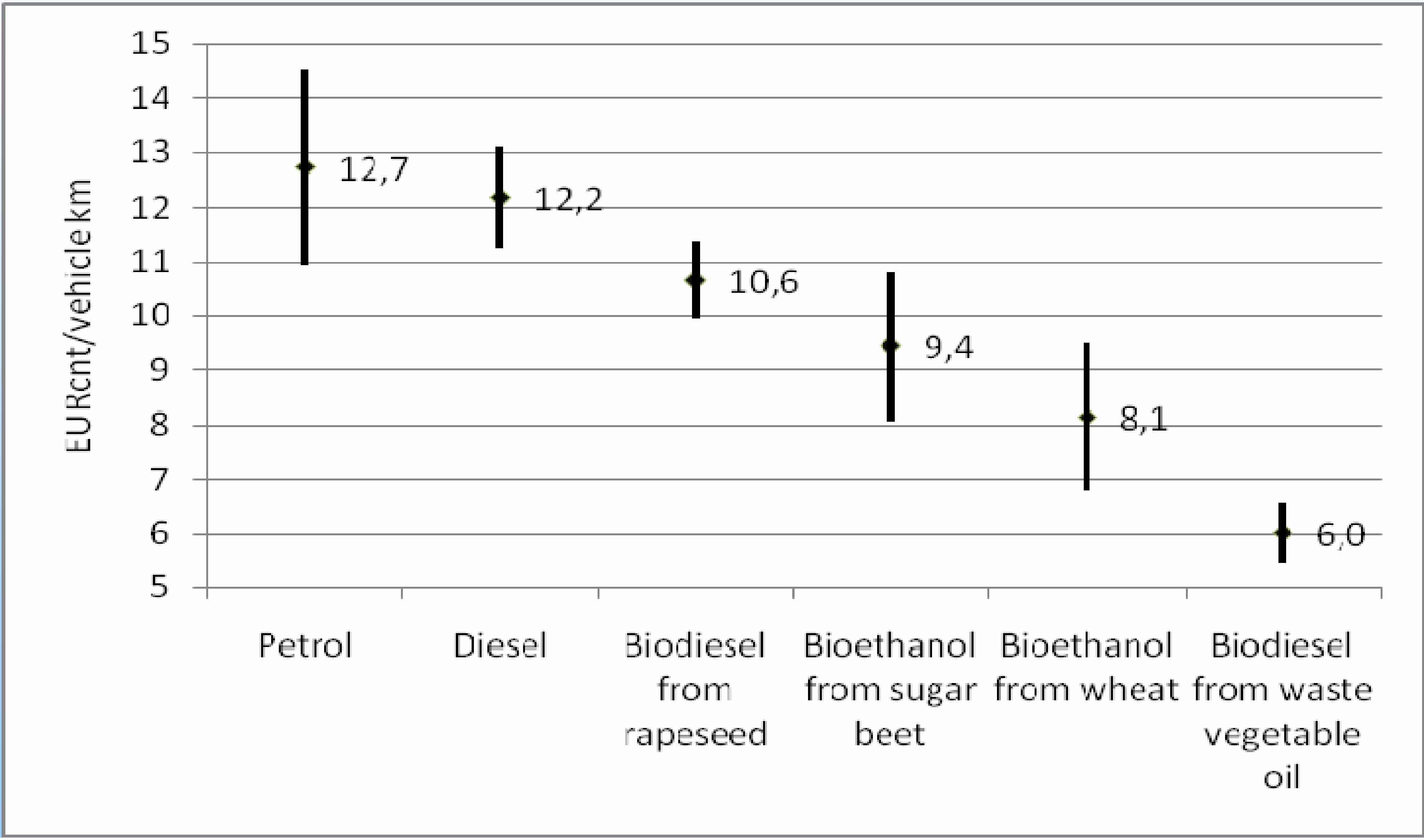
# The range of social costs of electricity generation in 2050 for FB-3p2



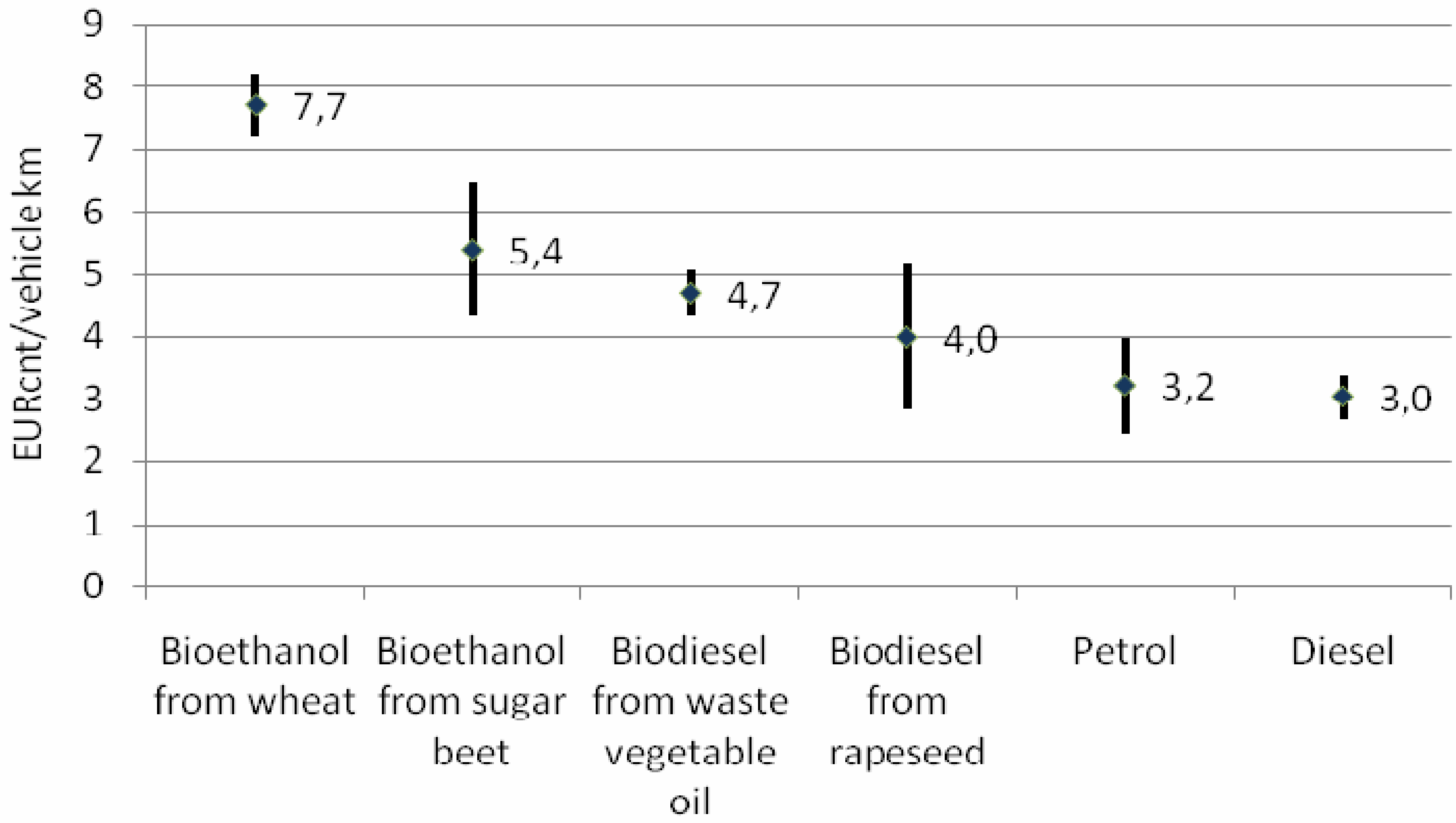
# The average and range of total costs of transport technologies in 2020 for FB-3p2



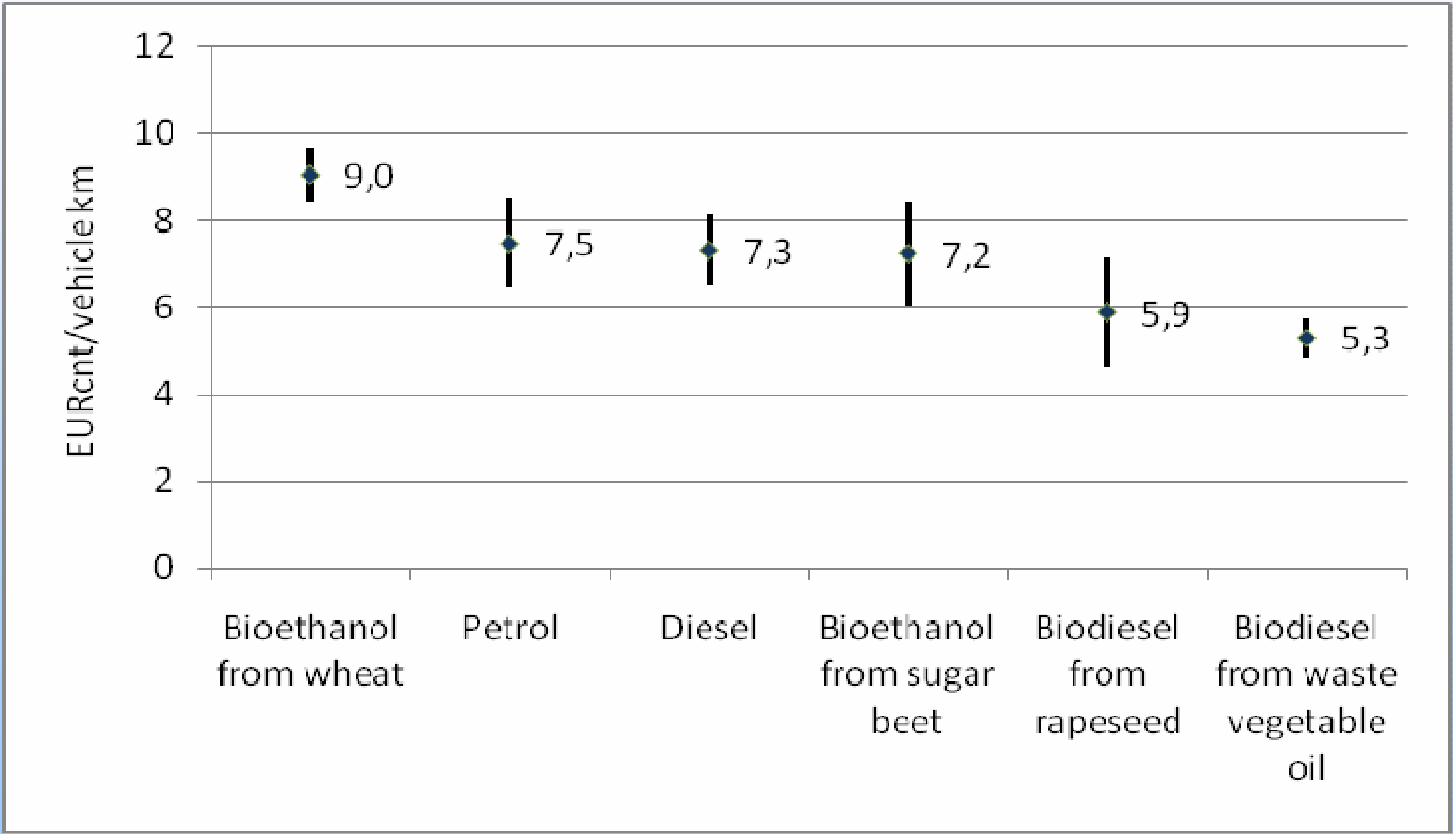
# The average and range of total costs of transport technologies in 2050 FB-3p2



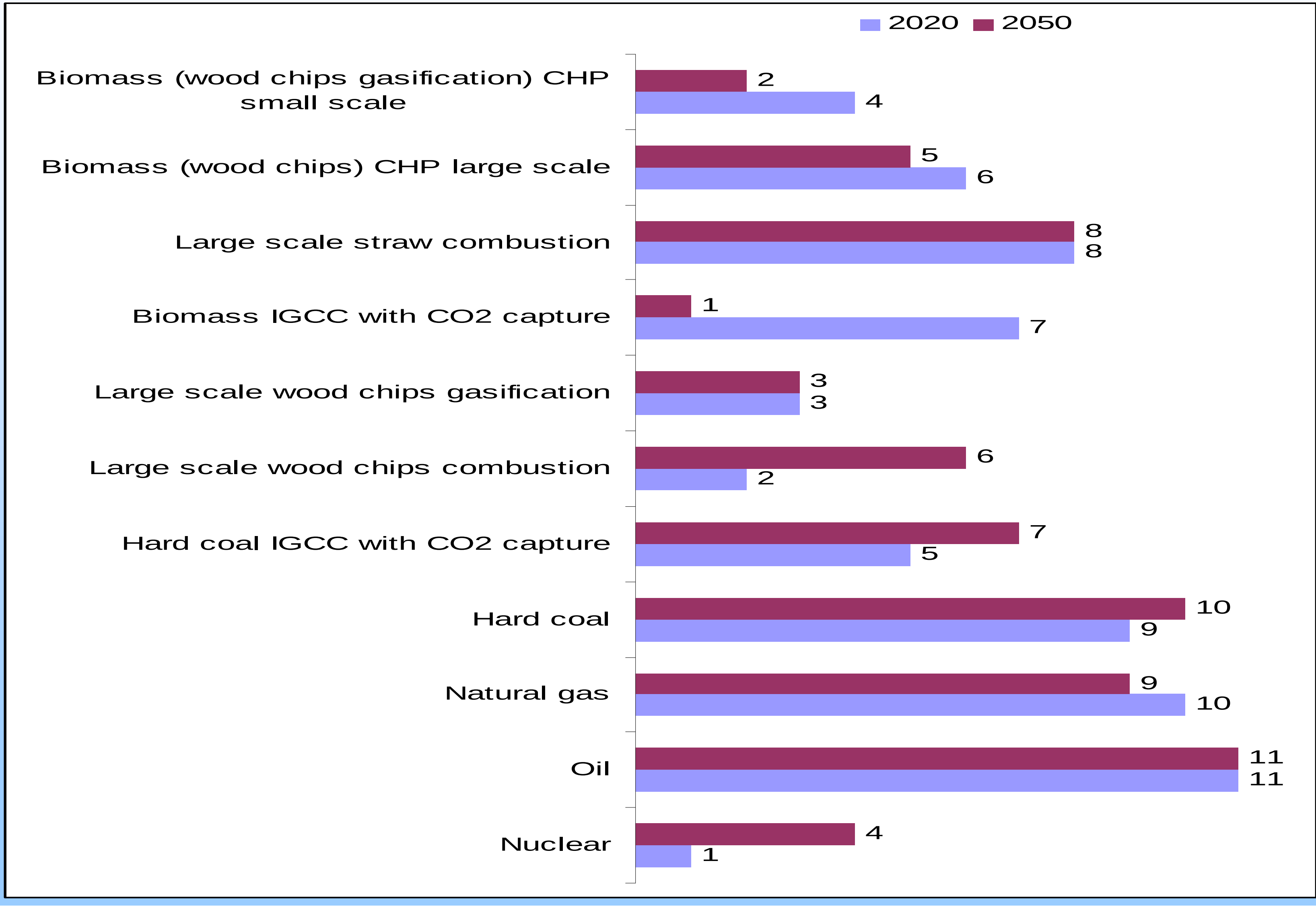
# The average and range of social costs of transport technologies in 2020 for SC1-3p2



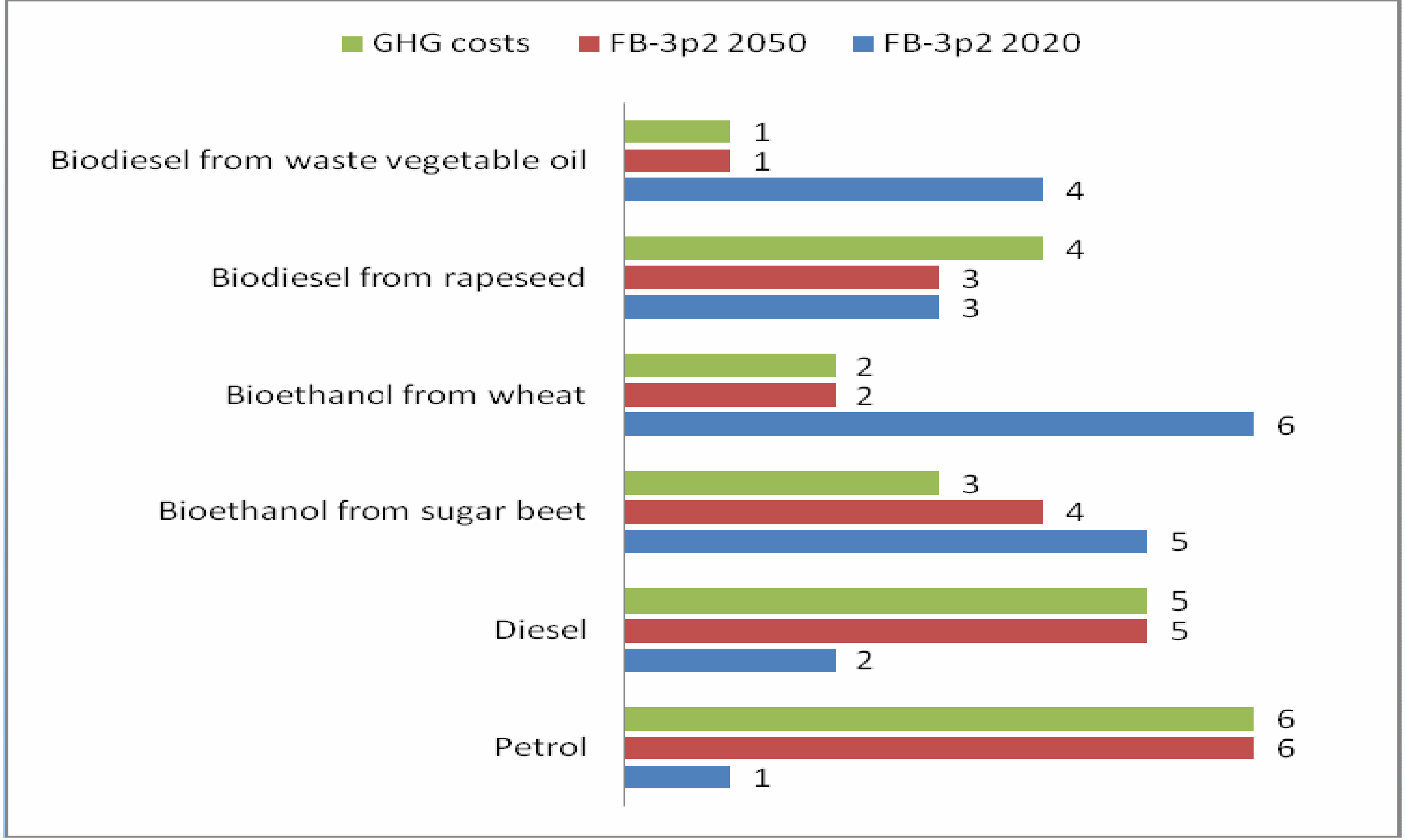
# The average and range of total costs of transport technologies in 2050 for SC1-3p2



# Ranking technologies in power sector based on total costs in 2020 and 2050 for the first best scenario FB-3p2



# Ranking of transport technologies based on total costs and external costs in 2020 and 2050 according FB-3p2 scenario



# Results and findings

The assessment of the main selected power and transport technologies based on external costs of GHG emissions and total costs was performed in 2020 and 2050 for the first best (FB-3p2) and second best scenarios (SC1-3p2; SC2-3p2). Scenarios with more strict targets (3.2 M/m2) were selected for technologies assessment.

11 main future electricity generation technologies were selected: nuclear, oil, natural gas, hard coal including hard coal technologies with CO2 capture and various biomass technologies (wood chips combustion, gasification, CHP, straw combustion, biomass IGCC with CO2 capture).

6 main transport technologies based on different fuels were selected: petrol, diesel, bioethanol from sugar beet and from wheat, biodiesel from rape seed and vegetable oil.

The most competitive technology according all policy scenarios based on external GHG costs in 2020 and 2050 is biomass IGCC with CO2 capture biomass followed by other biomass technologies. Nuclear is ranked in the middle. In transport sector- biodiesel from vegetable oil and bioethanol from wheat.

# Results and findings for power sector

- Technologies ranking based on external GHG emission costs and total costs are similar for FB-3p2 scenario in 2050 because of very high carbon price (375 EUR/tCO2 eq) as external costs overweight impact on private costs in technologies ranking.
- The most expensive technology in terms of total costs for all main policy scenarios in 2020 and 2050 is oil. **The most competitive technology for all scenarios in 2020 is nuclear followed by large scale wood chips combustion technologies and in 2050 - biomass IGCC with CO2 capture followed by biomass wood chips gasification CHP small scale.**
- The ranking of biomass technologies based on total costs is different for specific scenarios and time frames and depends on carbon price obtained by specific scenarios. Very high carbon prices make more competitive technologies having low life cycle GHG emission such as biomass IGCC with CO2 capture and biomass wood chips gasification technologies though these technologies in terms of private costs are more expensive than other biomass technologies.

# Results and findings for transport

•The ranking of transport technologies based on total costs for the first best scenario in 2020 and 2050 provides opposite results. Because of high carbon price **in 2050 the petrol and diesel based transport technologies are ranked as the last attractive though in 2020 these transport technologies are ranked as the most competitive**. At the same time biodiesel from waste vegetable oil and bioethanol from wheat based technologies are the most competitive in 2050 though these technologies in 2020 were ranked as the least attractive.

• Because of very high carbon prices in 2050 in scenario FB-3p2 the ranking of transport technologies based on total costs and GHG emission costs are very similar but very different for all other policy scenarios especially in year 2020 where fuel costs are dominating in transport technologies ranking because of comparatively low carbon prices however in 2050 the carbon price is the main determinant in ranking. Especially FB-3p2 scenario provides the competitive advantage for low carbon transport technologies such as biodiesel and bioethanol.