Working Party on Economic and Environmental Policy Integration

INSTRUMENTS AND TECHNOLOGIES FOR CLIMATE CHANGE POLICY

ANNEX 3: AN INTEGRATED ENERGY AND MATERIALS SYSTEMS MODELLING APPROACH

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1. INTRODUCTION

The present study is initiated in the OECD ‘subsidies, taxes and resource pricing’ programme. The study is funded by the Dutch Ministry of Housing, Spatial Planning and the Environment. The four topics that are covered by the OECD sustainable development programme are integrated into this project. This volume is Annex 3 of the reporting which consists of four volumes:

Main report: Summary and policy recommendations.
Annex 1: Model characteristics and results on the aggregate energy and materials systems level, including intercontinental trade and the aggregated Western European energy and materials systems.
Annex 2: Sectoral results, including ancillary benefits of GHG emission reductions in terms of waste management.

Section 1 of this Annex gives a detailed listing of the demand categories and technical (improvement) options. Subsequently in Section 2, the technical options are allocated to the two policy frameworks as defined in the main report and in Annex 1. This allocation is based on the results of a workshop of an international panel of experts. Section 3 provides the proceedings of this workshop.

Demand categories

The definition of the ‘energy system’ and the ‘materials system’ is based on the final product service category. All process activities and emissions related to the demand categories in Table 1.1, are included in the category ‘energy system’. All processes and emissions related to the demand categories in Table 1.2, are included in the category ‘materials system’. For buildings and for road vehicles a split has been made between the direct energy use (which is considered to be part of the energy system) and the materials inputs and outputs (which are considered to be part of the materials system).
Table 1.1: Demand categories in the energy system

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD</td>
<td>Agricultural diesel demand</td>
</tr>
<tr>
<td>AE</td>
<td>Agricultural electricity demand</td>
</tr>
<tr>
<td>AG</td>
<td>Natural gas to agricultural sector</td>
</tr>
<tr>
<td>C0</td>
<td>North Eur. Service sect. Space heat</td>
</tr>
<tr>
<td>C1</td>
<td>Middle Eur. Service sect. Small building</td>
</tr>
<tr>
<td>C2</td>
<td>Middle Eur. Service sect. Large building</td>
</tr>
<tr>
<td>C3</td>
<td>South Eur. Service sect. Space heat</td>
</tr>
<tr>
<td>CE</td>
<td>Commercial other electricity demand</td>
</tr>
<tr>
<td>CG</td>
<td>Desks</td>
</tr>
<tr>
<td>I1</td>
<td>LTH(^1) large industry</td>
</tr>
<tr>
<td>I2</td>
<td>HTH(^2) large industry</td>
</tr>
<tr>
<td>I3</td>
<td>LTH small industry</td>
</tr>
<tr>
<td>I4</td>
<td>HTH small industry</td>
</tr>
<tr>
<td>I5</td>
<td>ELE large industry</td>
</tr>
<tr>
<td>I6</td>
<td>ELE small industry</td>
</tr>
<tr>
<td>RA</td>
<td>Water heating - North Europe</td>
</tr>
<tr>
<td>RB</td>
<td>Water heating - Middle Europe</td>
</tr>
<tr>
<td>RC</td>
<td>Water heating - South Europe</td>
</tr>
<tr>
<td>RD</td>
<td>Dishwashers</td>
</tr>
<tr>
<td>RE</td>
<td>Other existing electric appliances</td>
</tr>
<tr>
<td>RF</td>
<td>Food preparation</td>
</tr>
<tr>
<td>RL</td>
<td>Lighting</td>
</tr>
<tr>
<td>RN</td>
<td>Other new electric appliances</td>
</tr>
<tr>
<td>RW</td>
<td>Washing machines</td>
</tr>
<tr>
<td>T3</td>
<td>Bus</td>
</tr>
<tr>
<td>T4</td>
<td>Rail Transport</td>
</tr>
<tr>
<td>T5</td>
<td>Water Transport Inland</td>
</tr>
<tr>
<td>T6</td>
<td>Air Transport</td>
</tr>
<tr>
<td>T7</td>
<td>Bunkers</td>
</tr>
</tbody>
</table>

---

1  LTH Low Temperature Heat.
2  HTH High Temperature Heat.
<table>
<thead>
<tr>
<th>FB</th>
<th>Beer</th>
</tr>
</thead>
<tbody>
<tr>
<td>FD</td>
<td>Dairy products</td>
</tr>
<tr>
<td>FE</td>
<td>Eggs and egg products</td>
</tr>
<tr>
<td>FF</td>
<td>Flour products</td>
</tr>
<tr>
<td>FG</td>
<td>Fruit</td>
</tr>
<tr>
<td>FM</td>
<td>Meat/fish</td>
</tr>
<tr>
<td>FO</td>
<td>Oil for food</td>
</tr>
<tr>
<td>FS</td>
<td>Sugar products</td>
</tr>
<tr>
<td>FM</td>
<td>Vegetables and melons</td>
</tr>
<tr>
<td>FW</td>
<td>Wool</td>
</tr>
<tr>
<td>IA</td>
<td>Residual Aluminium</td>
</tr>
<tr>
<td>IB</td>
<td>Residual Bricks</td>
</tr>
<tr>
<td>IC</td>
<td>Residual Chlorine</td>
</tr>
<tr>
<td>ID</td>
<td>Residual Glass</td>
</tr>
<tr>
<td>IK</td>
<td>Residual Sodium chloride</td>
</tr>
<tr>
<td>IM</td>
<td>Machinery</td>
</tr>
<tr>
<td>IP</td>
<td>Residual Polyolefins</td>
</tr>
<tr>
<td>IR</td>
<td>Residual Ammonia</td>
</tr>
<tr>
<td>IS</td>
<td>Residual Petrochemicals</td>
</tr>
<tr>
<td>IU</td>
<td>Residual Cement clinker</td>
</tr>
<tr>
<td>IV</td>
<td>Residual Paper</td>
</tr>
<tr>
<td>IX</td>
<td>Residual Sawn wood (15% H2O)</td>
</tr>
<tr>
<td>IY</td>
<td>Tyres [Mt]</td>
</tr>
<tr>
<td>IZ</td>
<td>Capital equipment</td>
</tr>
<tr>
<td>JR</td>
<td>Electr./telecomm. wire [Mt copp. wire equiv.]</td>
</tr>
<tr>
<td>JS</td>
<td>Pipes and ducts [Mt PVC equiv.]</td>
</tr>
<tr>
<td>JT</td>
<td>Window frames [1000 million frames]</td>
</tr>
<tr>
<td>JV</td>
<td>Cellars [100 million m²]</td>
</tr>
<tr>
<td>KA</td>
<td>Industrial pressure vessels [pcs]</td>
</tr>
<tr>
<td>KB</td>
<td>Nuts, bolts, nails etc. [Mt steel equiv]</td>
</tr>
<tr>
<td>KC</td>
<td>Pipelines [Mt steel equiv]</td>
</tr>
<tr>
<td>P1</td>
<td>Beverages, carbonated [Gl]</td>
</tr>
<tr>
<td>P2</td>
<td>Beverages, non-carbonated [Gl]</td>
</tr>
<tr>
<td>P3</td>
<td>Dairy products, no milk [Mt]</td>
</tr>
<tr>
<td>P4</td>
<td>Wet food [Gl]</td>
</tr>
<tr>
<td>P5</td>
<td>Dry food, non-susceptible [Gl]</td>
</tr>
<tr>
<td>P6</td>
<td>Dry food, susceptible [Gl]</td>
</tr>
<tr>
<td>P7</td>
<td>Non-food liquids [Gl]</td>
</tr>
<tr>
<td>P8</td>
<td>Dry non-food [Gl]</td>
</tr>
<tr>
<td>P9</td>
<td>Carrier bags [10^9 bags]</td>
</tr>
<tr>
<td>PA</td>
<td>Industrial bags [Mt]</td>
</tr>
<tr>
<td>PB</td>
<td>Transport packaging [Gl]</td>
</tr>
<tr>
<td>PC</td>
<td>Pallet wrapping [10^9 trip units]</td>
</tr>
<tr>
<td>R1</td>
<td>SFD³ use – North Europe</td>
</tr>
<tr>
<td>R2</td>
<td>MFD⁴ use – North Europe</td>
</tr>
<tr>
<td>R3</td>
<td>SFD use – Middle Europe existing</td>
</tr>
<tr>
<td>R4</td>
<td>MFD use – Middle Europe</td>
</tr>
<tr>
<td>R5</td>
<td>SFD use – Middle Europe new type 1</td>
</tr>
<tr>
<td>R6</td>
<td>SFD use – South Europe</td>
</tr>
<tr>
<td>R7</td>
<td>MFD use – South Europe</td>
</tr>
<tr>
<td>R8</td>
<td>SFD use – Middle Europe new type 2</td>
</tr>
<tr>
<td>RJ</td>
<td>Industrial/agricultural buildings type 1</td>
</tr>
<tr>
<td>RK</td>
<td>Industrial/agricultural buildings type 2</td>
</tr>
</tbody>
</table>

---

1. SFD Single Family Dwellings.
2. MFD Multi Family Dwellings.
Table 1.2: Demand categories in the materials system

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>Outside wall cladding [1000 million m²]</td>
</tr>
<tr>
<td>RO</td>
<td>Solid food containers</td>
</tr>
<tr>
<td>RP</td>
<td>Furniture (chests)</td>
</tr>
<tr>
<td>RQ</td>
<td>Appliance materials use dummy</td>
</tr>
<tr>
<td>RR</td>
<td>Refrigerators and freezers</td>
</tr>
<tr>
<td>RT</td>
<td>Tumble driers</td>
</tr>
<tr>
<td>RU</td>
<td>Textiles (excl. cotton)</td>
</tr>
<tr>
<td>RV</td>
<td>Floor cladding [1000 million m²]</td>
</tr>
<tr>
<td>RX</td>
<td>Compost</td>
</tr>
<tr>
<td>RZ</td>
<td>Interior wall cladding [1000 million m²]</td>
</tr>
<tr>
<td>T0</td>
<td>Passenger car</td>
</tr>
<tr>
<td>T1</td>
<td>Van</td>
</tr>
<tr>
<td>T2</td>
<td>Truck</td>
</tr>
<tr>
<td>TH</td>
<td>High volume roads</td>
</tr>
<tr>
<td>TL</td>
<td>Low volume roads</td>
</tr>
<tr>
<td>TR</td>
<td>Railway tracks</td>
</tr>
<tr>
<td>TS</td>
<td>Waterworks (THW⁵ equivalents)</td>
</tr>
<tr>
<td>TU</td>
<td>Pallets (1000 million pcs)</td>
</tr>
</tbody>
</table>

5 THW Tropical HardWood.
Table 1.3: Product service demand trends in the MATTER model (index)

<table>
<thead>
<tr>
<th>Code</th>
<th>Product service</th>
<th>Unit</th>
<th>1990</th>
<th>2020</th>
<th>2050</th>
<th>Contribution 2030 (Mt CO₂ equiv.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0/1/2/3</td>
<td>Service sector buildings</td>
<td>[m²]</td>
<td>100</td>
<td>147</td>
<td>164</td>
<td>629</td>
</tr>
<tr>
<td>R1/5/6/8</td>
<td>Single family dwellings (2 types)</td>
<td>[m²]</td>
<td>100</td>
<td>122</td>
<td>128</td>
<td></td>
</tr>
<tr>
<td>R2/4/7</td>
<td>Multi family dwellings</td>
<td>[m²]</td>
<td>100</td>
<td>160</td>
<td>228</td>
<td></td>
</tr>
<tr>
<td>R4</td>
<td>Industrial/agricultural buildings type 1</td>
<td>[m²]</td>
<td>100</td>
<td>109</td>
<td>119</td>
<td></td>
</tr>
<tr>
<td>R5</td>
<td>Industrial/agricultural buildings type 2</td>
<td>[m²]</td>
<td>100</td>
<td>108</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>Beverages, carbonated</td>
<td>[10^9 litres]</td>
<td>100</td>
<td>117</td>
<td>131</td>
<td>127</td>
</tr>
<tr>
<td>P2</td>
<td>Beverages, non-carbonated</td>
<td>[10^9 litres]</td>
<td>100</td>
<td>120</td>
<td>139</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>Dairy products, no milk</td>
<td>[10^9 litres]</td>
<td>100</td>
<td>132</td>
<td>163</td>
<td></td>
</tr>
<tr>
<td>P4</td>
<td>Wet food</td>
<td>[10^9 litres]</td>
<td>100</td>
<td>152</td>
<td>204</td>
<td></td>
</tr>
<tr>
<td>P5</td>
<td>Dry food, non-susceptible</td>
<td>[10^9 litres]</td>
<td>100</td>
<td>112</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>P6</td>
<td>Dry food, susceptible</td>
<td>[10^9 litres]</td>
<td>100</td>
<td>152</td>
<td>204</td>
<td></td>
</tr>
<tr>
<td>P7</td>
<td>Non-food liquids</td>
<td>[10^9 litres]</td>
<td>100</td>
<td>151</td>
<td>203</td>
<td></td>
</tr>
<tr>
<td>P8</td>
<td>Dry non-food</td>
<td>[10^9 litres]</td>
<td>100</td>
<td>111</td>
<td>123</td>
<td></td>
</tr>
<tr>
<td>P9</td>
<td>Cameer bags</td>
<td>[10^9 bags]</td>
<td>100</td>
<td>115</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>PA</td>
<td>Industrial bags</td>
<td>[Mt]</td>
<td>100</td>
<td>157</td>
<td>213</td>
<td></td>
</tr>
<tr>
<td>PB</td>
<td>Transport packaging</td>
<td>[10^9 litres]</td>
<td>100</td>
<td>142</td>
<td>185</td>
<td></td>
</tr>
<tr>
<td>PC</td>
<td>Pallet wrapping</td>
<td>[10^9 trp units]</td>
<td>100</td>
<td>175</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>TU</td>
<td>Pallets</td>
<td>[10^9 pieces]</td>
<td>100</td>
<td>125</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>T9</td>
<td>Passenger car (2 types)</td>
<td>[pieces]</td>
<td>100</td>
<td>144</td>
<td>193</td>
<td>1207</td>
</tr>
<tr>
<td>T1</td>
<td>Van</td>
<td>[pieces]</td>
<td>100</td>
<td>123</td>
<td>131</td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>Truck</td>
<td>[pieces]</td>
<td>100</td>
<td>138</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>IA</td>
<td>Residual aluminium</td>
<td>[Mt]</td>
<td>100</td>
<td>134</td>
<td>150</td>
<td>215</td>
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<tr>
<td>IB</td>
<td>Residual bricks</td>
<td>[Mt]</td>
<td>100</td>
<td>50</td>
<td>50</td>
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<tr>
<td>IC</td>
<td>Residual chlorine</td>
<td>[Mt]</td>
<td>100</td>
<td>71</td>
<td>71</td>
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<tr>
<td>ID</td>
<td>Residual glass</td>
<td>[Mt]</td>
<td>100</td>
<td>267</td>
<td>300</td>
<td></td>
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<tr>
<td>IK</td>
<td>Residual sodium chloride</td>
<td>[Mt]</td>
<td>100</td>
<td>106</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td>IM</td>
<td>Machinery</td>
<td>[pieces]</td>
<td>100</td>
<td>110</td>
<td>119</td>
<td></td>
</tr>
<tr>
<td>IS</td>
<td>Residual petrochemicals</td>
<td>[Mt]</td>
<td>100</td>
<td>155</td>
<td>175</td>
<td></td>
</tr>
<tr>
<td>IT</td>
<td>Capital equipment</td>
<td>[pieces]</td>
<td>100</td>
<td>115</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>IR</td>
<td>Fertilisers</td>
<td>[Mt]</td>
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<td>120</td>
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<td>150</td>
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<tr>
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<td>Residual paper</td>
<td>[Mt]</td>
<td>100</td>
<td>186</td>
<td>200</td>
<td>53</td>
</tr>
<tr>
<td>N1</td>
<td>Non Energy Use: Lubricants + Bitumen</td>
<td>[PJ]</td>
<td>100</td>
<td>100</td>
<td>100</td>
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</tr>
<tr>
<td>CG</td>
<td>Desks</td>
<td>[pieces]</td>
<td>100</td>
<td>134</td>
<td>175</td>
<td>33</td>
</tr>
<tr>
<td>JS</td>
<td>Pipes and ducts</td>
<td>[Mt PVC equiv.]</td>
<td>100</td>
<td>175</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>JT</td>
<td>Window frames</td>
<td>[10^9 frames]</td>
<td>100</td>
<td>119</td>
<td>138</td>
<td></td>
</tr>
<tr>
<td>JV</td>
<td>Cellars</td>
<td>[10^9 m²]</td>
<td>100</td>
<td>119</td>
<td>137</td>
<td></td>
</tr>
<tr>
<td>RM</td>
<td>Outside wall cladding</td>
<td>[10^9 m²]</td>
<td>100</td>
<td>138</td>
<td>175</td>
<td></td>
</tr>
<tr>
<td>RV</td>
<td>Floor cladding</td>
<td>[10^9 m²]</td>
<td>100</td>
<td>125</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>RZ</td>
<td>Interior wall cladding</td>
<td>[10^9 m²]</td>
<td>100</td>
<td>125</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>SU</td>
<td>Residual cement clinker</td>
<td>[Mt]</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>49</td>
</tr>
<tr>
<td>IX</td>
<td>Residual sawn wood</td>
<td>[Mt]</td>
<td>100</td>
<td>138</td>
<td>144</td>
<td></td>
</tr>
<tr>
<td>JR</td>
<td>Electricity / telecomm. wire</td>
<td>[Mt copper wire equiv.]</td>
<td>100</td>
<td>121</td>
<td>143</td>
<td>203</td>
</tr>
<tr>
<td>KA</td>
<td>Industrial pressure vessels</td>
<td>[pieces]</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>KB</td>
<td>Nuts, bolts, nails, etc.</td>
<td>[Mt steel equiv.]</td>
<td>100</td>
<td>119</td>
<td>138</td>
<td></td>
</tr>
<tr>
<td>KC</td>
<td>Pipeline</td>
<td>[Mt steel equiv.]</td>
<td>100</td>
<td>138</td>
<td>175</td>
<td></td>
</tr>
<tr>
<td>RP</td>
<td>Furniture (chests)</td>
<td>[pieces]</td>
<td>100</td>
<td>113</td>
<td>125</td>
<td>113</td>
</tr>
<tr>
<td>RQ</td>
<td>Appliance materials use dummy</td>
<td>[pieces]</td>
<td>100</td>
<td>125</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>RU</td>
<td>Textiles (excl. cotton)</td>
<td>[Mt]</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>RX</td>
<td>Compost</td>
<td>[Mt]</td>
<td>100</td>
<td>125</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>TH</td>
<td>High-volume roads</td>
<td>[m²]</td>
<td>100</td>
<td>137</td>
<td>175</td>
<td>20</td>
</tr>
<tr>
<td>TL</td>
<td>Low-volume roads</td>
<td>[m²]</td>
<td>100</td>
<td>113</td>
<td>118</td>
<td></td>
</tr>
<tr>
<td>TR</td>
<td>Railway tracks</td>
<td>[km]</td>
<td>100</td>
<td>121</td>
<td>143</td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>Waterworks</td>
<td>[Mt THW equivalents]</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

The levels of demand for these categories are determined by applying the rate of economic growth for the economy, taken demand elasticities and relative price changes due to GHG-policies into account. Table 1.3 provides an overview of demand trends and the relevance of demand categories for the total GHG emissions, calculated with MARKAL including all upstream and downstream emissions. The figures indicate that buildings and transportation are the two main categories. In comparison, 1990 emissions amounted to 4250 Mt CO₂ eq for the whole of Western Europe. Note that Table 1.3 covers only demand categories with materials relevance (e.g. lighting is excluded, see Table 1.2).
2. TECHNICAL (IMPROVEMENT) OPTIONS (TOS)

The following tables provide an overview of technical options (processes) that are included in MATTER 3.0. They are split into the economic sectors that have been discussed in Annex 2.

- electricity production (section 2.1)
- transportation sector (section 2.2)
- refineries (section 2.3)
- industrial sector (section 2.4)
- residential sector (section 2.5)
- commercial sector (section 2.6)
- agriculture (section 2.7)
- waste (section 2.8)

The processes are further grouped in the basis of the MARKAL coding convention. All processes have a code consisting of 3 characters. All competing processes have the same first two characters. The first character is indicative of the sector (C = commercial; E = electricity generation; I = industry; R = residential; T = transport). However because the number of processes exceeds the number of characters, this coding practice could not always be followed strictly.

The TOs have been split into three groups:

- E: existing and widely applied (reference processes) that entail TOs that are cost saving at prevailing prices and are gradually replacing installed technologies, except for the case that the total capacity of the TO is subject to political bounds (e.g. nuclear energy). They are part of the base case scenario (column 2).

All other TOs are eligible for being selected in all the least cost combinations of options that satisfy the GHG targets. So all of them can become part of the I or C scenarios. The TOs are subdivided into (see also Chapter 3):

- TOs that are not considered in case the policy-continuation (C) framework is applied because they would result in significant cost increases for those exposed (industrial) sectors. Also this category includes TOs that imply new technology whose success is uncertain and thus cannot be prescribed. These ‘no cost-increase’ TOs are labelled ‘N’ (column 3).

- TOs that are considered in case the policy-continuation (C) framework is applied, because they are (also) applied in the sheltered sectors (where cost increase cannot result in carbon leakage or negative impacts on economic activity) are labelled ‘Y’ (column 4).
The category ‘E’ (Existing) has been added because the model needs at least one feasible chain of processes in order to come up with a feasible solution. Therefore some technologies have been inserted that are already more or less in full use. Processes in the category E are available in all model runs.

TOs may be bounded, because of various reasons like land availability (in case of biomass TOs), or geographical constraints (e.g. the production of hydro power). A small ‘b’ indicates whether such bounds are applied (column 5).

A number of TOs are part of a chain of processes and therefore should be considered as a part of such a chain. For example, in the materials system, the model includes the production of a new aluminium car frame and its use as two different TOs. In such cases both TOs must be allocated to the same category, although — in theory — they can belong to different categories. In order to avoid such conflicting allocations, only the production of aluminium car frames has been considered in the following list. As a consequence the listing below is a subset of the set of all TOs, included in the model database.

Certain options have been defined separately for the three regions north, middle and southern Europe. North includes Scandinavia (Denmark, Finland, Iceland, Norway and Sweden). Middle includes Austria, Belgium, France, Germany, Luxembourg, Netherlands, Switzerland and the UK. South includes Greece, Italy, Spain and Portugal. This split has been applied for technologies where climate conditions are important for the techno-economic assessment (PV, biomass production, residential and commercial heating, cooling).

The last column (6) in the following tables indicates the additional transaction costs in case of the application of regulation instead of price-based instruments. The additional costs are expressed as the relative increase of the price per unit of physical product (see Annex 1 for a discussion of transaction costs). For example, a 10% price increase of the biomass gasifier/STAG power plant BE2 in Table 2.1.1 indicates that the price of the electricity output in the base case increases by 10% if regulation alone is applied as a policy instrument.

2.1 Electricity production

GHG emissions of centralised power plants can be reduced by both regulatory approaches and price-based instruments. Under the C scenarios, such TOs are assumed to incur assuming additional transaction costs (compared with the I scenarios). The total capacity of nuclear power plants is assumed not to exceed current Western European capacity.
### Table 2.1.1: Centralised Power Plants [1]

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE2 Biomass gasifier/STAG(^6) power plant</td>
<td>N</td>
<td>b</td>
<td>Y</td>
<td>b</td>
<td>10</td>
</tr>
<tr>
<td>BE3 Biomass gasifier/dedicated STAG</td>
<td>Y</td>
<td>b</td>
<td>Y</td>
<td>b</td>
<td>10</td>
</tr>
<tr>
<td>BE4 Biomass gasifier/SOFC(^7)</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EC4 New pulverised coal power plant</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EC5 Integrated coal gasification power plant</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EC6 New lignite fired power plant</td>
<td>Y</td>
<td>b</td>
<td>Y</td>
<td>b</td>
<td>10</td>
</tr>
<tr>
<td>EC7 Integrated lignite gasification power plant</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ED1 New oil fired power plant</td>
<td>N</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EG3 New STAG gas fired power plant</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EH0 Medium and high head hydro</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EH1 Low head hydro</td>
<td>N</td>
<td>b</td>
<td>N</td>
<td>b</td>
<td>-</td>
</tr>
<tr>
<td>EH2 Hydro pumped storage</td>
<td>N</td>
<td>b</td>
<td>N</td>
<td>b</td>
<td>-</td>
</tr>
<tr>
<td>EH3 Hydro pumped storage (more expensive)</td>
<td>N</td>
<td>b</td>
<td>N</td>
<td>b</td>
<td>-</td>
</tr>
<tr>
<td>EH4 Hydro Iceland for Aluminium smelters</td>
<td>N</td>
<td>b</td>
<td>N</td>
<td>b</td>
<td>-</td>
</tr>
<tr>
<td>EN0 LWR(^8) nuclear power plant</td>
<td>N</td>
<td>b</td>
<td>N</td>
<td>b</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2.1.2: Decentralised electricity production (new renewables) [1]

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES1 Solar PV(^9) in Middle Europe</td>
<td>Y</td>
<td>b</td>
<td>Y</td>
<td>b</td>
<td>30</td>
</tr>
<tr>
<td>ES2 Solar PV in South Europe</td>
<td>Y</td>
<td>b</td>
<td>Y</td>
<td>b</td>
<td>30</td>
</tr>
<tr>
<td>ES3 Solar PV from South Europe for rest Europe</td>
<td>Y</td>
<td>b</td>
<td>Y</td>
<td>b</td>
<td>30</td>
</tr>
<tr>
<td>ET1 Geothermal energy</td>
<td>Y</td>
<td>b</td>
<td>Y</td>
<td>b</td>
<td>-</td>
</tr>
<tr>
<td>EW4 Large onshore wind turbine</td>
<td>Y</td>
<td>b</td>
<td>Y</td>
<td>b</td>
<td>-</td>
</tr>
<tr>
<td>EW5 Large onshore wind turbine/storage</td>
<td>Y</td>
<td>b</td>
<td>Y</td>
<td>b</td>
<td>-</td>
</tr>
<tr>
<td>EW6 Large offshore wind turbine/storage</td>
<td>Y</td>
<td>b</td>
<td>Y</td>
<td>b</td>
<td>-</td>
</tr>
</tbody>
</table>

PV electricity production have been given additional transaction costs if applied under the C scenarios, because they affect thousands of owners or users, so regulation seems to be complicated and laborious.

In the model calculations, all renewables have been included in the C scenarios and are part of the (costly) EU policy targets regarding the share of renewables in total energy production. Because of their high costs they become part of the I scenarios only at high penalty levels.

The feasibility of industrial CHP is highly dependent on local conditions. So if regulatory approaches were applied they would be costly or ineffective or—probably—both.

---

6 STAG Steam and Gas Combined Cycle.
7 SOFC Solid Oxide Fuel Cell.
8 LWR Light Water Reactor.
9 PV PhotoVoltaics.
Table 2.1.3: Decentralised electricity production, industrial combined heat and power generation [1,2]

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD1 Lignine boiler/large ind. CHP</td>
<td>E</td>
<td>b</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BD2 Lignine gasifier/large ind. CHP</td>
<td>N</td>
<td>b</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BE1 Wood gasification/small ind. CHP</td>
<td>N</td>
<td>b</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECA Coal FBC CHP plant</td>
<td>N</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGD New gas turbine CHP plant</td>
<td>N</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGE New STAG CHP plant</td>
<td>N</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGF New gas engine generator set</td>
<td>N</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGG SOFC/gas turbine combination</td>
<td>N</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CO₂ removal and underground storage can be applied for large centralised power production. The technology is not yet applied on a large scale, but experiences with enhanced oil recovery suggest that no major technological problems exist.

Table 2.1.4: CO₂ removal and storage, centralised electricity production

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQB CO removal/storage IGCC</td>
<td>N</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SQD CO₂ removal/storage gas fired STAG</td>
<td>N</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2 Transportation sector

The selection of vehicle engine concepts and transportation fuels is at present subject to regulatory approaches (voluntary agreements) as well as price-based instruments (fuels taxes). More efficient engines are likely to be more efficiently produced by price-based instruments than regulatory approaches. Therefore they have been given additional transaction costs as soon as they were incorporated in the C scenarios. (It is unclear which concept has the highest environmental and economic benefits and it is still unclear which concept will become the dominant one during the next decades. As a consequence, regulation may very well lead to the wrong choices. Unfortunately this cannot be modelled. The costs of such 'mistakes' are simulated by higher assumed transaction costs only.)

10 CHP Combined Heat and Power generation.
11 FBC Fluid Bed Combustion.
12 IGCC Integrated Coal Gasification Combined Cycle.
Table 2.2.1: Road vehicle engines/fuels [3]

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>T01</td>
<td>Gasoline car partly IIC(^{13})</td>
<td>Y</td>
<td>b</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>T02</td>
<td>Gasoline car IIC</td>
<td>Y</td>
<td>b</td>
<td>10</td>
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</tr>
<tr>
<td>T03</td>
<td>Diesel car partly IIC</td>
<td>Y</td>
<td>b</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>T04</td>
<td>Diesel car IIC</td>
<td>Y</td>
<td>b</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>T05</td>
<td>Hydrogen fuel cell car RB</td>
<td>Y</td>
<td>b</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>T06</td>
<td>Methanol car IIC</td>
<td>Y</td>
<td>b</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>T07</td>
<td>Ethanol car IIC</td>
<td>Y</td>
<td>b</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>T08</td>
<td>Electric car mid term RB(^{14})</td>
<td>Y</td>
<td>b</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>T09</td>
<td>Electric car long term RB</td>
<td>Y</td>
<td>b</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>T0A</td>
<td>Ethanol car partly IIC</td>
<td>Y</td>
<td>b</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>T0D</td>
<td>Diesel standard car</td>
<td>E</td>
<td>b</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>T0E</td>
<td>Electric car short term RB</td>
<td>Y</td>
<td>b</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>T0F</td>
<td>Hydrogen fuel cell car</td>
<td>Y</td>
<td>b</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>T0G</td>
<td>Gasoline car standard</td>
<td>E</td>
<td>b</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>T0M</td>
<td>Methanol car partly IIC</td>
<td>Y</td>
<td>b</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>T11</td>
<td>Diesel van, IIC</td>
<td>Y</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T12</td>
<td>Diesel van, IIC, CVT(^{15})</td>
<td>Y</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T13</td>
<td>Gasoline van, IIC</td>
<td>Y</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T14</td>
<td>Gasoline van, IIC, CVT</td>
<td>Y</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T15</td>
<td>Hydrogen fuel cell van, RB</td>
<td>Y</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T16</td>
<td>Electric van, mid term, RB</td>
<td>Y</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T17</td>
<td>Electric van, long term, RB</td>
<td>Y</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T18</td>
<td>Hybrid van, RB, CVT</td>
<td>Y</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1D</td>
<td>Diesel van, standard</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1E</td>
<td>Electric van, short term, RB</td>
<td>Y</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1F</td>
<td>Hydrogen fuel cell van</td>
<td>Y</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1G</td>
<td>Gasoline van, standard</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1H</td>
<td>Hybrid van, RB</td>
<td>Y</td>
<td>30</td>
<td></td>
<td></td>
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<tr>
<td>T21</td>
<td>Diesel truck with IIC</td>
<td>Y</td>
<td>10</td>
<td></td>
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<tr>
<td>T22</td>
<td>Diesel truck with MF and IIC</td>
<td>Y</td>
<td>10</td>
<td></td>
<td></td>
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<tr>
<td>T23</td>
<td>Diesel truck with MF, IIC and CVT</td>
<td>Y</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T33</td>
<td>Electric bus long term with MF and RB</td>
<td>Y</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3D</td>
<td>Diesel bus standard</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3E</td>
<td>Electric bus mid term with MF and RB</td>
<td>Y</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3F</td>
<td>Fuel Cell bus with MF and RB</td>
<td>Y</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T4D</td>
<td>Diesel rail transport</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T4E</td>
<td>Electric rail transport</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T5D</td>
<td>Diesel inland ships</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T5F</td>
<td>Hydrogen inland ships</td>
<td>E</td>
<td>30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{13}\) IIC Improved Internal Combustion.

\(^{14}\) RB Regenerative Braking.

\(^{15}\) CVT Continuous Variable Transmission.

\(^{16}\) MF Modified Frame.
Table 2.2.2: Transportation infrastructure [4]

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>Transaction costs under the C scenarios [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH1 Asphalt high volume roads</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>TH2 Concrete high volume roads</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>TL1 Asphalt low volume roads</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>TR1 Use concrete railway tracks</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>TR2 Use wood railway tracks</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>TS1 Use THW¹⁷ waterworks</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>TS2 Use steel waterworks</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>TS3 Use concrete waterworks</td>
<td>Y</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

2.3 Refineries

Refineries are basically large industries where regulation could be applied, since the number of actors is rather limited. However, the CO₂ impact of TOs depends on the energy source that is applied (e.g. biocrude or regular crude, methanol from natural gas or methanol from biomass). Moreover, the integration of refineries, petrochemical industries and the transportation sector and the co-production of many oil products can result in unexpected consequences if the regulatory approaches are not very detailed and updated frequently. As a consequence, price based instruments seem a more appropriate mechanism and some additional transaction costs are assumed, in case regulatory instruments are assumed in the scenarios.

Table 2.3.1: Refineries, current concepts [5]

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
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<th>(4)</th>
<th>(5)</th>
<th>Transaction costs under the C scenarios [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCR Catalytic reformer</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OFC Fluid catalytic cracker</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OFX Flexi coker</td>
<td>Y</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OHI Refinery heavy crude</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OHC Hydrocracker</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OHF Hydrocracker for fuel oil</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OHY Hycon</td>
<td>Y</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OLI Refinery light crude</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OME Methanol from natural gas</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>OVS Visbreaker</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>INW MTBE¹⁸ production</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>IWA Asphalt production</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>JIB Lubricants from refinery</td>
<td>E</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

¹⁷ THW Tropical HardWood.

¹⁸ MTBE MethylTertiaryButylEther.
Table 2.3.2: Refineries, recovery of petrochemical feedstocks

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>Transaction costs under the C scenarios [%]</th>
</tr>
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<tbody>
<tr>
<td>ROZ Butylene recovery from refineries</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>SRU Benzene recovery from refineries</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>SRV Xylene recovery from refineries</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>25</td>
</tr>
</tbody>
</table>

Table 2.3.3: Refineries, addition of biofuels

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
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<th>(4)</th>
<th>(5)</th>
<th>Transaction costs under the C scenarios [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBA Ethanol addition to gasoline</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>SBB Methanol addition to gasoline</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
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</tbody>
</table>

Table 2.3.4: Refineries, production of hydrogen

<table>
<thead>
<tr>
<th>(1)</th>
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<th>(4)</th>
<th>(5)</th>
<th>Transaction costs under the C scenarios [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SXA Hydrogen production from natural gas</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>SXB Hydrogen production from fuel oil</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>SXC Hydrogen production from petrookes</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>SXD Hydrogen production from electricity</td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

Both biofuels and hydrogen can be gradually introduced into the transportation system through integration with the existing refinery production. It is still unclear which concept is the best and the application of price-based instruments seem to be the most appropriate. Both types of TOs are assumed to affect the sheltered sectors, hence cost increases will be passed on.

2.4 Industrial sector

Both emission reduction options and the emission sources are very diverse. This would lead to very high transaction costs, should governments opt for regulatory approaches.

The technological feasibility of many separately modelled new technologies is still uncertain (e.g. inert anodes in aluminium smelters and CCF for iron production). Price-based instruments are to be preferred. In case of end-of-pipe technology for large industries (CO₂ removal, reduction N₂O emissions) —few actors.

For the building and construction industry decisions regarding insulation and materials selection are taken on a project basis. As a consequence the customer exerts considerable influence. The customer can be more influenced by regulation. Hence, these options have been allocated to both regulation and pricing.
<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1A</td>
<td>Gas boiler/LTH(^{19})/large industry</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I1B</td>
<td>Fuel oil boiler/LTH/large industry</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I1C</td>
<td>Coal boiler/LTH/large industry</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I1D</td>
<td>Hydrogen boiler/LTH/large industry</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I1E</td>
<td>Electric heatpump/LTH/large industry</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I1F</td>
<td>Heat exchanger/LTH/large industry</td>
<td>N</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>I2A</td>
<td>Gas burner/HTH(^{20})/large industry</td>
<td>N</td>
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</tr>
<tr>
<td>I2B</td>
<td>Fuel oil burner/HTH/large industry</td>
<td>E</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>I2C</td>
<td>Coal burner/HTH/large industry</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I2D</td>
<td>Hydrogen burner/HTH/large industry</td>
<td>N</td>
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<td></td>
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<tr>
<td>I2E</td>
<td>Electric heating/HTH/large industry</td>
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<tr>
<td>I2F</td>
<td>LPG(^{21}) burner/HTH/large industry</td>
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<tr>
<td>I3A</td>
<td>Gas boiler/LTH/small industry</td>
<td>E</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>I3B</td>
<td>Gas oil boiler/LTH/small industry</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I3C</td>
<td>Coal boiler/LTH/small industry</td>
<td>N</td>
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<td></td>
</tr>
<tr>
<td>I3D</td>
<td>Hydrogen boiler/LTH/small industry</td>
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<tr>
<td>I3E</td>
<td>Absorption heatpump/LTH/small industry</td>
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<td>I3F</td>
<td>Compression heatpump/LTH/small industry</td>
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<tr>
<td>I3H</td>
<td>Heat exchanger/LTH/small industry</td>
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<tr>
<td>I3T</td>
<td>Straw boiler/LTH/small industry</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>I3W</td>
<td>Wood boiler/LTH/small industry</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>I4A</td>
<td>Gas boiler/HTH/small industry</td>
<td>N</td>
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<td></td>
</tr>
<tr>
<td>I4B</td>
<td>Gas oil boiler/HTH/small industry</td>
<td>N</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>I4T</td>
<td>Straw boiler/HTH/small industry</td>
<td>N</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>I4W</td>
<td>Wood boiler/HTH/small industry</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I5A</td>
<td>Electric appliances&amp;light/ELE/large industry</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I5M</td>
<td>Electric drive/ELE/large industry</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I5N</td>
<td>Advanced Electric drive/ELE/large industry</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I6A</td>
<td>Electric appliances&amp;light/ELE/small industry</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I6M</td>
<td>Electric drive/ELE/small industry</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I6N</td>
<td>Advanced Electric drive/ELE/small industry</td>
<td>N</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

19 LTH Low Temperature Heat.
20 HTH High Temperature Heat.
21 LPG Liquified Petroleum Gas.
### Table 2.4.2: Non-ferrous metals production [6]

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>Transaction costs under theC scenarios [%]</th>
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</thead>
<tbody>
<tr>
<td>IAA Aluminium production Hall-Heroult</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAB Aluminium Hall-Heroult+point feeders</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAC Aluminium production inert anodes</td>
<td></td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAD Al Hall-Heroult+point feeders Iceland</td>
<td></td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAE Al production inert anodes Iceland</td>
<td></td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IAR Aluminium production recycling</td>
<td></td>
<td></td>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEA Copper production (concentrate to cathode)</td>
<td></td>
<td></td>
<td>E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEC Copper recycling (to cathode)</td>
<td></td>
<td></td>
<td>E</td>
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### Table 2.4.3: Ferrous metals production [6]

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
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<th>(4)</th>
<th>(5)</th>
<th>Transaction costs under theC scenarios [%]</th>
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</thead>
<tbody>
<tr>
<td>IG1 Continuous casting</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG2 Hot strip mill</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG3 Plate mill</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG4 Wire rod mill</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG5 Heavy section mill</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG6 Rebar mill</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG7 Cold rolling mill</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG8 CRC annealing &amp; tempering</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG9 CRC finishing &amp; packaging</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGA Iron prod. BF max coal injection</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>IGB Iron prod. COREX 23</td>
<td>N</td>
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<tr>
<td>IGD Coke oven</td>
<td>E</td>
<td></td>
<td></td>
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<tr>
<td>IGE Sponge iron prod. DRI</td>
<td>N</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGF/IGH/IGJ/IHC/IHE CO₂ removal/storage iron production</td>
<td>N</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>IGS Steel prod. hot rolling advanced</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGO Electro galvanizing</td>
<td>E</td>
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<td>IGP Hot dip galvanizing</td>
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<td></td>
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<tr>
<td>IGQ Steel prod. BOF + additional scrap</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGR Steel prod. scrap/EAF</td>
<td>E</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>IGS Steel prod. BOF</td>
<td>E</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGT Steel prod. DRI/EAF</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGV Sinter production</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGW Pellet production</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IHA Charcoal production for steel industry</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IHW Alloy steel preparation&amp;finishing</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IHX Cast iron production (Cupola)</td>
<td>E</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

22 CRC Cold Rolled Coil.
23 CCF Cyclone Converter Furnace.
24 DRI Direct Reduced Iron
25 BOF Basic Oxygen Furnace.
26 EAF Electric Arc Furnace.
### Table 2.4.4: Petrochemical olefins production [7]

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>Transaction costs under the C scenarios [%]</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IND Petroch. Naphtha cracker</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>INB Petroch. Gas oil cracker</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>INC Petroch. Ethane cracker</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>IND Petroch. Oxydative coupling</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td>N</td>
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</tr>
<tr>
<td>INE Petroch. MTO(^2)</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td>N</td>
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</tr>
<tr>
<td>INF Petroch. LPG cracker</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td>E</td>
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<tr>
<td>ING Ethanol dehydrogenation</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>INH Flash pyrolysis wood</td>
<td>N</td>
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<td></td>
<td>N</td>
<td></td>
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27 MTO Methanol To Olefins.
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\textsuperscript{28} TPA Terephthalic Acid.
\textsuperscript{29} VCM VinylChloride Monomer.
\textsuperscript{30} UF Urea Formaldehyde.
\textsuperscript{31} MEK MethylEtylKeton.
\textsuperscript{32} TDI TolueneDiIsocyanate.
\textsuperscript{33} AES Alkyl Ether Sulphates.
**Table 2.4.6: Petrochemical production polymerisation [7]**

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**Table 2.4.7: Fertiliser industry [9]**

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34 PP Polypropylene.
35 PE Polyethylene.
36 PS Polystyrene.
37 PET PolyethylenTerephthalate.
38 ABS Acrylonitrile Butadiene Styrene.
39 SBR Styrene Butadiene Rubber.
40 PUR PolyUrethane.
41 BR Butadiene Rubber.
42 PHB/PHV PolyHydroxyButyrate/PolyHydroxyValerate.
### Table 2.4.8: Inorganic and ceramic materials production [9]

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### Table 2.4.9: Paper and pulp industry [2]

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### Table 2.4.10: Wood industry [2]

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### Table 2.4.11: Electric appliances, building and renovation etc.

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<td>IYB Tyre production natural rubber</td>
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### Table 2.4.12: Building and construction industry [4]

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### Table 2.4.13: Car industry [10]

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<td>KD3 Large plastic car production</td>
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<td>KD4 Large standard car production</td>
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<td>KE4 Standard van production</td>
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<td>KF3 20-t Standard truck production</td>
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<td>JC2 Small aluminium car production</td>
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### 2.5 Residential sector

The demand for appliances by the residential sector is not sensitive to price changes. The large number of households makes regulating each of them cumbersome. In this case, regulation of suppliers seems more appropriate, which reduces the number of actors considerably. Therefore no additional transaction costs have been assumed in case of C scenarios.
Table 2.5.1: Residential heating, single family dwellings, northern Europe [3,11]

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<th>Transaction costs under the C scenarios [%]</th>
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<th>(4)</th>
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<td></td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1B District heat + floor insulation + heat recovery</td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
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<tr>
<td>R1C Gas boiler</td>
<td></td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1D Condensing gas boiler</td>
<td></td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1E R1D + floor insulation</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1F R1E + PU foam + heat recovery</td>
<td></td>
<td></td>
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<tr>
<td>R1G R1F + coated glass</td>
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<tr>
<td>R1H R1F + coated and gasfilled glass</td>
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<td>R1J Total energy heat</td>
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<td>R1K R1J + floor insulation + heat recovery</td>
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<td>Y</td>
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<td>R1L R1J + maximum insulation</td>
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<td>R1M Petroleum products</td>
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<td>R1N Electric resistance</td>
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<td>E</td>
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<td>R1O Coal stove</td>
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<tr>
<td>R1P Wood stove</td>
<td>Y b</td>
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Table 2.5.2: Residential heating, multi family dwellings, northern Europe [3,11]

<table>
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<td></td>
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</tr>
<tr>
<td>R2B R2A + coated glass</td>
<td></td>
<td>Y</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>R2C R2B + heat recovery</td>
<td></td>
<td>Y</td>
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<tr>
<td>R2D District heat + maximum insulation</td>
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<td>Y</td>
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<td>R2E Gas boiler</td>
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<td>E</td>
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<tr>
<td>R2F Condensing gas boiler</td>
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<td></td>
<td>E</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>R2G R2F + coated glass</td>
<td></td>
<td></td>
<td>Y</td>
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<tr>
<td>R2H R2G + heat recovery</td>
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<td>Y</td>
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<tr>
<td>R2I R2F + coated glass</td>
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<td>R2J Petroleum products</td>
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<td>R2L Coal stove</td>
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<tr>
<td>R2M Wood stove</td>
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<td>Y b</td>
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Table 2.5.3: Residential heating, existing single family dwellings, middle Europe [3,11]

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<tr>
<td>R3B District heat + floor insulation + heat recovery</td>
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<td>R3C Gas boiler</td>
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<tr>
<td>R3D Condensing gas boiler</td>
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<td></td>
<td>E</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R3E R3D + floor insulation</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R3F R3E + PU foam + heat recovery</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
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</tr>
<tr>
<td>R3G R3F + coated glass</td>
<td></td>
<td></td>
<td>Y</td>
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<tr>
<td>R3H R3F + coated and gasfilled glass</td>
<td></td>
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<td>Y</td>
<td></td>
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<tr>
<td>R3I R3F+3coated and gasfilled glass</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
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<tr>
<td>R3J Total energy heat</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R3K R3J + floor insulation + heat recovery</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
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<td></td>
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<tr>
<td>R3L R3J + maximum insulation</td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
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<tr>
<td>R3M Petroleum products</td>
<td></td>
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<td></td>
<td>E</td>
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</tr>
<tr>
<td>R3N Electric resistance</td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R3O Coal stove</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>R3P Wood stove</td>
<td>Y b</td>
<td></td>
<td></td>
<td>P b</td>
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### Table 2.5.4: Residential heating, multi family dwellings, middle Europe [3,11]

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<tr>
<td>R4B R4A + coated glass</td>
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<tr>
<td>R4C R4B + heat recovery</td>
<td>Y</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>R4D District heat + maximum insulation</td>
<td>Y</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R4E Gas boiler</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>R4F Condensing gas boiler</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R4G R4F + coated glass</td>
<td>Y</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R4H R4G + heat recovery</td>
<td>Y</td>
<td>-</td>
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<td></td>
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<tr>
<td>R4I R4F + maximum insulation</td>
<td>Y</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R4J Petroleum products</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R4K Electric resistance</td>
<td>Y</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>R4L Coal stove</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R4M Wood stove</td>
<td>Y b</td>
<td>-</td>
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### Table 2.5.5: Residential heating, new single family dwellings, middle Europe [3,11]

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<td>-</td>
<td></td>
<td></td>
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<tr>
<td>R5B District heat+floor insul.+heat recov.</td>
<td>Y</td>
<td>-</td>
<td></td>
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<tr>
<td>R5C District heat+maximum insulation</td>
<td>Y</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5D Conventional gas boiler</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5E Condensing gas boiler</td>
<td>E</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5F R5E+floor insulation</td>
<td>Y</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5G R5F+heat recovery</td>
<td>Y</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5H R5G+coated glass</td>
<td>Y</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5I R5G+coated and gasfilled glass</td>
<td>Y</td>
<td>-</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>R5J R5G+3*coated and gasfilled glass</td>
<td>Y</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>R5K Electric heatpump: heat + water</td>
<td>Y b</td>
<td>-</td>
<td></td>
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<tr>
<td>R5L R5K+floor insulation</td>
<td>Y b</td>
<td>-</td>
<td></td>
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<td></td>
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<tr>
<td>R5M R5L+coated glass</td>
<td>Y b</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R5N R5L+coated and gasfilled glass</td>
<td>Y b</td>
<td>-</td>
<td></td>
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<tr>
<td>R5O R5K + triple glass + impregnated wall insulation</td>
<td>Y b</td>
<td>-</td>
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<td>R5P Total energy heat</td>
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<td>-</td>
<td></td>
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<tr>
<td>R5Q R5P+floor insulation+heat recovery</td>
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<td>R5R R5P+maximum insulation</td>
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<td>R5S Petroleum products</td>
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<td>R5T Electric resistance</td>
<td>Y</td>
<td>-</td>
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<tr>
<td>R5U Coal stove</td>
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<td>R5V Wood stove</td>
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### Table 2.5.6: Residential heating, single family dwellings, southern Europe [3,11]

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<th>Transaction costs under the C scenarios [%]</th>
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<td>(1)</td>
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<tr>
<td>R6A District heat exchanger</td>
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<tr>
<td>R6B District heat + floor insulation + heat recovery</td>
</tr>
<tr>
<td>R6C Gas boiler</td>
</tr>
<tr>
<td>R6D Condensing gas boiler</td>
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<tr>
<td>R6E R6D+floor insulation</td>
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<tr>
<td>R6F R6E+PU foam + heat recovery</td>
</tr>
<tr>
<td>R6G R6F+coated glass</td>
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<tr>
<td>R6H R6F+coated and gasfilled glass</td>
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<tr>
<td>R6I R6F+3*coated and gasfilled glass</td>
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<tr>
<td>R6J Total energy heat</td>
</tr>
<tr>
<td>R6K R6J + floor insulation + heat recovery</td>
</tr>
<tr>
<td>R6L R6J + maximum insulation</td>
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<tr>
<td>R6M Petroleum products</td>
</tr>
<tr>
<td>R6N Electric resistance</td>
</tr>
<tr>
<td>R6O Coal stove</td>
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<tr>
<td>R6P Wood stove</td>
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### Table 2.5.7: Residential heating, multi-family dwellings, southern Europe [3,11]

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<th>Transaction costs under the C scenarios [%]</th>
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<td>R7A District heat exchanger</td>
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<td>R7B R7A + coated glass</td>
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<tr>
<td>R7C R7B + heat recovery</td>
</tr>
<tr>
<td>R7D District heat + maximum insulation</td>
</tr>
<tr>
<td>R7E Gas boiler</td>
</tr>
<tr>
<td>R7F Condensing gas boiler</td>
</tr>
<tr>
<td>R7G R7F+coated glass</td>
</tr>
<tr>
<td>R7H R7G+heat recovery</td>
</tr>
<tr>
<td>R7I R7F+maximum insulation</td>
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<tr>
<td>R7J Petroleum products</td>
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<tr>
<td>R7K Electric resistance</td>
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<tr>
<td>R7L Coal stove</td>
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<td>R7M Wood stove</td>
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### Table 2.5.8: Water heating, northern Europe [3,11]

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<th>Transaction costs under the C scenarios [%]</th>
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<td>RA0 Combined heating and hot water</td>
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<tr>
<td>RA1 Gas boiler water heater</td>
</tr>
<tr>
<td>RA2 Combi boiler water heater</td>
</tr>
<tr>
<td>RA3 Electric water heater</td>
</tr>
<tr>
<td>RA4 Electric heatpump boiler</td>
</tr>
<tr>
<td>RA5 Petroleum products water heater</td>
</tr>
<tr>
<td>RA6 Coal water heater</td>
</tr>
<tr>
<td>RA7 Wood water heater</td>
</tr>
<tr>
<td>RA8 Solar boiler; electric heatpump backup</td>
</tr>
<tr>
<td>RA9 Solar boiler; gas backup</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>RB0</td>
</tr>
<tr>
<td>RB1</td>
</tr>
<tr>
<td>RB2</td>
</tr>
<tr>
<td>RB3</td>
</tr>
<tr>
<td>RB4</td>
</tr>
<tr>
<td>RB5</td>
</tr>
<tr>
<td>RB6</td>
</tr>
<tr>
<td>RB7</td>
</tr>
<tr>
<td>RB8</td>
</tr>
<tr>
<td>RB9</td>
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<tr>
<td>RBA</td>
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<tr>
<td>RBB</td>
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<table>
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<th>Transaction costs under the C scenarios [%]</th>
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<tr>
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<td>Combined heating and hot water</td>
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<tr>
<td>RC1</td>
<td>Gas boiler water heater</td>
</tr>
<tr>
<td>RC2</td>
<td>Combi boiler water heater</td>
</tr>
<tr>
<td>RC3</td>
<td>Electric water heater</td>
</tr>
<tr>
<td>RC4</td>
<td>Electric heatpump boiler</td>
</tr>
<tr>
<td>RC5</td>
<td>Petroleum products water heater</td>
</tr>
<tr>
<td>RC6</td>
<td>Coal water heater</td>
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<tr>
<td>RC7</td>
<td>Wood water heater</td>
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<tr>
<td>RC8</td>
<td>Solar boiler; electric heatpump backup</td>
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<tr>
<td>RC9</td>
<td>Solar boiler; gas backup</td>
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### Table 2.5.11: Appliances [3]

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<td>Conventional dishwasher</td>
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<tr>
<td>RD2</td>
<td>Dishwasher (enzymatic detergent)</td>
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<td>-</td>
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<tr>
<td>RD3</td>
<td>Dishwasher (enzymes; ASD^1; optical sensor)</td>
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<tr>
<td>RES</td>
<td>Other existing electric appliances</td>
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<tr>
<td>RF1</td>
<td>Gas cooker</td>
<td>E</td>
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<td>-</td>
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</tr>
<tr>
<td>RF2</td>
<td>Electric cooker</td>
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<tr>
<td>RF3</td>
<td>Infrared jet impingement cooker</td>
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<td>RF4</td>
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<td>RF5</td>
<td>Coal cooker</td>
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<td>RF6</td>
<td>Wood cooker</td>
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<td>RL1</td>
<td>Incandescent lamp residential</td>
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<td>RL2</td>
<td>Halogen lamp residential</td>
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<td>RL3</td>
<td>Fluorescent lamp residential</td>
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<td>RL4</td>
<td>PL/SL lamp (&gt;350 hours/year)</td>
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<td>RL5</td>
<td>PL/SL lamp (300-350 hours/year)</td>
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<td>RL6</td>
<td>PL/SL lamp (200-300 hours/year)</td>
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<td>RR1</td>
<td>Old type refrigerator</td>
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<td>RR2</td>
<td>Standard refrigerator (3 cm insulation)</td>
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<td>RR3</td>
<td>Better insulated absorption refrigerator</td>
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<td>RR4</td>
<td>Improved absorption refrigerator</td>
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<td>RR5</td>
<td>Stirling refrigerator (krypton panels)</td>
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<td>RR6</td>
<td>Stirling refrigerator (soft vac. Panels)</td>
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<tr>
<td>RT1</td>
<td>Tumble drier (conventional)</td>
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</tr>
<tr>
<td>RT2</td>
<td>Tumble drier (improved)</td>
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<td>-</td>
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</tr>
<tr>
<td>RT3</td>
<td>Tumble drier (improved)</td>
<td>Y</td>
<td>-</td>
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</tr>
<tr>
<td>RT4</td>
<td>Tumble drier (improved; high speed spin)</td>
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</tr>
<tr>
<td>RT5</td>
<td>Heat pump drier (improved; high speed spin)</td>
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<td>RW1</td>
<td>Conventional washing machine</td>
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<tr>
<td>RW2</td>
<td>Washing machine (ASD, optical sensor)</td>
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</tbody>
</table>

\^1 ASD Adjustable Speed Drive.
2.6 Commercial sector

The commercial sector is generally more price sensitive than the residential sector (where largely the same technologies can be applied). However the price sensitivity is lower than for e.g. the industrial sector. Regulation through building ordinances etc. is a feasible — and often applied — option in case of new buildings, but much less in case of renovation of an existing building stock. The diversity of options favours price-based instruments.

For simplicity, no additional transaction costs have been assumed.

Table 2.6.1: Commercial heating, northern Europe [3,11]

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<tr>
<th>(1)</th>
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<th>(5)</th>
<th>Transaction costs under the C scenarios [%]</th>
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<td>C01</td>
<td>Condensing gas boiler</td>
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<tr>
<td>C02</td>
<td>Cond. boil+low-emittance glass</td>
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<tr>
<td>C03</td>
<td>Cond. boiler+low-e+heat recovery</td>
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<td></td>
<td></td>
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<tr>
<td>C06</td>
<td>Oil boiler</td>
<td>E</td>
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<tr>
<td>C07</td>
<td>Oil boiler+low-emittance glass</td>
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<td>C08</td>
<td>Oil boiler+low-e+heat recovery</td>
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<td>C0A</td>
<td>Coal boiler</td>
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</tr>
<tr>
<td>C0B</td>
<td>Coal boiler+low-emittance glass</td>
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<td>C0M</td>
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Table 2.6.2: Commercial heating small offices, middle Europe [3,11]

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44 TE Total Energy (combined electricity and heat production).
### Table 2.6.3: Commercial heating large offices, middle Europe [3,11]

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### Table 2.6.4: Commercial heating, southern Europe [3,11]

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### Table 2.6.7: Packaging concepts [12]

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## Agriculture

### Table 2.7.1: Agricultural crops [13]

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### Table 2.7.2: Agricultural animal products

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### Table 2.7.3: Agricultural products

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### Waste

### Table 2.8.1: Energy recovery from waste [14]

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### Table 2.8.2: Waste separation

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### Table 2.8.3: Waste product disassembly

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### Table 2.8.4: Waste plastic handling

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Table 2.8.5: Recycling of other synthetic organic products

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Table 2.8.6: Mitigation of CH₄ emissions from waste disposal sites

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35
3. DEFINING THE POLICY SCENARIOS: CONCLUSIONS OF AN INTERNATIONAL EXPERT PANEL WORKSHOP

3.1 Introduction: the Panel

The international panel of experts was set up to assist the researchers in making “the distinction between TOs that are likely to be brought about most readily by using regulatory instruments (R TOs) and those that are likely to be realised best, using price-based instruments (P TOs).”

Initially it was hoped for that by looking at a concrete technical options (TOs), it would be possible to identify (beyond too much doubt), which TOs would require price-based instruments. It was expected that notably the materials substitution TOs would fall into this category since the majority of them require the involvement of many actors and rely on many different technologies and seemingly endless applications. This attempt failed (see “Conclusions of the Panel”).

The complexity of the issue makes the choice for a TO as being particularly suitable for a price-based approach, or conversely as being particularly suitable for a regulatory approach, rather subjective and presumably also country specific (depending on its regulatory tradition). To cancel out as much subjectivity as possible and to bring as much experience as possible to bear on the distinction, it was decided to seek the advise of experts from different backgrounds. The panel consisted of experts that were selected by the OECD secretariat, mainly on the basis of suggestions of members of the Working Party on Economic and Environment Policy Integration (WPEEPI). Because of the focus of the research on Europe, the members came almost exclusively from European countries.
3.2 The Questions

The panel was asked to comment on a proposal conceived by the researchers, for the categorisation of the TOs for GHG reductions in two categories: P-TOs and R-TOs. This proposal consisted basically of two elements:

1. the criteria for categorisation and
2. the categorisation of approximately 400 TOs itself, that the researcher felt would result from applying the criteria.

All technical options are assumed to be achievable through price-based instruments. So by default, all technical options, would belong to this category, which was dubbed “P(-TOs)”. Of course, a number of these options might require complementary regulations, or regulatory reform to be effective. The basic assumption behind this approach is, however, that generally price-based instruments are more

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Pricing methods were defined as applying taxes and tradable permits. It was not clearly stipulated that, in the context of this study, regulatory approaches would include voluntary agreements. Several panel members drew our attention to this omission. They also indicated that in their opinion these TO’s would not qualify as TO’s to be achieved by pricing methods. As a consequence they remained to be treated as R-TO’s.
cost-effective, especially when their realisation would require many upstream and downstream adaptations\(^{46}\). As a consequence, if this option would be available, governments would opt for pricing, if necessary accompanied with regulation.

The second category, labelled “R(-TOs)”, would consist of those technical options that would be applied in the absence of the possibility to use pricing. The most compelling reason for the absence of the pricing option is likely the fear of loss of competitiveness. The R-category would also include TOs which would anyway be regulated, because regulation would be seen as superior to pricing. Comparing the LCCs of TO’s based on price-based instruments with those based on regulatory approaches would indicate the loss of cost effectiveness due to the impossibility of applying price-based instruments. In summary the categorisation entailed no more than indicating the R-TOs, either because regulation is preferable over pricing, or that would be regulated in absence of the pricing option. The R-category is a subset of the P-category because it was assumed that all options could be achieved by price-based instruments.

The detailed categorisation proposal made a distinction between TOs, which the researchers were confident would fall into R, and those whose qualification as P-TO, or R-TO was seen as more questionable, labelled P/R. Panel members were invited to express their views regarding these TOs in particular.

In addition the panel was asked to comment on two questions.

1. *Whether the panel felt it useful to assume that the costs regulatory approaches should be augmented with transaction cost adders, proportional with the number of actors involved in the various TOs.*

2. *Whether the panel would like to assume particular TOs not to capture more than \(x\)% of the market", in model terms whether particular TOs should be given a certain “upper bound”*

A very few panel members commented on the first question, none on the second.

\(^{46}\) It is often argued that if many upstream and downstream adaptations are required, governments should step in, issuing regulations as to reduce the uncertainty for firms. On the other hand, such regulations are extremely difficult to devise, requiring requirements that follow technical developments. Such regulations are almost inevitably not very efficient and thus costly. The first best solution therefore would be the application of pricing methods; regulatory approaches a second best choice, if uncertainties seem to be insurmountable.
3.3 Panel’s overall conclusions

Not the criteria, but their application poses the greatest difficulties for categorisation

Generally, the criteria met with approval. There was considerably less consensus on the actual categorisation, following the proposed criteria (in a number of cases as amended by the panel member). Virtually all panel members emphasised that many more TOs can, and will be regulated in practice than the researchers suggested. A number of them stressed the use of “smart regulation” (regulatory approaches that are performance based and allow firms to chose cost efficient solutions, as often is the case in for example voluntary agreements) (see Table 3.1, below).

The choice for regulation is influenced by other factors than ex-ante efficiency considerations

Several members of the panel also argued that the actual choice for regulation might be influenced by other factors than ex-ante efficiency considerations only, in particular several of the panel members mentioned:

1. If regulations are properly monitored and enforced, they ensure environmental outcomes of the regulated industry more precisely than price-based instruments

2. In case a TO would require fundamental upstream and downstream adaptations (structural-technological changes –as opposed to behavioural ones), that would involve a limited number of large actors, some panel members argued that R-approaches would be preferable, since they will reduce the uncertainty facing producers. Others, however, argued in favour of P-approaches, since this would stimulate more of the necessary (and extremely difficult to predict) adaptations, from various actors –especially if these actors cannot easily be identified
(ex-ante) by the regulating authorities, for example because the relevant technologies are used or can be used in many sectors, or has not yet been fully matured.

3. R-approaches will be adopted under certain conditions, notably: low abatement costs relative to production costs; oligopolistic, monopolistic markets; because of their political transparency and low transaction costs for governments. One panel member suggested that R-approaches would in general be preferable for producers (relatively small number of well informed actors); P-approaches for consumers (large number of ill informed actors).

4. In case of distorted markets (e.g. electricity generation, or obligatory products specifications), R-approaches would be preferable.

5. The adaptation of new technologies also depends on qualitative aspects of the new products or processes.

3.4 Discussion and consequences for scenario modelling

It turned out that according to the panel, there are so many potential possibilities to regulate new technologies, for example by imposing regulations on a limited number of strategically placed actors, that — at least in theory — the regulatory alternative could not be dismissed beforehand in any TO considered. As a consequence it was not possible to reach consensus of the definition of the R-TOs as a subset of the P-TOs. However, often panel members disagreed on the applicability of either price-based or regulatory instruments for particular TOs.

Apart from differences in backgrounds of the panel members, several speculations with respect to the reasons for the lack of consensus may be put forward.

First, whatever environmental policy measure is taken, it is not taken in a vacuum. New measure will have their effects in conjunction with existing regulations, existing price measures (charges, taxes, tradable permits), and other circumstances (e.g. market structures, geography, political and institutional frameworks). The choice of instruments is influenced by such initial conditions, which vary over countries and over time. Moreover, the more complex an issue is and the larger and more wide spread its potential consequences, the more likely governments need to change a mix of a number of regulations and prices at the same time. This explanation was extensively discussed at the workshop.

Second, there are differences in policy perspectives. If one views environmental policy as finding answers to a number of (urgent) problems, one will start by defining these problems and seek the easiest way to alleviate them. Often such a problem oriented approach will lead to direct regulatory approaches, aimed at limiting specific emissions, by specific actors. If, by contrast, one seeks to address systemic causes for environmental degradation, one may be inclined to look for more wide ranging policies, in particular price-based instruments. Judgements with respect of cost-effectiveness of policies, of course, also depends on the policy perspective one takes. In case of GHG mitigation policies it may be expected that the emphasis of such wide ranging policies that include many sectors simultaneously with their forward and backward linkages and, by consequence, are sector and technology blind, may gain in importance. This possible explanation suggested itself to the researchers.
Conclusion with respect to the definition of the scenarios

The researchers drew the following conclusion from the Panels discussions with respect to defining the scenarios:

The overriding criteria for choosing regulatory approaches seem to be: The TO

- has a significant effect on (GHG-) emissions;
- is to be applied by a limited number of actors, that are easily addressed by regulatory agencies (which also implies low transaction costs);
- does not lead to cost increases for the regulated sector, or higher costs can easily be recuperated.

It seems that in present day environmental policy a potential loss of overall efficiency of policies is sacrificed in favour of defending the competitiveness of large industries, concrete political actions that are easy to communicate, and avoiding (more abstract) sector and technology blind policies (systemic and more cost-effective policies). To draw out the potential loss of effectiveness and efficiency, these practices had to be compared with a construct that would simulate systemic policies (the “ideal policy”).

Most of the relevant technical options concern energy and materials intensive sectors that compete on world markets and constitute of a limited number of large firms. Hence the majority of the technical options in the model could, and in fact probably would, be regulated, with the restriction that this would not lead to any significant cost increases for those exposed sectors.

In view of these conclusions, it was decided to abandon the attempt to single out particular TOs as R-TOs. Instead the scenarios have been constructed along the lines of Policy-Continuation and an Ideal policy. The scenarios that should simulate the Policy-Continuation framework were constructed on the basis of all TOs, be it that in the Policy-Continuation scenarios, all TOs got additional bounds as to prevent non recoupable price increases for the exposed sectors. (Recoupable price increases, for instance of electricity prices for sheltered sectors and households are not subjected to additional bounds.) This distinction is presented in Table 3.1, in which the R/LC TO’s are those that entered the Policy-Continuation scenarios with the additional “no cost increase bound.”

3.5 Panel’s comments on TO-level

Energy: Fossil fuels switch

The proposed category for all these TOs, regardless of the sector, was P, meaning that no TO would enter the calculations as a R-TO, for the following reason. Fuel switches often have significant effects on cost structures and require upstream and downstream adjustments. The significant cost effects will deter governments from action because of fear of loss of competitiveness. Most of the relevant industries (electricity production, refineries, and large non-materials industries) compete on world markets or produce intermediate products whose prices influence significantly the costs of final products that are traded on world markets. The complex upstream and downstream adaptations makes a R-approach prone to significant inefficiencies. By contrast, an international approach, like the introduction of tradable permits or parallel changes of taxes, would circumvent both problems. If such an approach were adopted, R-approaches in other sectors would automatically become obsolete.
Four panel members, however, indicated a far more prominent role of R-approaches, notably in sectors with only a few large actors: energy production, refineries and non-materials, large industries, because they are easily addressed by means of negotiated agreements and other forms of regulation. Following this lead, R-based fuel switches in these industries have been introduced. In the electricity producing sector they take the form of upper and lower limits with respect to the share of renewables in total fuel consumption. Regarding the refineries, and non-materials, large industries, –belonging to the “exposed” sector– we assume that only those TOs are going to be (unilaterally) regulated if they incur negative or zero costs to the regulated exposed sector. Because the rather limited numbers of actors in these sectors, low transaction costs are assumed (Table 3.2.).

One panel member suggested R-approaches for fossil fuels switches in small businesses. Another panel member suggested also to categorise fuel switches (biomass, or CHP) in the residential sector (district heating) to be regulated through planning measures. As a consequence, these TOs have been put in the R-category, be it with high transaction costs.

Energy: Nuclear

Two panel members suggested nuclear energy for electricity production to be categorised as R, since the nuclear energy sector is highly regulated. The nuclear options have been entered in the calculations, by assuming R-approaches and no change in capacity.

Energy: Increased energy efficiency

Four panel members argued that TOs to enhance energy efficiency in households (and the commercial sector) would be more sensitive to price changes than assumed in the researchers’ proposal, while one, acknowledging such higher price elasticities, underlined that nevertheless enhancing insulation of new buildings would in practice be realised by R-approaches. (Others stressed the need for more P-oriented approaches especially for energy saving in renovated buildings, which –in some countries– constitutes an increasing share of housing supply.) The relevant TOs for households, the commercial sector and small and medium sized enterprises, all being “sheltered” sectors, will be classified as R, with no restriction on costs and with high transaction costs.

Four panel members stressed the possibility to regulate combined CHP, acknowledging the plant specificity of the technology and as a consequence the superiority of P-approaches to this end. One panel member made the point that existing regulations might have to be changed first, before P-approaches could have effect. As a result, CHP options will enter the calculations regarding R-approaches, with no cost limits and with high transaction costs. Although changing regulations that inhibit markets to perform well is a prerequisite for relative price changes to be effective, this type of regulatory reform could not be transformed into values for relevant parameters in the calculations.

Two panel members, advocated R-approaches to enhance the energy efficiency in electricity generation, transport, non-materials producing (large and small) firms, as well in waste management. When large firms were concerned, the TOs that entail negative or zero costs were entered as R-approaches, with low transaction costs. For small firms (assuming that they belong predominantly to the sheltered sector) TOs were categorised as R, without cost limits and with high transaction costs.

47 This holds also true for materials specifications that run counter to GHG reduction objectives.
Although no remarks were made specifically concerning the transport sector (vehicle production and fuels consumption) extrapolating the line of thinking behind the comments, it was decided to make two sets of calculations with respect of transport. One set includes those TOs that incur negative or zero costs for the vehicles manufacturers in the R-approaches (with low transaction cost). The other set of calculations mimics governments’ policies that require vehicle producers to have a certain percentage of their sales meeting strict emission standards. Both sets of calculations take into account that changes in the characteristics of vehicles induce upstream fuel switches. These TOs also include changes in materials use for vehicles production (see the “materials” section of Table 3.2).

One panel member suggested regulatory approaches in waste management. However, TOs that increase energy efficiency as well as waste heat utilisation are included in the TOs available to other sectors, like electricity generation, non-materials industries, the residential and the commercial sector, or are dealt with under “materials, energy recovery from waste”. In all cases R-approaches have been assumed.

**Energy: CO₂-capture and disposal, power plants**

Two panel members argued in favour of R. TOs to the effect of CO₂-capture and disposals with negative or zero costs have been entered as R-approaches into the calculations, both in the electricity generation sector as well in refineries. In both cases they are treated in the usual way: TOs with negative or are costs were assumed to be regulated, at low transaction costs.

**Energy: Renewables**

Three panel members suggested more prominent role for regulating the use of biomass (and presumably wind) in electricity generation. By contrast, one saw a more prominent role for prices in stimulating PhotoVoltaic systems. It was decided to enter certain TOs in the R-approaches, following the general rules regarding negative or zero costs for exposed sectors and transaction costs set according to the number of actors. In case of large industrial plants, this rule eliminates the –technically– available TOs. Therefore, under the R-alternatives, no renewables TOs for these industries are imputed. In Table 3.2, this is indicated with “n.r.” (not relevant)

**Energy: Waste heat utilisation**

One panel member suggested R-approaches for electricity generation, non-materials large and small industries, the residential sector, the commercial sector, and waste management. These TOs are included in the R-approaches, following the general rules with respect to costs and transaction costs.

**Materials: NO₂/CH₄ removal, conversion; industry, disposal sites**

One panel member suggested to include the relevant TOs in the R-approach. Following this advise and the general rules stating that in the exposed sectors only TOs with negative or zero costs will be regulated, only a number of TOs are part of the R-approaches. In those cases, they are assumed to have low transaction costs.
Materials: NO₂/CH₄ emission reduction; agriculture

No change suggested. The TOs available for this sector are not entered into the R-category. Changes to these emissions require many upstream and downstream adaptations and, in spite of the agricultural sector being heavily regulated, it seems safe to assume that such changes could not be brought about with at least a strong impetus of changes in relative prices.

Materials: Increased materials efficiency

One panel member opted for a regulatory approach in the materials producing industry. This suggestion has been followed, again adhering to the general rules that in the exposed sectors only those TOs will be regulated, that have negative or zero costs. In those sectors, transaction costs are assumed to be low.

CO₂ capture and disposal; industry

One panel member suggested a regulatory approach. However, all these techniques would lead to sometimes large−cost increase, and therefore conflict with the general rule that the exposed sectors would not be confronted with any regulations that imply significant cost increases. As a consequence, there appear to be no TOs for CO₂-capture and disposal by industry to be part of a R-approach.

Materials: Increased energy efficiency; materials industry

One panel member categorised increased energy efficiency in the materials producing industry as suitable for regulatory approaches. This suggestion has been followed, applying the general rules with respect to cost increases for the exposed industries and transaction costs.

Feedstock substitution

According to the proposal, feedstock substitution would be categorised as P. This proposal has been modified into R, but applying the general rule about negative and zero costs for exposed industries, leaves us virtually with no TO for materials substitution to be imputed in any R-strategy.

Materials recycling/reuse

One panel member categorised these TOs as to be achieved by R-approaches in the materials producing sector as well as the residential and commercial sector. These TOs indeed have now been categorised as R, applying the usual rule concerning negative or zero costs for the exposed sector and transaction costs in accordance of the number of actors. The TOs regarding materials recycling and reuse in agriculture are included in energy recovery from waste.

Energy recovery from waste

One panel member saw preferable regulatory options in electricity generation and in the materials producing industry. Another panel member saw advantages of regulatory approaches in agriculture. These
technologies, however are captured under Energy, waste heat utilisation, increased energy efficiency (for the materials producing sector) and renewables in agriculture.

**Enhancing forestry**

No suggestions were received from panel members. These TOs therefore have been treated according to the original proposal as R-TOs, with low transaction costs.
### Table 3.1. Overview of the R-category of technical options

<table>
<thead>
<tr>
<th>Technical option</th>
<th>Sector →</th>
<th>Electricity Production</th>
<th>Transport</th>
<th>Refineries</th>
<th>Industry</th>
<th>Residential sector</th>
<th>Commercial sector</th>
<th>Agriculture</th>
<th>Waste</th>
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<tr>
<td>N₂O/CH₄ industry/disposal sites</td>
<td>R/LC, TL</td>
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<td>N₂O/CH₄ agriculture</td>
<td>R/LC, TL</td>
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<td>Increased M-efficiency</td>
<td>R/LC, TH</td>
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<td>CO₂ capture and disposal industry</td>
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<td>Increased E-efficiency industry</td>
<td>R/LC, TH</td>
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<td>Feedstock substitution</td>
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<tr>
<td>M-recycling re-use</td>
<td>R/LC, TL</td>
<td>R/bounds</td>
<td>R/LC, TL</td>
<td>R/LC, TL</td>
<td>R/LC, TL</td>
<td>R; TH</td>
<td>R, TH</td>
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<tr>
<td>Enhancing forestry</td>
<td>R/LC, TL</td>
<td>R/bounds</td>
<td>R/LC, TL</td>
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<td>R/LC, TL</td>
<td>R; TH</td>
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**Key:**

- **R/bounds:** Regulatory approach setting upper or lower limits (or both) to production or to emissions
- **R/LC:** Regulatory approach demanding only TOs with negative, no, or very low extra (life cycle) costs.
- **nr:** Assumed: no TOs suitable for C are available in this sector (see text)
- **TH:** High transaction costs
- **TM:** Medium transaction costs
- **TL:** Low transaction costs
REFERENCES


