Industrial Ecology master's programme 2008
Stage de fin d'étude ingénieur 2008

Achieving Carbon-Neutral Car Manufacturing Plants

A Strategic Approach for Toyota Motor Europe

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A Strategic Approach for Toyota Motor Europe

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ABSTRACT

On Toyota Motor Europe request, a study on renewable energy investment opportunities has been conducted in order to assess the potential of alternative energy sources to contribute to the ultimate target of carbon-neutral car manufacturing plant. The project work was developed in a step-by-step approach. The first step started with an evaluation of the current performance of seven production plants. A selection of 12 indicators covering 5 areas of concern have been used to quantify and compare the relative performance of their production activities in terms of energy use, energy-related CO_2 emissions, energy cost, energy security and European target for renewable energy sources in final energy use. The next step of the project was the creation of an *energy model* (mathematical model) to estimate the potential environmental and economical benefits from renewable energy technology implementation on-site. This second step resulted in a *global roadmap* (ranking of options) for Toyota Motor Europe as a whole and in *EMC-specific roadmaps* for each production plant, in order to achieve CO_2 emission reduction in the most cost-efficient way. As a final step for the project, a concrete example of the roadmap application is given to estimate the environmental performance improvements in production activities. This project concludes that renewable energy sources have the potential to be a major contributor in carbon-neutral plant activities. Therefore renewable energy sources combined with other energy and CO_2 reduction activities makes the ultimate target of carbon-neutral plants a reasonable target to be reached.

Keywords: Carbon-neutral; Sustainability; Renewable energy; Car manufacturing; Production plant; Automotive industry; Europe

ACKNOWLEDGEMENT

- To Steve Hope, general manager, and to Mitsuo Kikuma, executive coordinator of the Plant Engineering & Safety Division at Toyota Motor Europe, for allowing me to work on this subject and having welcomed me in the company;
- To Christopher Wadsworth, manager of the environmental team, for his supervision and his support;
- To Carine Christophe, environmental engineer, for answering my innumerable questions and her enthusiasm;
- To Timothy Waltniel, facility senior engineer, for his assistance in all steps of the project and his patience;
- To Jan-Olof Dalenbäck, professor in Building Services Engineering at Chalmers University of Technology, for his supervision and his help;
- To François Humbert, head of the Industrie et Environnement Option at ESSTIN, for his occasional assistance;
- To Kim, Machteld and Rosanna for sharing their office space and their kindness;
- To Regine and Alain for helping me when I had administrative or technical problems;
- To all PLE&S members for their kindness and the cakes;
- To all the employees of Toyota Motor Europe's Production Engineering and R&D for their sympathy and their welcome.

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LIST OF ACRONYMS

AEBIOM	European Biomass Association
ADEME	Agence de l'Environnement et de la Maîtrise de l'Énergie
BAT	Best Available Technology
BHE	Borehole Heat Exchanger
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
EC	European Commission
ED	Electrodeposition
EGEC	European Geothermal Energy Council
EMC	European Manufacturing Company
ESCO	Energy Service Company
ESHA	European Small Hydropower Association
ESTIF	European Solar Thermal Industry Federation
EUBIA	European Biomass Industry Association
EWEA	European Wind Energy Association
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
IEA	International Energy Agency
LCC	Life Cycle Cost
MSW	Municipal Solid Waste
NPV	Net Present Value
O&M	Operation and maintenance
PT	Pre-treatment
RES	Renewable Energy Source
RES-E	Renewable Energy Source for electricity generation
RES-H	Renewable Energy Source for heat generation
RTD	Research and Technological Development
RTO	Regenerative thermal oxidizer
SHP	Small Hydropower
SWH	Solar Water Heating
TME	Toyota Motor Europe
TMIP	Toyota Motor Industries Poland
TMMF	Toyota Motor Manufacturing France
TMMP	Toyota Motor Manufacturing Poland
TMMT	Toyota Motor Manufacturing Turkey
TMUK-B	Toyota Motor Manufacturing United Kingdom, Burnaston
TMUK-D	Toyota Motor Manufacturing United Kingdom, Deeside
TPCA	Toyota Peugeot Citroen Automobile
TPS	Toyota Production System
VOC	Volatile Organic Compound
WtE	Waste-to-Energy
WWT	Waste Water Treatment

1 INTRODUCTION

In the context of an **international master programme in *Industrial Ecology*** for Chalmers University of Technology and an **engineer formation in *Industrie et Environnement*** for ESSTIN, I carried out a thesis internship from the 1st of September 2008 to the 28th of February 2009 at Toyota Motor Europe Technical Centre in Zaventem (Belgium) which is the head office responsible for the European production sites. I have been assigned to the **Environmental Department** of the **Plant Engineering & Safety Division** within **Production Engineering Division**.

In this thesis work I was asked to answer a "simple" question: *How to become carbon-neutral in Toyota Motor Europe production activities?* This question opens the study on many different domains, not only environmental, but also legal, institutional, economic, social, technical… Thus we had to narrow down the study to a more reasonable subject by defining the scope and boundaries of the study.

1.1 Company information [1]

Toyota first began selling cars in Europe under an official distributor agreement in Europe in 1963. Since then, the company has matured into the leading Japanese car manufacturer in this highly competitive market. Toyota has invested almost €7 billion throughout Europe since 1990, and currently employs approximately 80,000 people, both directly and through dealership channels. Toyota's operations in Europe are supported by a network of 29 National Marketing and Sales Companies in 48 countries, a total of 3,300 sales outlets, and 9 manufacturing plants.

1.2 Context of the study

With growing environmental concern in all human activities, one has no choice but to reduce his energy use and pollution. One way to accomplish pollution reduction is to develop new energy systems based on carbon-free energy sources. Renewable energy sources, however, are usually not economically preferable compared to traditional carriers (i.e. fossil fuel). In order to achieve the major changes needed to decrease the environmental impacts of the industry, it is necessary to change, develop and build a favourable framework to overcome the present economic, technical, regulatory and institutional barriers.

To be successful over the long-term, companies have to be able to balance the expectations of various stakeholders (society, employees, customers, business partners and shareholders) through dialogue, transparency and working together. Socially responsible [2] companies integrate social, environmental and economic concerns in their business operations and in their interaction with their stakeholders on a voluntary basis (beyond legal requirements).

Toyota has in place a system for the coordination and promotion of initiatives important in contributing towards the sustainable development of society and the world. As part of this system, the Toyota Earth Charter* (adopted in 1992, revised in 2000) is based on the Guiding Principles at Toyota adopted in 1992 (revised in 1997), and embodies the comprehensive approach to global environmental issues. Toyota has been

* Appendix I - *Table 34: Toyota Earth Charter*

involved in environmental activities since 1963* and is now implementing its *Fourth Toyota Environmental Action Plan* [2] which seeks to achieve a balance between Toyota's growth and harmony with society, and to contribute to the development of a sustainable society. The first subject of this action plan (*CO_2 emissions management*) applied to TME is aiming at **tackling energy and global warming issues by reducing CO_2 emissions in all Toyota's European operations** (production and non-production areas). In response to this direction, *Sustainable Plant* activities† have been started at production level in two EMCs: TMMF and TMUK.

Reaction to this direction, the *Sustainable Plant* project includes the following areas of activity:

- Increase energy use efficiency;
- Reduce CO_2 emissions;
- Reduce water use and increase wastewater recycling;
- Reduce waste generation and increase waste valorisation;
- Minimise of VOC emissions and increase VOC recovery;
- Preserve and enhance biodiversity.

In this thesis work, we focused on the second area of activity: reduce CO_2 emissions. It is important to note that the scope of this study is limited by the production sites' boundaries and consequently, non-production and logistics activities outside the EMCs are excluded. And finally all CO_2 emissions associated with the production activities are the **energy-related emissions**.

1.3 Current situation

To achieve carbon-neutral energy use, important efforts have to be done on TME side. Under business as usual conditions, European average electricity price is expected to increase by 22.74% compared to 2000 price while the CO_2 per kWh reduction will around 22.35% compared to 2005 level (see *Figure 1* and *Figure 2*).

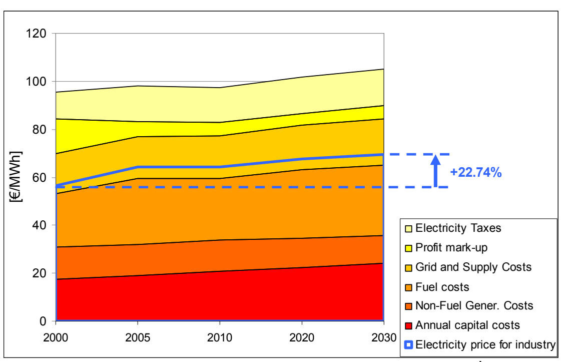


Figure 1: Average electricity price in EU ‡

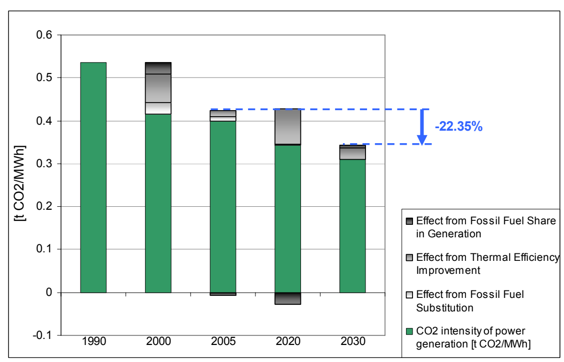


Figure 2: Carbon intensity of energy

* Appendix I - *Table 35: Environmental Chronological Table*

† The term "*sustainable plant*" refers to the concept of a plant that fully utilizes natural resources, while existing in harmony with the natural environment. Such plants can operate for more than 100 years with a drastically reduced environmental impact.

‡ Information from Eurostat, European Energy and Transport, Trends to 2030 - update 2007, Chapter 6.8 Cost and price of electricity [4]

The current situation at TME regarding energy use and CO_2 emissions is following an encouraging general trend: the energy use and CO_2 emission per vehicle produced is going down. During the financial year 2007 (FY07), the total energy used for production activities in the 7 manufacturing plants considered in this study was 1,103,024 MWh (1,355 kWh/vehicle) and the global energy-related emissions from production activities were 319,572 t CO_2 (392.5 kg CO_2 /vehicle). Those figures are annually reported in the European Sustainability Report [1] and the *Figure 3* below shows the evolution over the last 7 years and the next 3 years (FY08 to FY10 are estimated values).

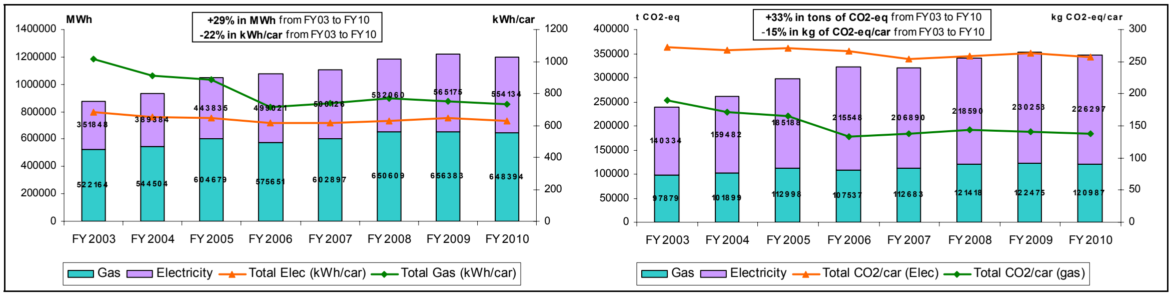


Figure 3: Toyota's environmental performance

To achieve this production efficiency increase in term of energy, and consequently a reduction in pollutant emissions, the Toyota Production System (TPS) evolves over the years to include new environmental targets to ensure that "car manufacturing can make more with less". The famous five concepts applied to production facilities are:

- **Yokoten**: applying best practice in all processes;
- **Kaizen**: continuous improvement;
- **Genchi Genbutsu**: going to the source to find the facts;
- **Just-in-time production** by 'pulling' products through the production line;
- **Active involvement** from all team members.

1.4 Objectives of the project

The project aims at investigating available options for energy system to achieve a carbon-neutral manufacturing plant through decoupling of environmental impact and business activities.

- Minimize environmental impact of production through CO_2 emission reduction;
- Use energy from renewable sources;
  ⇨ Determine the technical potential of RES in each EMC;
  ⇨ Estimate economic and environmental benefits;
- Use of "bridging technologies" if zero-carbon is not reachable immediately;
  ⇨ Substitution of carbon-based energy sources by lower-carbon sources.

1.5 Methodology

The basis of TPS is to prioritise elimination of the problem to the source when possible, reduce/minimise consumption and emissions, increase conversion efficiency and then go to alternative solutions. The *Figure 4* summarises those principles.

To narrow down the study, we decided to focus on the forth step of the pyramid (in bold red) since the two first ones are Kaizen activities done by the ESCO team and energy conversion improvement done by the EMC themselves. We are thus "on the other side" of improvement: whereas the three first steps are effectively reducing the use of energy, the study starts from a given amount of energy used and we will "remove its CO_2 content". This reasoning makes sense since the aim is to achieve carbon-neutral production activities and energy reduction has limits, renewable and low-carbon technologies are the only way to further reduce energy-related CO_2 emissions.

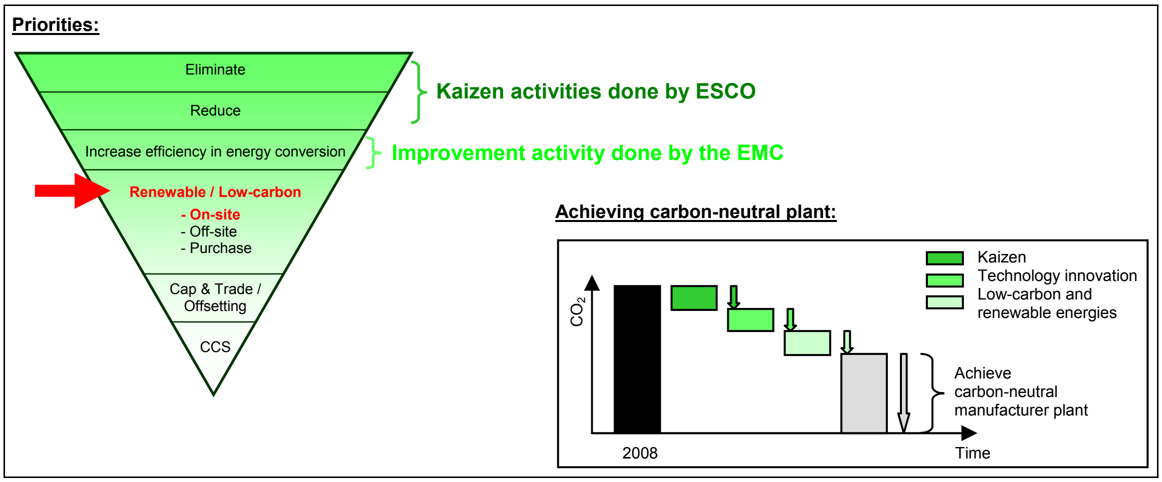


Figure 4: Toyota's Strategy

To work with renewable and low-carbon energy sources, boundaries also had to be set to limit the possibilities and obtain a sizable study given the limited time of the internship.

Table 1: Investment and energy generation options

Option	Investment type	Energy generation type
1A	Toyota	On-site energy generation
1B	Toyota	Off-site energy generation (within EMCs region)
1C	Toyota	Off-site energy generation (within Europe)
1D	Toyota	Joint implementation
1E	Toyota	Clean Development Mechanism
2A	Partnership	On-site energy generation
2B	Partnership	Off-site energy generation (within EMCs region)
2C	Partnership	Off-site energy generation (within Europe)
2D	Partnership	Joint implementation
2E	Partnership	Clean Development Mechanism
3A	Third-party	On-site energy generation
4	Purchase energy from RES	Off-site energy generation

In the following report, we focus on the 1A option (**Toyota investment with on-site energy generation**) based on management decision.

The study will be done in a 3-step approach as follow:

1. **EMC assessment** (Chapter 2) based on 5 categories (energy, CO_2, cost, security of supply, and RES);
2. **Technology assessment** (Chapter 3) based on CO_2 reduction cost;
3. Results summary for the option 1A in the form of a **global roadmap for TME** and **specific roadmaps for each EMC** (Chapter 4).

2 EMC ASSESSMENT

2.1 Production activities

A map of Europe with the seven selected production plants location can be found in *Figure 50* (Appendix I).

The main processes for car manufacturing are:
- **Press** shop: metal sheets are cut and shaped by the application of pressure;
- **ED** shop: manufacturing of the vehicle axle;
- **Welding** shop: manufacturing process to join metal parts;
- **Plastic** shop: manufacturing of dashboard and bumpers;
- **Paint** shop: body parts and plastic parts are painted;
- **Engine** shop: in TMMF until October 2008, now this activity is exclusively done by the part manufacturing plants (TMUK-D, TMMP and TMIP);
- **Assembly** line: all parts are added to the vehicle in a sequential manner.

Table 2: Manufacturing processes in vehicle production plants

	TMUK-B	TMMF	TMMT	TPCA
Press	✓	✓	✓	✓
ED parts	✓	✓		
Welding	✓	✓	✓	✓
Plastic	✓	✓	✓	
Paint	✓	✓	✓	✓
Engine		✓ *		
Assembly	✓	✓	✓	✓

The main processes for part manufacturing are:
- **Casting** process: molten metal poured or injected into a mould;
- **Forging** process: metal shaped by plastic deformation;
- **Machining** process: material removal method;
- And finally, all parts are assembled in the **assembly** line.

Table 3: Manufacturing processes in part production plants

	TMUK-D	TMMP	TMIP
Casting	✓	✓	✓
Forging		✓	
Machining	✓	✓	✓
Assembly	✓	✓	✓

* The engine shop has been removed in October 2008

2.1.1 Toyota Motor Manufacturing UK, TMUK-B and TMUK-D

The United Kingdom is a key market for Toyota both in terms of sales and manufacturing. As part of its wider European strategy, the company has established two production centres which began operations in 1992: a vehicle plant at Burnaston, near Derby, and an engine plant at Deeside, in North Wales.

The vehicle plant at Burnaston (TMUK-B), with annual production capacity of 285,000 vehicles, manufactures Auris and Avensis models for European market. The Avensis is also exported to Japan. Over 2.2 million vehicles have been produced since operations began in 1992.

The engine plant at Deeside (TMUK-D) currently produces 1.4, 1.6 and 1.8-litre petrol engines for Auris and Avensis models made at the Burnaston plant. Until October 2008, it also produced machined parts for engine assembly at TMMF, TMMT and other plants around the world. Over 2.2 million engines have been produced since operations began in 1992.

Figure 5: TMUK-B and TMUK-D production sites

2.1.2 Toyota Motor Manufacturing France, TMMF

The Yaris production plant began operations in January 2001. Production capacity has been increased to a maximum of 270,000 units per year, running into 3 shifts operation. The Yaris is exported to over 25 countries throughout Europe. The engine assembly unit was created in April 2002, and is in charge of the 1.3-litre petrol and 1.4-litre diesel engine manufacturing. The plant produced its millionth car in December 2006.

Figure 6: TMMF production site (1999)

The Valenciennes-Onnaing production unit has been entirely designed with the aim of the Toyota Production System (TPS). The plant is made of one single building with the shape of a star, in order to optimise in all stages of the manufacturing process the flow of parts, vehicles and information. Buffer stocks areas are also kept to a minimum.

2.1.3 Toyota Motor Manufacturing Turkey, TMMT

Toyota Motor Manufacturing Turkey is a vehicle production plant located in Adapazari – Turkey. TMMT manufactures Auris and Corolla Verso models. Majority of the production is exported to over 30 countries, which are located mainly in Europe. Today, with an annual production capacity of 150,000 units, Toyota Motor Manufacturing Turkey is one of the ten biggest overseas manufacturing operations of Toyota, and one of the biggest manufacturing companies of Turkey.

Figure 7: TMMT production site

2.1.4 Toyota Motor Manufacturing Poland, TMMP

Toyota Motor Manufacturing Poland Sp. Zo. o. in Walbrzych was established in 1999. TMMP manufactures main components (engines and transmissions) for car models produced in Europe and in Africa. The factory produces transmissions for Toyota Aygo, Yaris, Auris, Corolla, Corolla Verso, Avensis, Citroen C1, Peugeot 107 and engines for Toyota Aygo, Yaris, Citroen C1 and Peugeot 107. The annual production capacity is 720,000 gearbox and 330,000 engines.

Figure 8: TMMP production site

The factory in Walbrzych in terms of production volume is one of Toyota's largest component production based outside Japan.

2.1.5 Toyota Motor Industries Poland, TMIP

Toyota Motor Industries Poland Sp. Zo. o. in Jelcz-Laskowice was established in 2002 as a joint-venture of two companies from Toyota: Toyota Motor Engineering & Manufacturing Europe SA / NV (TMEM), whose task is to manage the activities of Toyota's European plants in the field of technology and production, and Toyota Industries Corporation (Tico) from Japan.

The plant produces 2.0 and 2.2-litre diesel engines D-4D for the Avensis, Auris and Corolla Verso. The annual production capacity of the plant is 180,000 engines.

Figure 9: TMIP production site

2.1.6 Toyota Peugeot Citroën Automobile, TPCA

Toyota Peugeot Citroën Automobile (TPCA) was established in 2005 as a joint-venture of Toyota Motor Corporation and PSA Peugeot Citroën. Cooperation of the two car manufacturers allows use of the most advanced and most efficient technologies in the automotive industry.

In TPCA, Toyota is in charge of the production, and applies the TPS (Toyota Production System) to guarantee production efficiency. The annual production capacity of the plant is 300,000 units of which 100,000 are Toyota Aygos.

Figure 10: TPCA production site

2.2 EMCs data analysis

All data can be found in more details in Appendix II.

2.2.1 Energy use

Source: Energy use: TME, KPI data FY07 for Sustainability Report 2008 [1]

The total energy use of the plant reflects the size of the production plant: the more it produces, the higher the energy use will be. The relationship between the 2 variables is shown in the *Figure 11*.

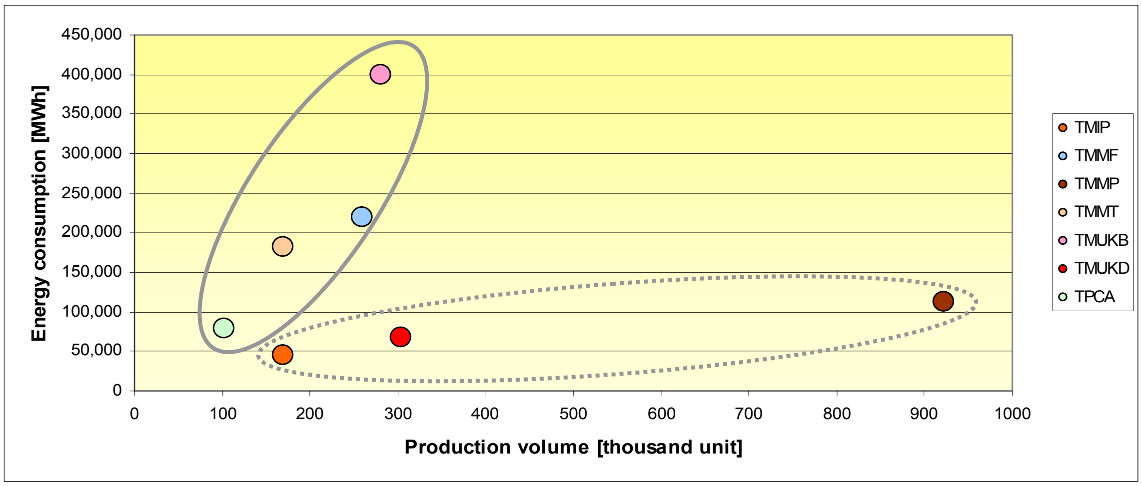


Figure 11: Production volume and energy use of the EMCs

Note: Distinction between vehicle and unit manufacturing plants.

2.2.2 CO_2 emissions

Sources: Enerpresse, Carbon Trust, EDF and national statistics.

The total energy-related CO_2 emission of a plant is linked to the energy use by the CO_2 emission factor presented further in this chapter. The relationship between the production volume and the CO_2 emissions is visualised in the *Figure 12*.

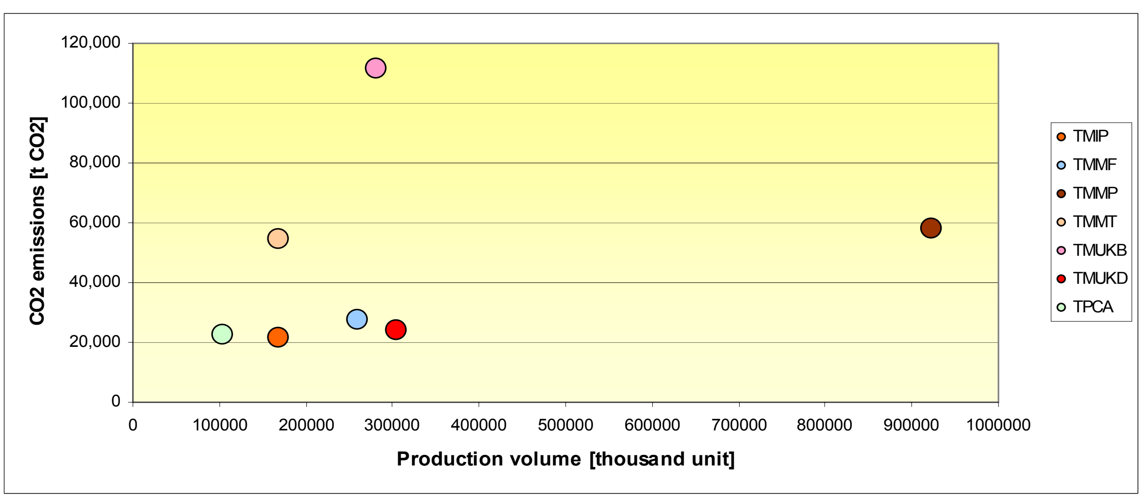


Figure 12: Production volume and CO_2 emissions of the EMCs

2.2.3 Energy cost

The energy prices are calculated as the energy invoice divided by the energy use. Electricity and gas are plotted separately in *Figure 60* and *Figure 61* in Appendix II.

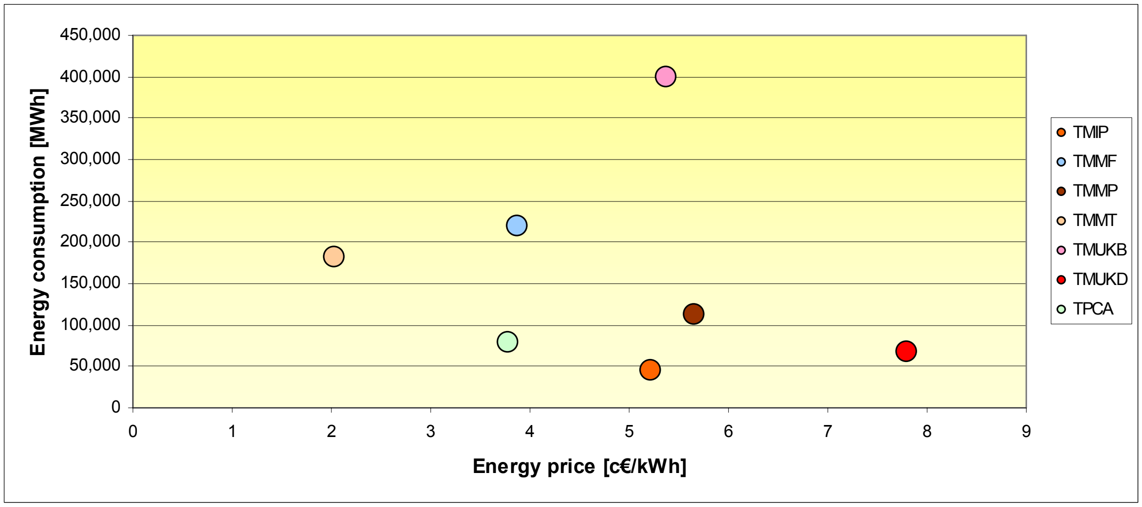


Figure 13: Energy price and consumption of the EMCs

2.2.4 Security of supply

Sources: Energy suppliers annual report, *BP Statistical Review of World Energy* (June 2008), Eurostat statistical yearbook 2008 - *Europe in figures* available on EC website [4]

The national statistics for energy imports are shown in the *Figure 14* and the natural gas imports in EMCs energy consumption in *Table 14*.

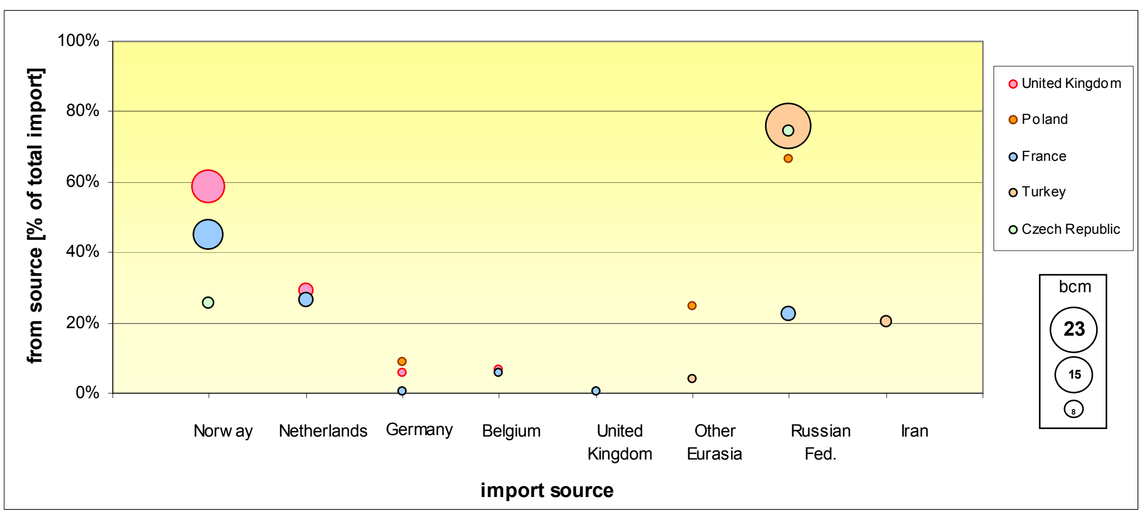


Figure 14: Security of supply at national level

The import sources on the left side of the graph are the most secured ones. The vertical axis represents the % of net import in gross inland consumption. The size of the dots represents the amount of imported energy in billion cubic meters (bcm).

Table 4: Security of supply of the EMCs (natural gas imports)

	Natural gas in electricity mix [%]	Total gas consumption (elec.+heat) [MWh]	Natural gas imports [%]	Total imported gas [MWh]	**Imports in energy mix [%]**
TMIP	1.8%	17,139	67.9%	11,635	**26.31%**
TMMP	1.8%	36,047	67.9%	24,470	**21.83%**
TMUKD	39.0%	40,013	19.3%	7,722.	**11.39%**
TMUKB	39.0%	309,853	19.3%	59,801	**14.94%**
TMMF	5.0%	125,165	80.6%	100,849	**45.96%**
TMMT	44.0%	139,150	87.2%	121,271	**66.88%**
TPCA	5.0%	52,455	97.0%	50,864	**65.36%**

2.2.5 Renewable energy sources

Sources: Proposal for a directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources*, Eurostat *European Energy and Transport Trends to 2030 - update 2007* [4], energy suppliers latest data available on their websites (see *Table 5*)

The European Commission has set challenging targets in the context of Climate Action programme which includes environmental and sustainable measures for the management of resources and their implementation as part of the EU's external policy. The EC is aiming at the so-called *20-20-20 targets*: reduction by 20% of GHG emissions, 20% share of energy from RES in the overall energy mix and 20% energy efficiency improvement by 2020. This programme aiming at reducing the EU dependence on fossil fuels imports (in particular oil and natural gas). The targets distribution among the member states is shown in the *Figure 15*. More detailed RES share evolution in final energy use are plotted in the next page (*Figure 16* to *Figure 20*) and the specific energy mix from energy suppliers are shown in the *Table 5*.

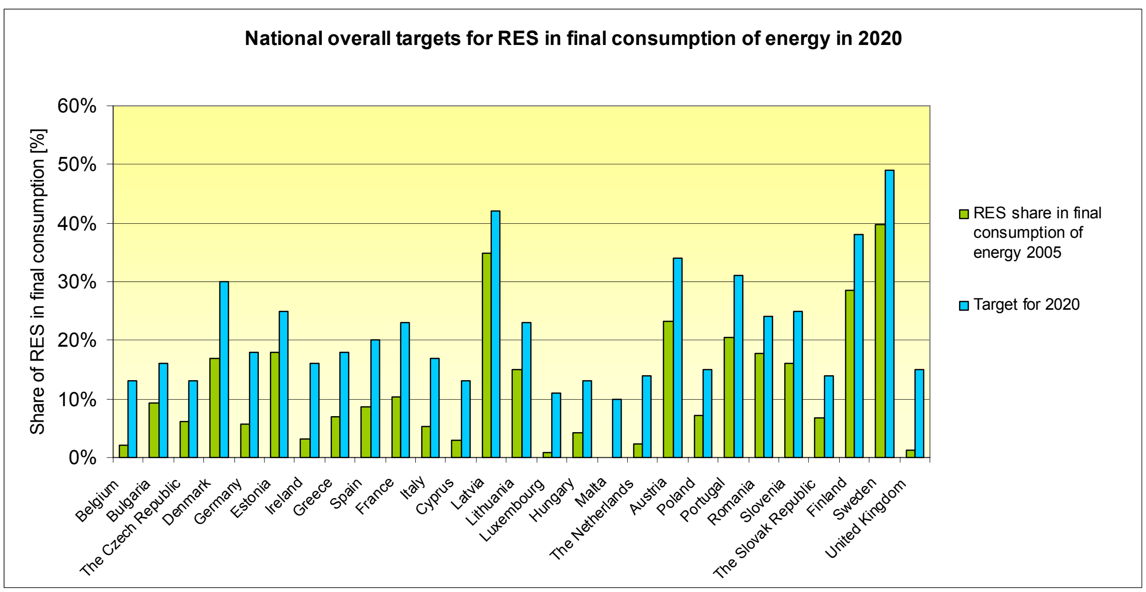


Figure 15: RES share in final energy use (2005) and target for 2020

* Text available on EUR-Lex website

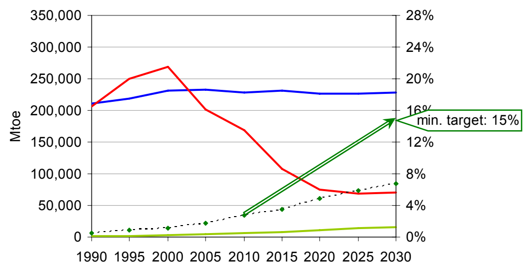


Figure 16: RES in UK

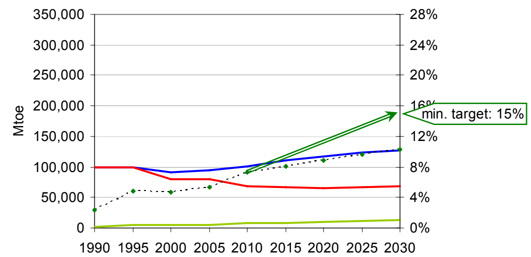


Figure 17: RES in Poland

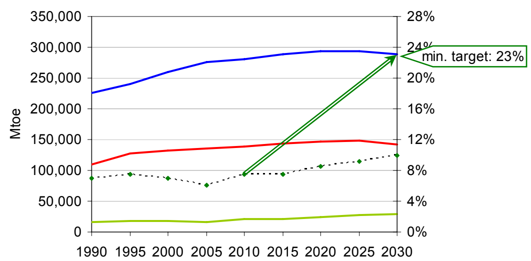


Figure 18: RES in France

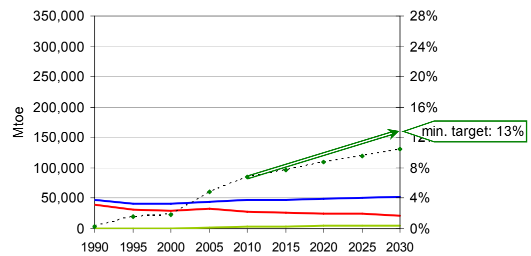


Figure 19: RES in Czech Republic

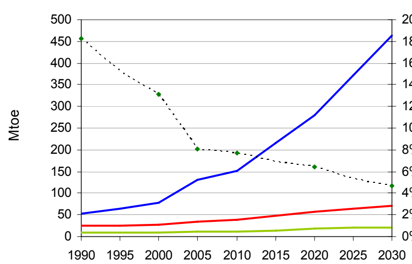


Figure 20: RES in Turkey

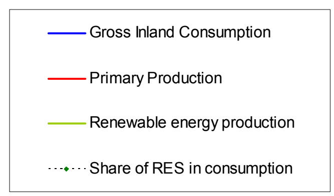
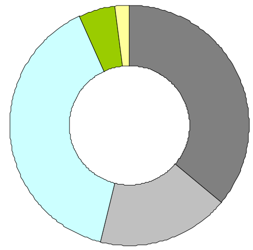
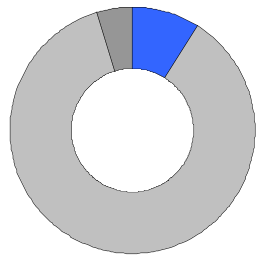
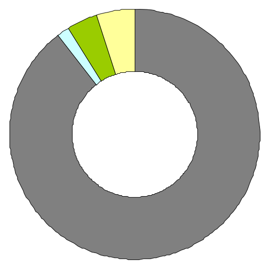
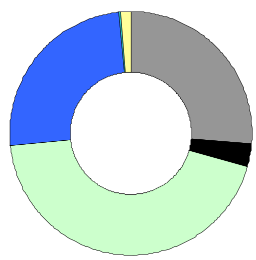
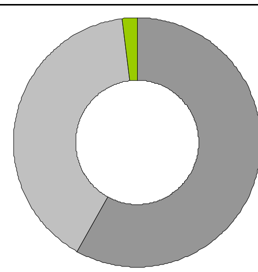


Table 5: EMC electricity supplier energy mix

UNITED KINGDOM[5] TMUK-B & TMUK-D centrica		Coal: 36% Nuclear: 18% Natural gas: 39% Renewables: 5% Other: 2%
FRANCE[6] TMMF eDF		Hydro: 9% Nuclear: 86% Fossil fuel: 5%
POLAND[7] TMMP & TMIP EnergiaPro Gigawat sp. z o.o. ENERGIAPRO		Coal: 89.37% Natural gas: 1.77% Renewables: 3.73% Other: 5.13%
TURKEY[8] TMMT ENERJISA		Coal: 26.3% Oil: 3.1% Natural gas: 44.0% Hydro: 25.1% Wind: 0.1% Other: 1.5%
CZECH REPUBLIC[9] TPCA CEZ GROUP		Fossil fuels: 58% (of which ~5% is gas) Nuclear: 40% Renewables:2%

2.3 Summary

Below, the summary and aggregation of all the data presented previously to visualize the global impact of each EMC activities for FY07. The *Table 6* below shows the results of a study made in the beginning of the internship. The scores range from 1 to 8 and the higher the score is, the higher the priority will be for the EMC to take action and reduce CO_2 emissions from its activities. The different contribution of each criterion is shown in the *Figure 21* on next page.

Table 6: Scores and ranking

In **bold**, key issues contributing to high score

data for part production plants ranked separately from vehicle production plants

		A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A	
	Production Volume	Total energy	Energy per unit	Total CO_2	CO_2 intensity	CO_2 per unit	Total energy cost	Energy price	Energy cost per unit	Security of supply	Distance-to-legal-target	RES in final energy use	RES in final energy use 2020	**Total score**	**Ranking**
TMUK-B	8.0	**8.0**	**8.0**	**8.0**	4.3	**8.0**	**8.0**	**5.5**	**8.0**	1.5	5.6	6.6	4.6	**76.2**	**1**
TMMF	7.4	4.4	4.7	2.0	1.9	2.1	3.2	4.0	3.4	5.7	**8.0**	4.9	3.2	**47.6**	**5**
TMMT	4.8	3.6	6.0	3.9	4.6	6.5	1.4	2.1	2.3	**8.0**	0.0	0.0	0.0	**38.4**	**7**
TPCA	2.9	1.6	4.2	1.6	4.5	4.4	1.1	3.9	3.0	3.0	5.2	**7.5**	4.2	**44.3**	**6**
TMUK-D	2.6	1.4	6.8	1.7	5.4	4.9	1.9	**8.0**	**8.0**	1.5	4.9	5.4	1.9	**52.0**	**3**
TMMP	8.0	2.2	3.7	4.2	**8.0**	3.9	2.3	5.8	3.2	2.0	5.3	6.0	1.2	**47.8**	**4**
TMIP	1.5	0.9	**8.0**	1.5	**7.6**	**8.0**	0.9	5.4	6.4	2.0	5.4	6.2	1.8	**54.1**	**2**

TMUK-B is clearly the highest priority due to its size (largest vehicle production plant), high energy price in UK (particularly electricity price), 75% of the electricity is produced from fossil fuels resulting in high CO_2 emissions and in a big gap with EU target for RES in final energy use by 2020. TMUK-D also scores high, obtaining the 3rd place in the ranking, for the same reasons except that it is a smaller production plant for engine parts and its electricity-to-gas ratio (it uses twice more electricity than gas). The only area where the UK plants are having low scores is security of supply (the blue block).

The two Polish plants also obtained high scores mainly due to the carbon content of electricity with close to 90% of electricity mix coming from fossil fuels (the green blocks). The main difference between the 2 plants is the production volume. TMMP produces engines and transmissions counted as independent units (1 engine + 1 transmission = 2 units). Its *energy use per unit* is the lowest one (less than half of TMIP *energy use per unit*). It is ranked 4th with a production volume more than 5 times higher than TMIP (ranked 2nd) which produces only engines.

TMUK-D and TMIP are very close in the total score. The sensitive points are the *per unit* criteria. On the one hand TMIP has a lower production energy efficiency (light red block) due to its relatively small size (TMUK-D production volume is twice higher than TMIP's one) and higher CO_2 emissions per unit (light green block), and on the other hand TMUK-D has the highest energy cost (yellow blocks).

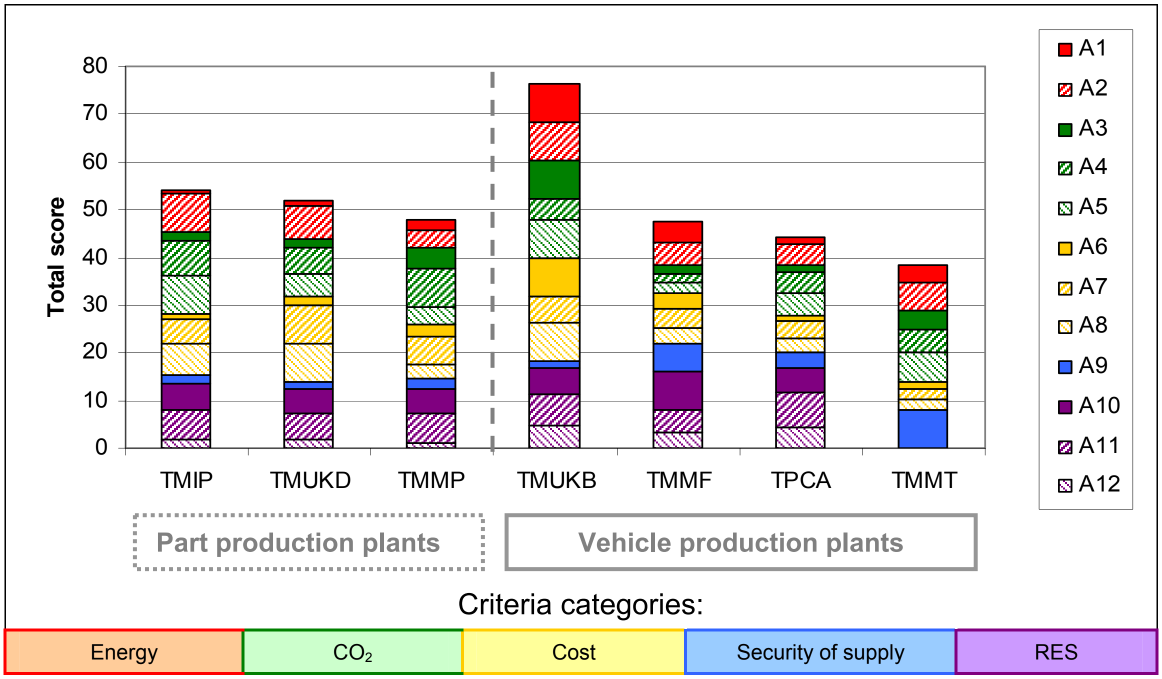


Figure 21: Total scores

TMMF is coming next at the 5th position, with the highest score in the criterion *distance-to-legal-target* (dark purple block): the European Commission has fixed its target to 23% of energy from RES in final energy use by 2020. Compared to the other countries where Toyota EMCs are located, this target is the highest and the most challenging one. The target is set at a national level and it is the government's and energy supplier's responsibility to use adapted incentives to reach this target. The reason for this criterion to be used is the proactive nature of the company which always targets the legal requirements as a minimum and not as an ultimate target. Another way to consider this criterion could be to use the opposite philosophy and reverse its weight in the total score: if the national energy mix is far from the target, the government and energy suppliers will do the necessary to reach it in due time, thus there is less left for the EMC to do. Regarding the other criteria, TMMF has a very low score for the CO_2 and energy cost categories (green and yellow blocks).

TPCA is ranked 6th with the lowest energy use per vehicle produced (highest production volume is Peugeot and Citroen included and smallest vehicle produced). TMMF and TPCA are the most recent manufacturing sites design to apply TPS and thus the most energy efficient EMCs.

TMMT is ranked 7th. The reasons behind TMMT low score are the *cost* (A6, A7 and A8) and the *RES* categories(A10, A11 and A12): its electricity and gas prices are the lowest of all the EMCs, Turkey does not have any legal target since it is not an EU Member State and 25.1% of Turkish electricity is generated from hydropower. On the other hand TMMT has the highest score for the criterion *security of supply* (A9) since 72% of the energy used in Turkey is imported (mostly from Russia), high energy consumption per unit and high CO_2 emissions (73.4% of electricity generated from fossil fuels). It is important to note that TMMT would be ranked 4th after TMUK-B, TMIP and TMUK-D if the *RES* category (A10, A11 and A12) is excluded.

The EMC scores are also shown in radar charts (*Figure 22*) to visualize different problematic area(s) of each EMCs: the largest the area is, the highest the (environmental, economical) impact of the EMC is. The aim is to reduce this area as much as possible (example with TMMF: lower energy consumption, lower CO_2 emissions, less energy imports… but increased energy cost).

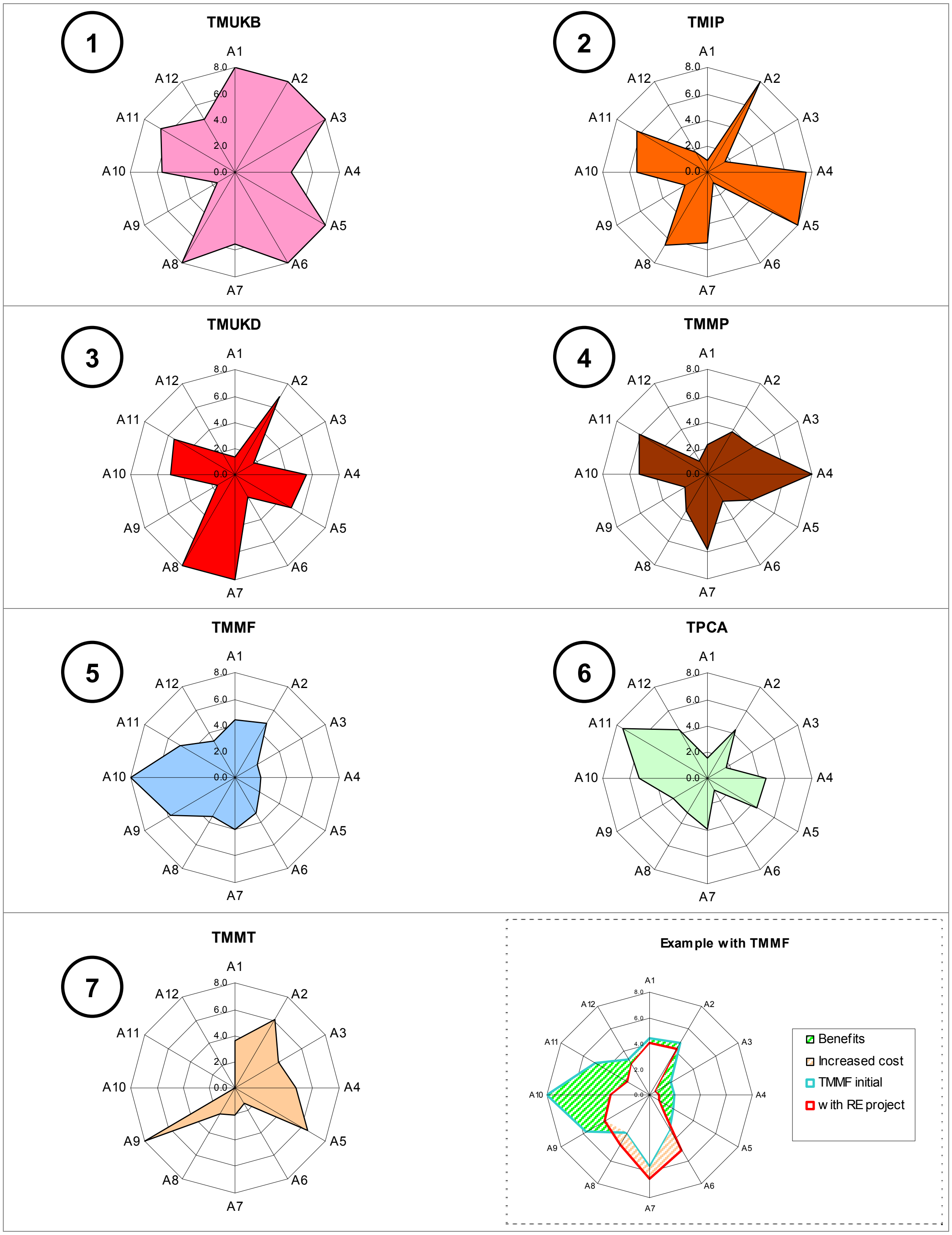


Figure 22: Results of the EMC evaluation in radar charts

3 TECHNOLOGY ASSESSMENT

3.1 Available energy sources and technologies

A total of seven energy sources are considered as alternatives to nuclear and fossil fuel (see list in *Table 7*).

Note: For more detailed description of the technology, see EC atlas of renewable energies[*]

Table 7: List of energy sources

		Renewable
1	Hydropower	✓
2	Biomass	✓
3	Non-renewable waste	
4	Solar	✓
5	Wind	✓
6	Geothermal	✓
7	Marine	✓

For each alternative energy source, several types of technology category can be distinguished as shown in the list below (*Table 8*).

Table 8: List of technology categories

		Electricity	Heat
1	Hydro large-scale	✓	
	Hydro small-scale	✓	
	Hydro pumped storage	✓	
2	Solid biomass[†] heating		✓
	Solid biomass CHP	✓	✓
	Biogas	✓	✓
	Liquid biofuels	✓	✓
3	Waste-to-energy heating		✓
	Waste-to-energy elec.-only[‡]	✓	
	Waste-to-energy CHP	✓	✓
4	Solar PV	✓	
	Solar air/water heating		✓
	Concentrated solar power	✓	
5	Wind turbine onshore	✓	
	Wind turbine offshore	✓	
6	Geothermal heating		✓
	Geothermal CHP	✓	✓
	Ground-source heat pump		✓
7	Wave	✓	
	Tidal	✓	
	OTEC (Ocean Thermal Energy Conversion)	✓	

[*] Renewables Overview, ATLAS Project [4]

[†] Including wood products, agricultural residues and other renewable waste (waste produced by households, industry, hospitals and the tertiary sector which contains **biodegradable** materials which are incinerated at specific installations).

[‡] In some countries (UK, Italy and Spain for instance), support for electricity generation from waste give has encouraged electrical recovery ahead of heat recovery and energy efficiency (*Source:* BREF, EC, August 2006)

3.1.1 Market share*

Source: Eurostat 2006

The energy generated from RES in EU27 is 1,215.77 TWh, equivalent to 9.2% of the final energy use. Biomass is the most important source of renewable energy and represents 68.9% of the total RES used in EU27.The second largest RES is hydro power with 20.5% followed by wind power (5.5%) and geothermal (4.3%).

The market share of the different technology per type of RES is summarised in *Table 9* below.

Table 9: Technology market share

(with corresponding legend for *Figure 23*)	Energy generation [TWh]	
	Electricity	**Heat**
Large hydro	319.10	
Small hydro	44.00	
Biomass from wood	45.85	663.00
Waste-to-energy	13.96	20.90
Wind onshore	72.90	
Wind offshore	10.00	
Solar PV	2.50	
Solar heating		8.14
Concentrated solar power	~0.00	
Geothermal	5.70	9.22
Marine	0.50	
TOTAL	**514.51**	**701.26**
	1,215.77	

Heat from biomass and large scale hydropower are the most common type of renewable energy sources. The market shares are visualised in *Figure 23* below **(Note that Y-axis is in logarithmic scale)**.

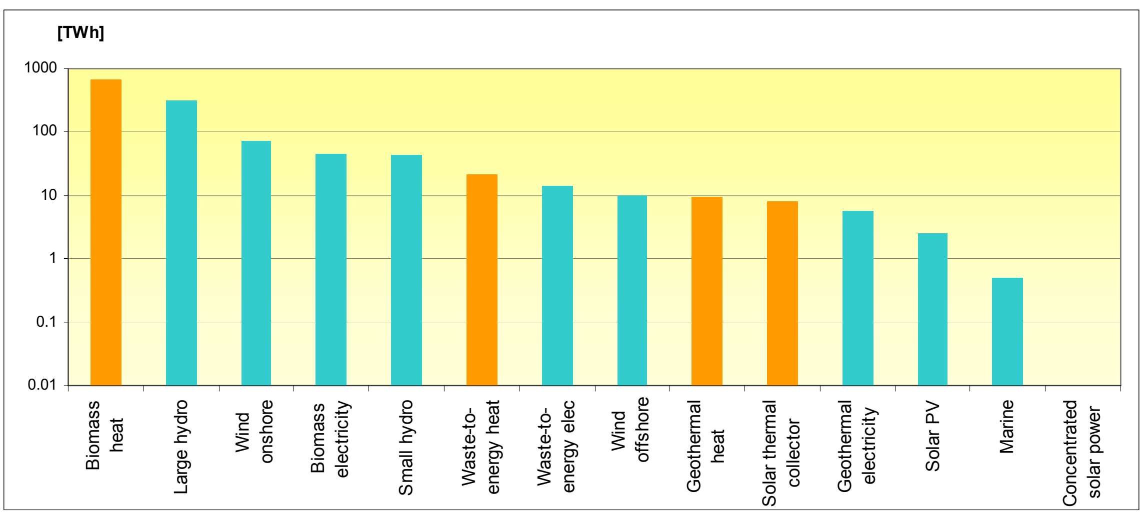


Figure 23: Actual energy generation in EU

* From latest data available on Eurostat and EurObserv'ER Barometers (statistics for 2006 and 2007 mostly)

3.1.2 Energy generation cost

The average energy generation cost in the middle column of *Table 10* includes capital cost, fuel cost (for biomass, mine, landfill and sewage gas), service costs (maintenance and repairs), operation cost (personnel for technical plant operation, insurance, administrative and leasing costs) and other variable costs for supplies, such as additional water, lubricating oil, the plant's own electricity requirement and disposal of residual materials. The minimum and maximum values are shown to give an idea of the cost range depending on the energy generating technology used.

Note: Cost values are based on 2006 level, with investment cost depreciate over the technical lifetime of the installation (20 years for waste, wind, geothermal and marine technology, 30 years for solar and biomass, and 35 years for hydro) using a discount rate of 5%.

Table 10: Energy generation cost

(with corresponding legend for *Figure 24*)	Generation cost [c€/kWh] *		
	Min ⊥	**Average**† ■	*Max* T
Large hydro	*3.0*	**3.0**	*15.0*
Small hydro	*3.0*	**4.4**	*18.0*
Biomass from wood (CHP)	*4.5*	**5.8**	*18.0*
Biomass from wood (h)	*1.5*	**4.5**	*9.0*
Waste-to-energy	*1.0*	**5.4**	*7.0*
Wind onshore	*3.5*	**4.8**	*7.2*
Wind offshore	*4.0*	**5.8**	*12.0*
Solar PV	*20.0*	**23.3**	*240.0*
Concentrated solar power	*18.0*	**20.0**	*51.0*
Solar heating	*3.0*	**8.7**	*37.5*
Geothermal (e)	*3.0*	**6.0**	*15.0*
Geothermal (h) *includes GSHP*	*0.8*	**3.0**	*7.5*
Marine	*8.0*	**8.7**	*37.5*

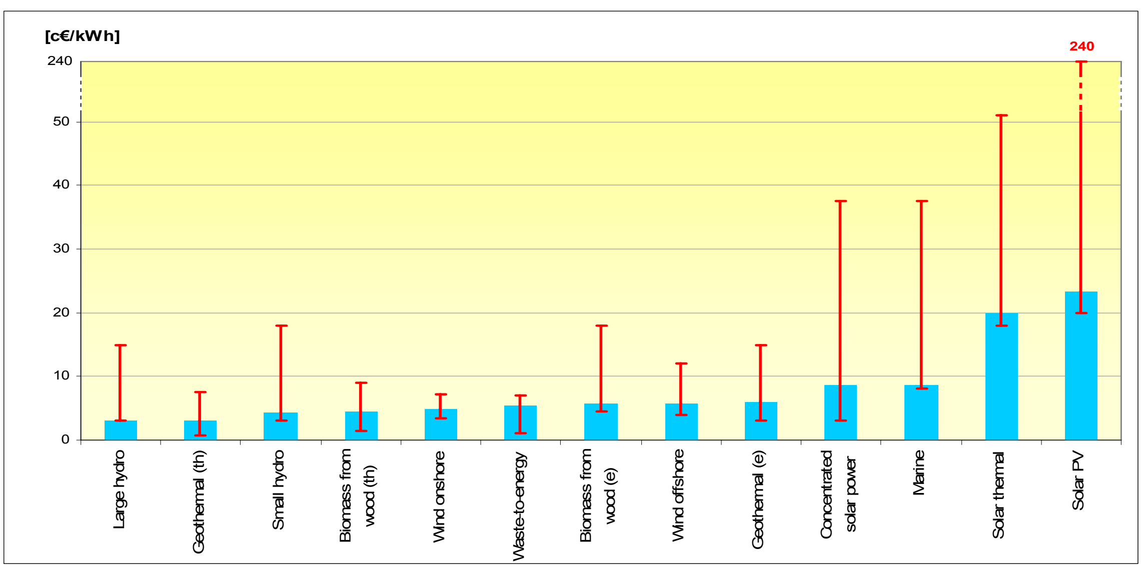


Figure 24: Average generation cost

* Minimum and maximum values in black from World Energy Assessment report, 2001 - update 2004, available on UNDP website, Values in red are assumptions (average values from various data sources: REN21, IEA, EC…)

† International average cost from energy calculator by IEA-RETD, available on IEA-RETD website[10]

3.1.3 Carbon footprint

The carbon footprint of the different technologies generating energy from renewable sources is summarised in *Table 9* below.

Table 11: Carbon footprint data sets (5 data sources)

[g CO_2-eq. / kWh]	EU Energy Policy Data*	CFP of electricity†	eBook X‡	eJournal Y§	eJournal Z**
Large hydro	20	10-30	4	10.6	3-43
Small hydro	5	<5		13.8	
Biomass from wood (CHP)	30	25-93	-160	27.2-86.1	35-99
Biomass from wood (h)	34			21.6-36.0	
Waste-to-energy					
Biogas				-580.0 (?)	
Wind onshore	30	4.64	7	10.8	8-30
Wind offshore	10	5.25		9.1	9-19
Solar PV	100	35-58	5	104.2	43-73
Solar heating	*Very low*		3	21.6	
Concentrated solar power				14.2	
Geothermal (e)				40.8	
Geothermal (h)	*Very low*				
Marine		25-50			

Note: Single values correspond to average or most common technology CFP. The lowest value for large hydro corresponds to scheme without storage. The lowest value for biomass electricity corresponds to wood co-combustion and for biomass heat to wood combustion plant. The highest values for wood biomass correspond to SRF (short rotation forestry). The average values for solar PV correspond to polycrystalline Si cells.

As it is clearly shown in this table, carbon footprinting of energy technologies gives a very wide range of results (the blue bar represents the average C-footprint and in red the range of data obtained with different considerations and methods).

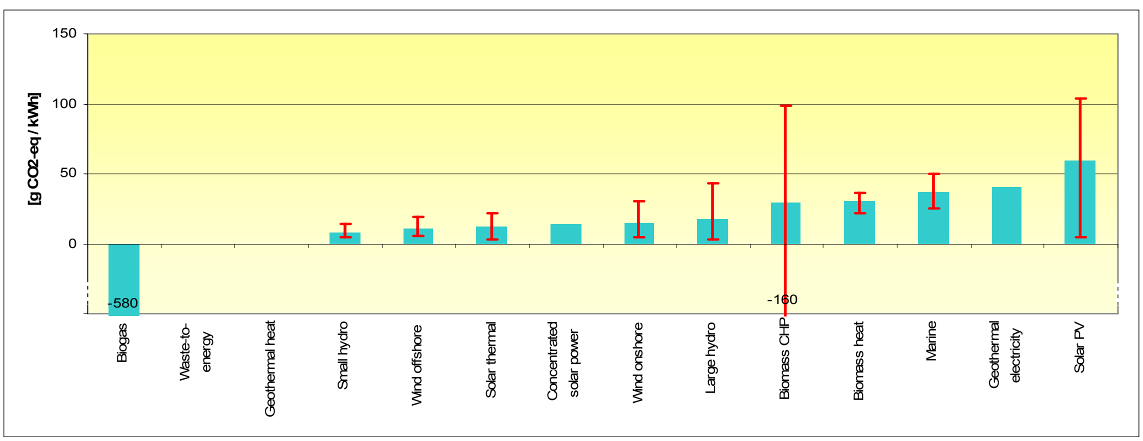


Figure 25: RES technology carbon footprint

* *Commission staff working document - EU Energy Policy Data*, available on EC website[4]

† UK Parliament, Postnote 268, October 2006, http://www.parliament.uk/parliamentary_offices/post/environment.cfm

‡ *Power Generation Technologies*, Paul Breeze (2005), Chapter 2: Environmental considerations

§ *Dynamic LCA of RE technologies*, Martin Pehnt (2005), Renewable Energy 31, January 2006, Pages 55-71

** *A guide to life-cycle GHG emissions from electric supply technologies*, Daniel Weisser (2006), Energy 32, September 2007, Pages 1543-1559

3.2 Technology selection for the assessment

As defined in the first chapter, the focus of this study is on on-site energy generation. Thus large-scale hydropower, off-shore wind turbines and marine technologies will not be considered as applicable for this study. Solar electricity alternatives are also excluded to focus on the most economically viable solution. Finally, geothermal heating and geothermal electricity generation has also been removed from the selection due to the location of the EMCs: the enthalpy is not exceptionally high in those regions. Only ground-source heat pumps will be used for space and water heating.

Table 12: Technology selection

	Selection	Reason for exclusion
Large hydro	✗	N/A
Small hydro	✓	
Biomass from wood (CHP)	✓	
Biomass from wood (heat)	✓	
Waste-to-energy (heat)	✓	
Waste-to-energy (CHP)	✓	
Wind onshore	✓	
Wind offshore	✗	N/A
Solar PV	✗	Lack of incentives in most of the EMCs
Concentrated solar power	✗	Insufficient resources in most of the EMCs
Solar heating	✓	
Geothermal heating	✗	Insufficient resources in most of the EMCs
Geothermal CHP	✗	Insufficient resources in most of the EMCs
Ground-source heat pump	✓	
Marine	✗	N/A

3.3 Assumptions

3.3.1 Energy generation technology

The first major assumption in this chapter will be the choice of specific energy generation technologies. For each type of energy source, we assume the use of the same technology in all plants, allowing the application of a single calculation template for all plants. Moreover, the same installation (and same installed capacity) will be considered to be able to fairly compare the performance of the technologies. In the following table, the installed capacity are expressed as the *maximum power output* for hydro, wind, heat pump and solar technologies, and as the fuel power input for biomass and waste-to-energy technologies.

Table 13: Technologies and size of the installations used for calculations

Small hydro	2.5 MW_e run-off river power station, without storage
Wind	2 MW_e wind turbine, Enercon E82
Ground-source heat pump	500 kW_{th} field of 100 borehole heat exchangers, 150 m deep
Solar heating	280 kW_{th} (~300 m^2) of water-based glazed flat plate collectors
Biomass heating	2 MW_{fuel} CFB water boiler
Biomass CHP	2 MW_{fuel} CFB boiler and steam turbine
Waste-to-energy heating	100 kW_{fuel} grate-fired water boiler
Waste-to-energy CHP	100 kW_{fuel} grate-fired boiler and steam turbine

3.3.2 Investment and O&M costs

The investment costs include all the costs incurred in producing a complete commissioned plant. Typical standard costs (see *Table 14*) for the chosen energy generation technologies are used in this chapter.

Table 14: Investment costs

	Unitary cost	Fixed O&M cost	Variable O&M cost	Source
Small hydro	2400 €/kW	50 €/kW/year	-	*
Wind	930 €/kW	28.5 €/kW/year	-	*
Solar heating	500 €/m^2	1.5% of investment	-	*
Ground-source heat pump	1100 €/kW	6 €/kW/year	-	†
Biomass heating	600 €/kW	2% of investment	15 €/MWh	†
Biomass CHP	3400 €/kW_e	4% of investment	15 €/MWh	†
Waste-to-energy heating	900 €/kW	49 €/kW/year	5.1 €/MWh	†
Waste-to-energy CHP	6800 €/kW_e	272 €/kW_e/year	25 €/MWh	†

3.3.3 COP and energy efficiency

The energy efficiencies (or conversion efficiency to include losses between energy fed into the system and energy actually used) are given in the table below:

Table 15: Energy conversion efficiencies

	Hydro	Wind	Solar	Biomass (th)	Biomass (CHP)	Waste (th)	Waste (CHP)
η	100%	100%	55%	80%	90% (η_e=30%)	75%	85% (η_e=25%)

* *Technology Data for Electricity and Heat generating Plants*, Danish Energy Authority et al., March 2005
† *RECaBS project - RE costs and benefits to society*, RETD, IEA, 2007

For ground-source heat pump, the coefficient of performance is defined as the heat energy transferred divided by the electricity supplied to the heat pump. In the calculations, the COP is assumed to be 3.3 on average.

3.3.4 Availability and load factors

The availability factor (A_f) of a power plant can be defined as:

- the amount of time that it is able to produce energy over a certain period divided by the total amount of the time in the period;
- its maximum power output in the local conditions divided by its maximum capacity if it was in the best running condition.

$$A_f = \frac{\text{amount of time the power plant is able to generate energy}}{\text{total amount of time for the considered period}}$$

The load factor or utilisability factor (L_f) is defined as:

- the actual amount of time the technology is generating energy divided by the total amount of the time in the period;
- the actual power usage divided by the maximum capacity if the technology was in the best running condition.

In this report, it is assumed that the technologies are used at their highest potential without exceeding the demand of the EMC.

$$L_f = \frac{\text{actual amount of time the power plant is generating energy}}{\text{total amount of time for the considered period}}$$

To simplify the calculation, we assume the same load factors, noted L_f, for all plants concerning GSHP, hydro, biomass and WtE technologies.

Table 16: Load factors for GSHP, hydro, biomass and WtE

	GSHP	Hydro	Biomass	Waste
A_f	~100%	45%	90%	90%
L_f	70%	45%	70%	70%

The load factors are limited by the production activities work load on a weekly basis. It is assumed that there is no energy demand on weekend but that energy generation technologies are used at full load during week-days.

For hydropower, the load factor should be calculated from the rated discharge (using the flow duration curve of the river section where the station would be installed), the catchments area and the net head estimation (vertical distance that the water falls through when generating useable power taking into consideration various head losses). Due to the lack of data from the closest water resource from the EMCs, it is assumed that the electrical power supply is available during 3500 hours per year (low average value). Site-specific load factors are used only for wind and solar power.

The annual average wind speed at hub height is calculated from the monthly average wind speed data*:

$$V_{wind\,80m} = V_{ref} \times \frac{\ln\left(z_{80m} / z_0\right)}{\ln\left(z_{ref} / z_0\right)}$$

Equation 1: Wind speed calculation

Where $V_{wind80mi}$ is the average wind speed at 80 meters in m/s, V_{refi} the average wind speed measured at z_{ref}, z_{80m} = 80 meters, z_o the roughness assumed to be 0.55 meters and z_{refi} the height of reference wind speed measurements in meters.

Then the power output curve from the E82 technical data† is used to determine the monthly average power output P_i from the monthly average wind speed data. The load factor is calculated as the sum of the monthly energy output (standard values are varying between 20% and 30%).

Finally solar heating, the average daily solar radiation data from the closest meteorological data will directly used, assuming that all the available solar energy is converted into heat with an energy conversion efficiency of 55% (see *Table 15*).

Table 17: Capacity factors for wind power and solar heating

	TMIP	TMMP	TMUK-D	TMUK-B	TMMF	TMMT	TPCA
Wind speed [m/s]	3.24	6.84	6.57	5.86	6.80	2.81	5.66
Wind energy [MWh/year]	403	4,405	4,487	199	2,777	3,977	2,970
Wind L_f	2.32%	25.69%	22.82%	15.93%	25.23%	1.14%	16.86%
	TMIP	TMMP	TMUK-D	TMUK-B	TMMF	TMMT	TPCA
Solar irradiance [kWh/m^2/yr]	1161.1	1161.1	1097.2	1089.9	1134.2	1463.3	1160.4

* Data from the closest meteorological station and average wind speed from on-site data for TMUK-B, TMMP and TMMF

† See the E82 power curve in *Figure 32* page 43

3.4 Calculation methodology

The first step is to determine the energy generated from the different renewable sources (for now, we assume that the desired amount of energy is the maximum possible with the local conditions/constraints).

$$\boxed{H = 24h \times 365d \times L_f}$$

Equation 2: Annual technical availability

$$\boxed{E_i = P_i \times H}$$

Equation 3: Energy generated from the alternative source in EMC_i

Where H is the annual running time in hours/year, L_f the capacity factor or load factor of the technology, i the EMC index, E_i the energy generated from the alternative source in MWh/year and P_i the electric or thermal capacity in MW.

The amount of avoided CO_2 emissions per year is calculated as follow:

$$\boxed{AvoidedCO_{2i} = E_{elec\,i} \times CO_{2\,elec\,i} + E_{heat\,i} \times CO_{2\,gas_i}}$$

Equation 4: Avoided CO_2 emissions by the use of alternative energy sources in EMC_i

Where $AvoidedCO_{2i}$ is the annual avoided CO_2 emissions in tons of CO_2-eq/year, CO_{2eleci} and CO_{2gasi} the emission factors in tons of CO_2-eq/MWh.

The next step is to calculate the initial investment cost to install P_i of power capacity and the return on investment (or return rate).

$$\boxed{C_{invest\,i} = Cost \times P_i}$$

Equation 5: Initial investment cost for an installation size of P_i

$$\boxed{C_{O\&M\,i} = FixCost \times P_i + VarCost \times E_i}$$

Equation 6: Annual operation and maintenance cost

$$\boxed{C_{benefits_i} = \left(E_{elec\,i} - E_{cons\,i}\right) \times Price_{elec\,i} + E_{heat\,i} \times Price_{gas_i} - C_{O\&M\,i}}$$

Equation 7: Annual economic benefits

Where $C_{investi}$ is the total investment in EMC_i to install P_i in €, $Cost$ the capital investment cost in €/kW, $C_{O\&Mi}$ the annual operation and maintenance cost in €/year, $FixCost$ and $VarCost$ are the fixed and variable operation and maintenance costs in €/MW/year and €/MWh respectively, E_{eleci} and/or E_{heati} the electricity and/or heat generated from the RES in MWh/year, $Price_{eleci}$ and $Price_{gasi}$ the electricity and gas price in €/kWh, E_{consi} the electricity consumed by the technology to be operational in MWh/year.

In France, Czech Republic and Turkey, the feed-in tariff for electricity sold on the grid is used instead of the electricity price in the cases of hydro, wind and biomass CHP technologies.

The life cycle cost is used as a basis for the performance indicators:

$$NPVfactor = 1 + (1-r) + (1-r)^2 + \ldots + (1-r)^{T-1} = \frac{1-(1-r)^T}{r}$$

Equation 8: Net present value factor for life cycle cost calculation

$$C_{LifeCyle_i} = C_{invest\,i} + C_{O\&M\,i} \times NPVfactor$$

Equation 9: Life cycle cost

$$EnergyCost = \frac{C_{LifeCycle}}{E_i \times T}$$

Equation 10: Energy generation cost

$$CO_2Cost = \frac{C_{LifeCycle}}{AvoidedCO_{2i} \times T}$$

Equation 11: CO_2 abatement cost

The life cycle cost is used as a basis for the performance indicator calculations.

3.5 Results

In the following subchapter, the energy generating technologies and the conditions in which they are applied will be shortly described. The economic and environmental performances are calculated on a life cycle basis.

For all the options, it will be assumed that the technology is used at its maximum potential with the given conditions and that the supply never exceeds the demand: all the energy produced is used (or sold on the grid when there is a FIT). Consequently each MWh generated gives some economic benefits. The sizes of the installation (see *Table 13* in chapter 3.3.1) are chosen to "fit" in the energy use of the plant and avoid losses (non-used energy).

Practically, the main concern would be the heat generation since it is not possible to sell it and in the calculations, it is assumed that the heat demand is constant on the monthly average value. The size of the installation is based on the lowest heat demand (July and August). The monthly average temperatures of the EMCs region are shown in *Figure 26* below.

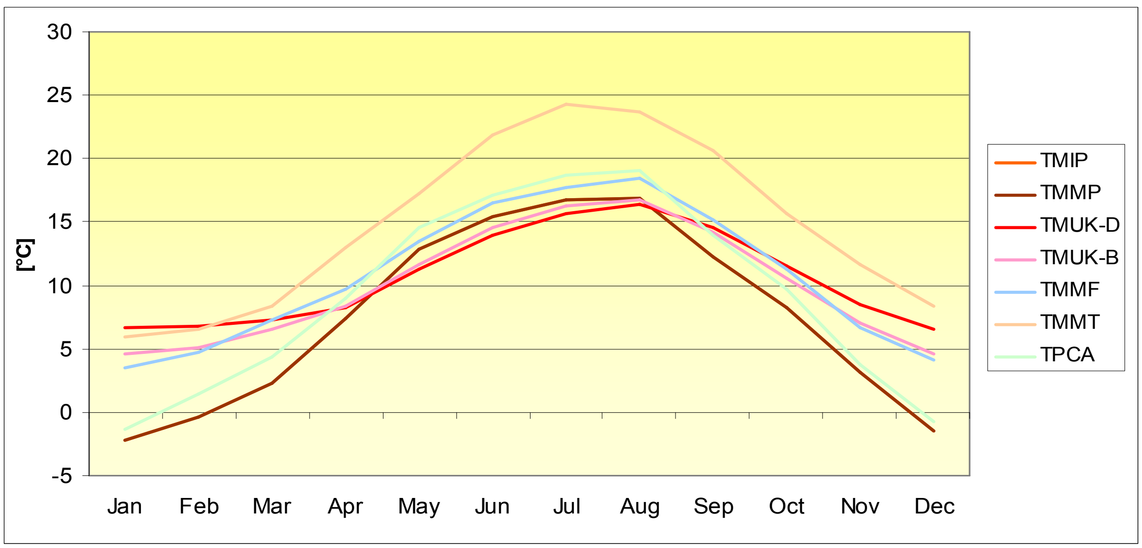


Figure 26: Monthly statistics for dry bulb temperatures [12]

3.5.1 Small hydro

Small hydropower is a more concentrated energy resource, more predictable than wind and solar, has a higher capacity factor and longer life than other renewables. On-site small hydropower generation potential is based on water resources availability to program the water use of the plant (catchment area, mean rain falls and portion of time during which the discharge equals or exceeds certain values). To give an overview of the resource available, the gross hydropower potentials for Europe are shown in *Figure 27* and the precipitation in the EMCs' regions in *Figure 28*.

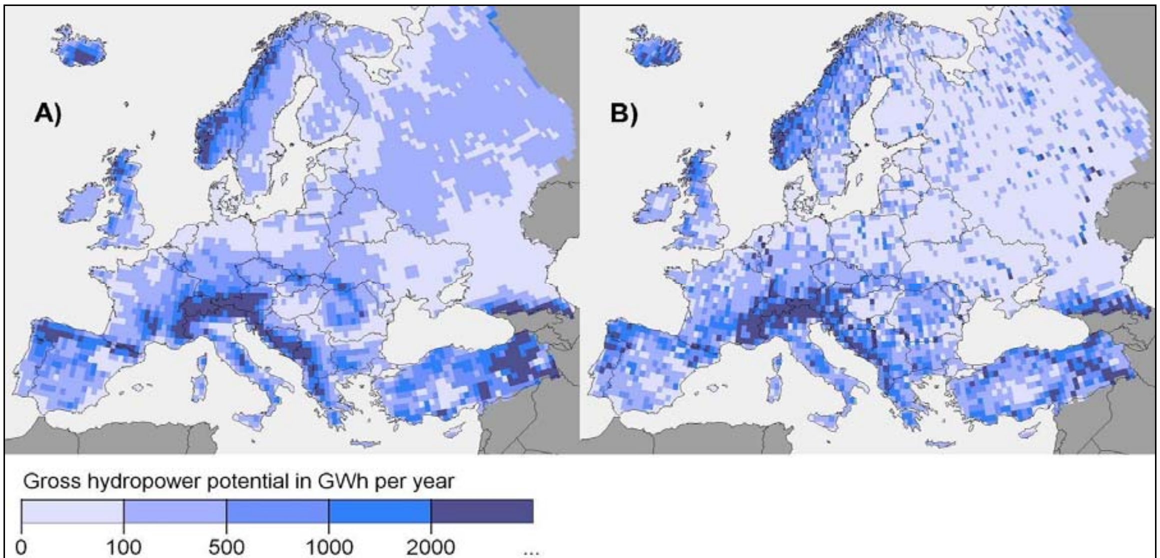


Figure 27: Gross hydropower potentials for Europe [14]

Note: The gross hydropower potentials are calculated following 2 methods: A) map on the left, each cell is assigned its total gross hydropower potential down to sea level; B) map on the right map, only the portion of the gross hydropower potential that can be locally utilized down to the next downstream cell is allocated to each cell.

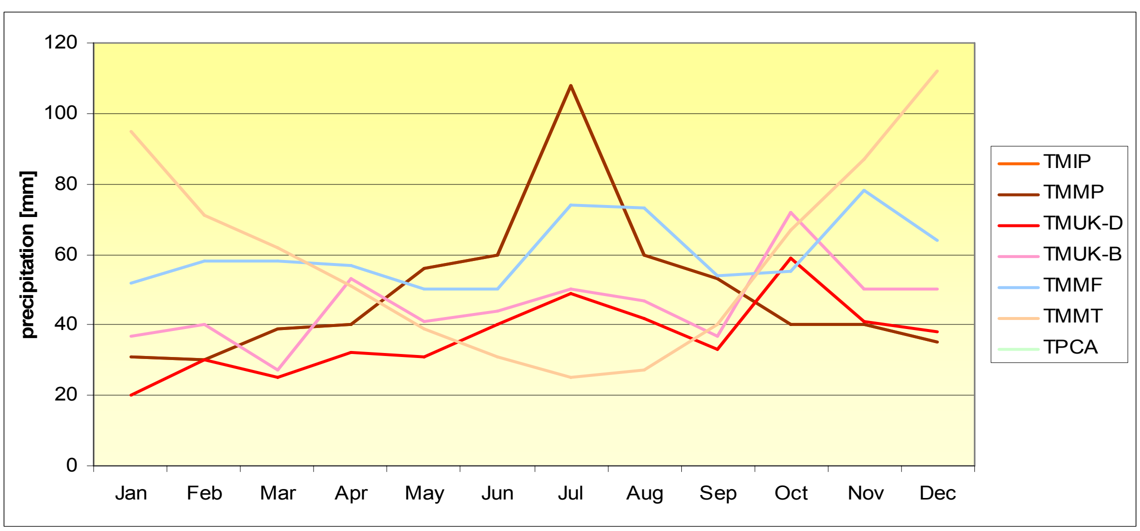


Figure 28: Monthly precipitation [12]

According to the head and discharge available, different types of turbine are used. The *Figure 29* shows the field of application of each type.

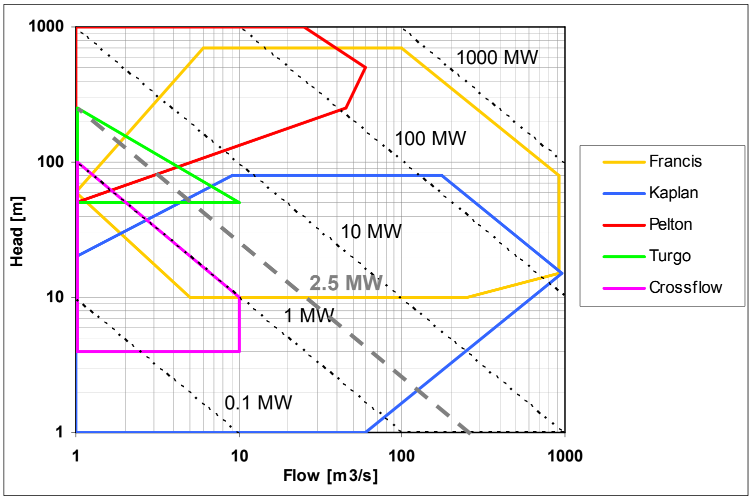


Figure 29: Field of application of different turbine types*

In this report, the selected SHP technology is run-of-river station which operates on base load and uses the incoming river flow continuously with a filling period of less than 2 hours. The main advantage is the low cost investments and constructions and the main disadvantage is energy generation fluctuations: during low flow periods the station cannot operate at its full installed capacity, and on the other hand, flood flows overflow the installation unexploited. The type of turbine is not specified since no data are available for flow and head values. For simplification in the following calculations, it is assumed that hydrological and environmental conditions are suitable to install a power station of 2.5 MW regardless the type of turbine, that permits/approvals/land rights are approved and interconnection/transmission feasible (possibility to extend/rent site where the water stream is). The technical lifetime is 20 years, the turnkey investment cost is 6 M€ per EMC, the annual operation and maintenance cost is 125,000 € (fixed and variable costs included) and the annual electricity output is 9,855 MWh.

Table 18: Small hydro performance

Hydro	TMIP	TMMF	TMMP	TMMT	TMUKB	TMUKD	TPCA
Annual avoided CO_2 [t/yr]	6,554	542	6,554	4,553	4,238	4,238	4,957
Annual benefits [€/yr]	535,096	885,138	557,757	417,025	804,867	872,990	761,950
Economic incentive [€/MWh]		102.5		55			90
Life cycle cost							
Baseline scenario [€]	8,469,215	6,703,552	8,759,969	3,886,429	11,930,460	12,804,497	7,886,409
With RE project [€]	7,603,785	1,346,989	7,603,785	4,535,880	7,603,785	7,603,785	4,110,376
Performance indicator							
Energy cost [€/kWh]	38.58	6.83	38.58	23.01	38.58	38.58	20.85
CO_2 cost [€/kg CO_2]	58.01	124.26	58.01	49.81	89.72	89.72	41.46

In all cases, hydro power gives positive results environmentally and economically. France obtains the best results thanks to the high FIT (6.07 c€/kWh + up to 4.18 c€/kWh with conditions). FIT policy is also applied in TMMT and TPCA (55 and 90 c€/kWh respectively). For the other countries, we assume that the energy generated is directly used on-site and the savings result from the non-purchased electricity.

* *Water turbine - Design and application*, available at http://www.nationmaster.com/encyclopedia/Water-turbine

3.5.2 Wind power

Wind power has the potential to make a major contribution to the world's increasing energy demand: according to Wind Force 12 (publication by GWEC*, EWEA and Greenpeace) 12 % of the world's electricity can be supplied by wind power in 2020.

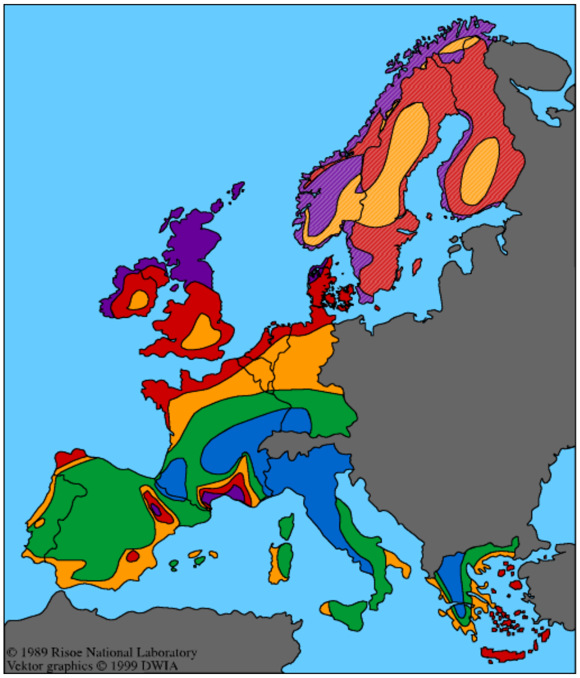


Figure 30: Wind resources in Europe [16]

Wind project feasibility is not only determined by the average wind speed, a large number of parameters are to be considered:

- Min. / max. wind speed and seasonal wind speed variation;
- Wind shear (different wind speed at different height), turbulence (because of obstacles) and roughness (friction with Earth surface);
- Visual effect, noise pollution, bird strikes, soil erosion, radar disturbance…

The average wind speed is recalculated (using the *Equation 1*) from the monthly statistics of the closest meteorological stations (measured at 10 m) and adjusted with values measured on-site for TMMF (7 months from the 28th of November 2002 to the 11th of June 2003) and TMUK-B (currently being done at TMUK-B since March 2008). The *Figure 31* shows the recalculated wind speeds at 80 m.

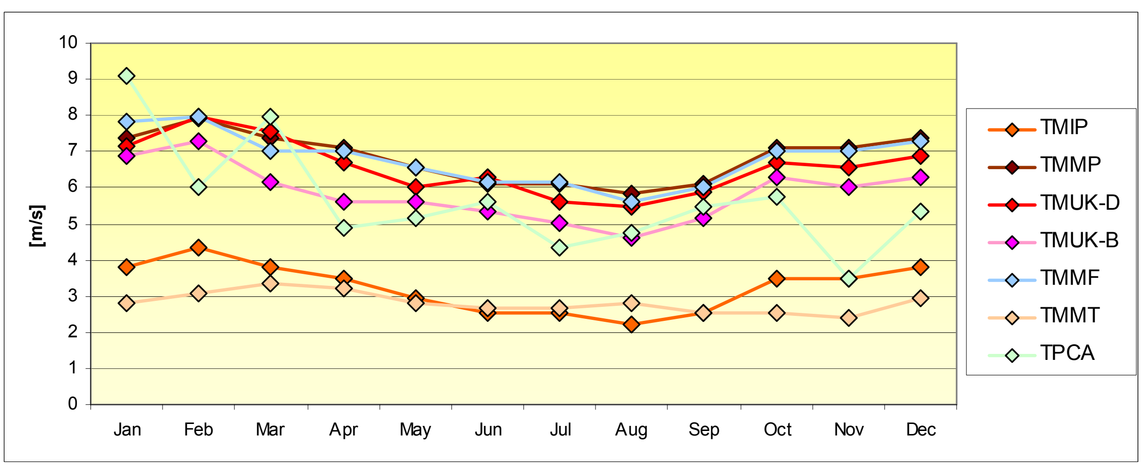


Figure 31: Monthly statistics for wind speeds at 80 meters [12]

* Global Wind Energy Council

The annual average power output per turbine commissioned is calculated on a monthly basis using the technical documentation of a 2 MW turbine: Enercon E82 (see *Figure 32* for the power curve of the E82 turbine).

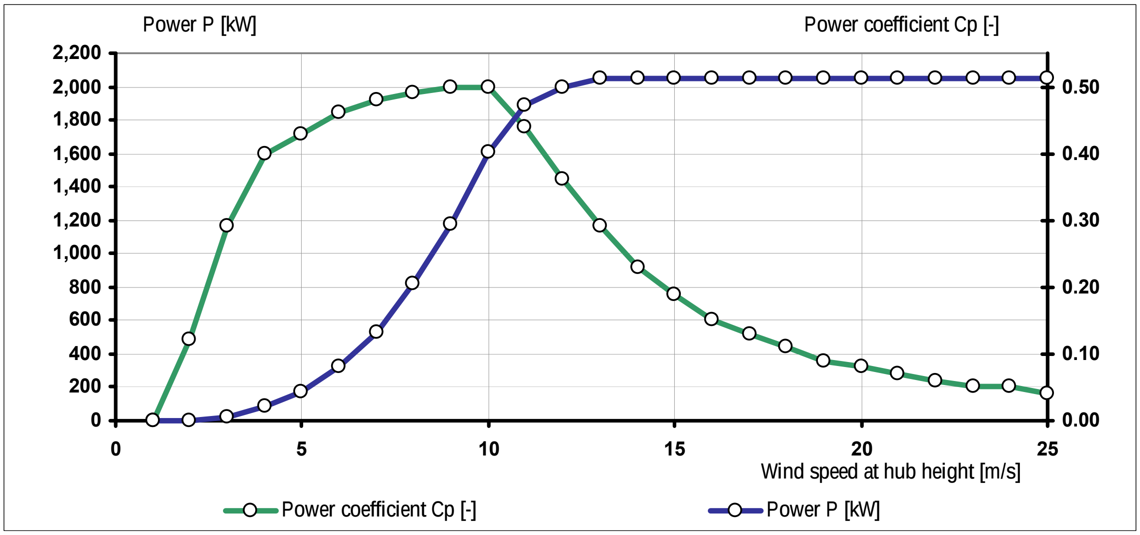


Figure 32: Power curve of the Enercon E82 wind turbine as function of the wind speed [12]

Moreover, it is assumed that construction authorization for one turbine can be obtained on all sites. The calculations are made on a monthly basis for more accuracy. Since the relationship between power output and wind speed is not linear (power curve in blue in the graph above), the results are more accurate when using month-by-month average rather than annual average: the annual energy output can be different for 2 sites having the same annual average wind speed. However, costs will be similar in all EMCs with a turnkey investment of 1.86 M€ for a 2 MW turbine, an O&M cost of 57,000 € per year and with a technical lifetime of 20 years.

Table 19: Wind power performance

Wind	TMIP	TMMF	TMMP	TMMT	TMUKB	TMUKD	TPCA
Wind speed at 80 m	3.24	6.80	6.84	2.81	5.86	6.57	5.66
Load factor	2.30%	25.14%	25.61%	1.14%	15.85%	22.70%	16.95%
Annual electricity [MWh/yr]	403	4,405	4,487	199	2,777	3,977	2,970
Annual avoided CO_2 [t/yr]	268	242	2,984	92	1,194	1,710	1,494
Annual benefits [€/yr]	-30,008	304,201	253,857	-46,047	205,008	345,760	210,271
Economic incentive [€/MWh]		82		55			90
Life cycle cost							
Baseline scenario [€]	346,316	2,996,284	3,988,386	78,532	3,361,643	5,167,529	2,376,471
With RE project [€]	2,591,326	953,304	2,591,326	2,529,334	2,591,326	2,591,326	1,538,631
Performance indicator							
Energy cost [€/kWh]	321.52	10.82	28.88	635.08	46.66	32.58	25.91
CO_2 cost [€/t CO_2]	483.47	196.75	43.42	1,374.62	108.51	75.76	51.50

TMIP and TMMT have the lowest average wind speed (based on the closest meteorological station data). Wind project on those two sites would not give a good economical and environmental performance. All the other EMCs give positive results in terms of economic and environmental performance, but the best performances are obtained in TPCA and TMMP.

3.5.3 Ground-source heat pump

Ground heat source is nearly infinite (inexhaustible in human terms), available all over the world and capable of delivering energy 24 hours a day throughout the year. Ground temperatures between 3 and 20°C (usual shallow underground temperature in European climate) are suitable for heating and cooling using heat pumps.

To quantify the shallow geothermal resource available, ground temperature should be used vs. temperature output need to be known to calculate the "real". The limitation would be the land area available on-site. The seasonal variations of air and ground temperatures are shown below in *Figure 26* (page 39) and *Figure 33* respectively.

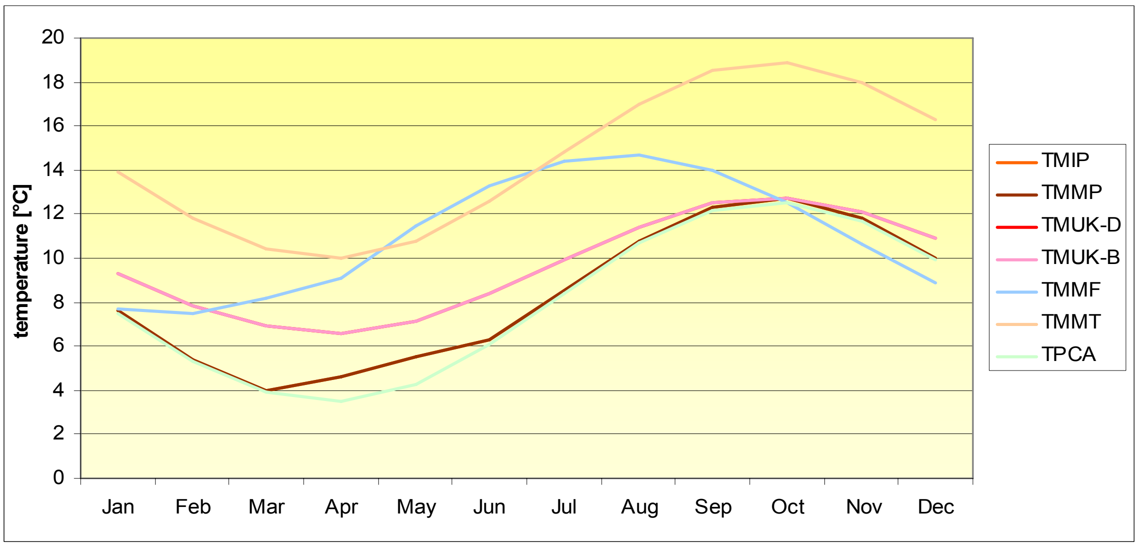


Figure 33: Monthly calculated "undisturbed" ground temperatures, 4 meter deep [12]

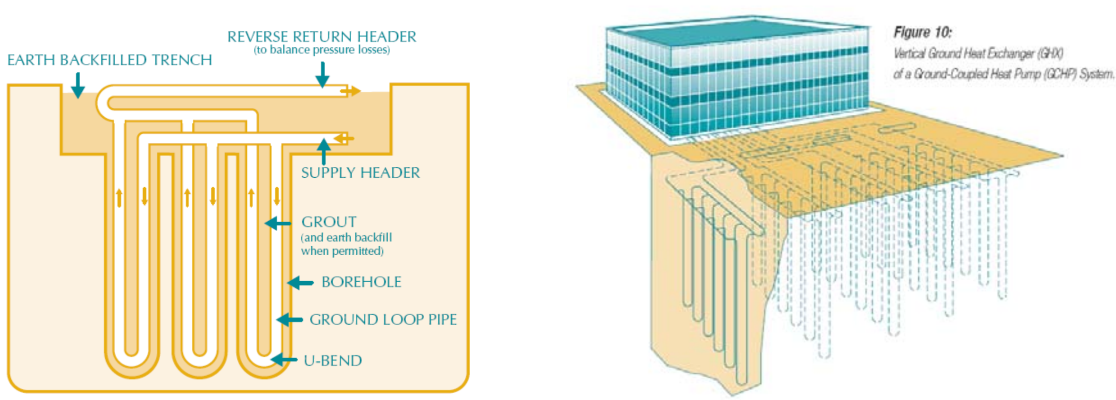


Figure 34: Basic scheme of GSHP with BHE, water/brine circuit*

To simplify the calculations, it is assumed that the COP is the same in all the EMCs (COP = 3.3) and that there is enough land available to install 500 kW_{th} of borehole heat exchangers. The installation required would be a field of 100 BHE, 150 m depth,

* *Ground-Source Heat Pump Project Analysis*, ENGINEERING & CASES TEXTBOOK, RETScreen International, Minister of Natural Resources Canada

covering ~ 5,200 m^2. Experience has shown that for heating purposes a single deep BHE (> 150 m deep) is more efficient than two shallow BHE (< 75 m). The yearly heating output is 3,066 MWh and the electric consumption to power the heat pump is 929 MWh over the technical lifetime of the installation assumed to be 20 years. The turnkey investment cost is 0.55 M€ and the O&M cost is 3 k€ per year.

Table 20: GSHP performance

Ground-source heat pump	TMIP	TMMF	TMMP	TMMT	TMUKB	TMUKD	TPCA
Annual avoided CO_2 [t/yr]	-	510	-	138	183	183	89
Annual benefits [€/yr]	20,291	30,753	18,073	8,233	1,257	-3,818	15,734
Life cycle cost							
Baseline scenario [€]	1,097,276	1,065,045	1,096,222	510,522	1,179,380	1,196,657	983,865
With RE project [€]	1,386,935	1,220,476	1,414,347	954,888	1,713,248	1,795,649	1,331,991
Performance indicator							
Energy cost [€/kWh]	22.62	19.90	23.07	15.57	27.94	29.28	21.72
CO_2 cost [€/t CO_2]	-	119.66	-	346.05	468.02	490.53	744.52

Note: The ground temperature data is not used in the calculations.

From those results, the best performance is obtained in TMMF due to the low electricity price and the high gas to electricity price ratio. But in any case, GSHP results in higher overall cost on a life cycle perspective compared to the baseline scenario (use of natural gas). Furthermore, in TMMP and TMIP, the CO_2 content of electricity is more than 3 times higher than the CO_2 content of gas: using a heat pump would result in an increase of the total energy-related CO_2 emissions in those two EMCs.

3.5.4 Solar heating

Solar heating in Europe has been intensively developed over the last decade, particularly in Spain, Greece and Italy, but also in Germany, Austria and France despite the fact that they do not enjoy as good solar resources as Southern countries, but the environmental policy in place give a good incentive for solar heating systems installation. A map of the European solar resources can be found below, showing a clear advantage for solar energy development in the Mediterranean region. Site-specific monthly statistics for daily solar irradiation are shown in *Figure 36*.

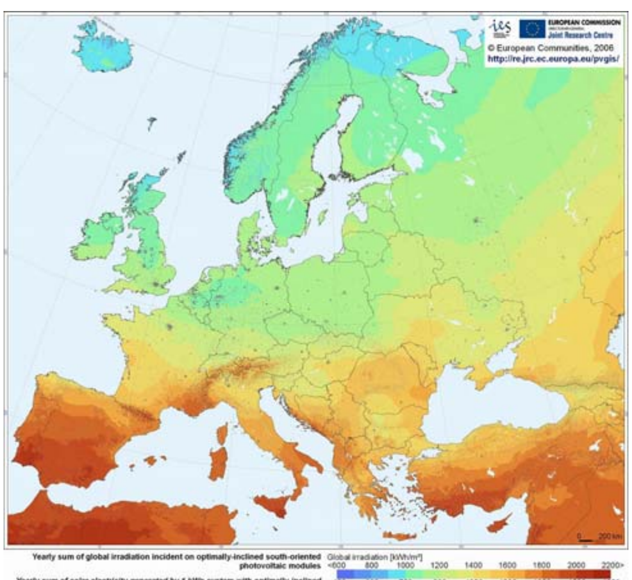


Figure 35: EU map of solar irradiation [4]

The most significant current solar heating applications are water pre-heating and industrial building heating (as for ground source heat pump previously presented). Those applications require low temperatures (30°C to 90°C), allowing the use of commercially available flat plate or vacuum tube collectors which are very efficient in this temperature range. Solar heat is used not only to provide process heat but also to heat industrial buildings.

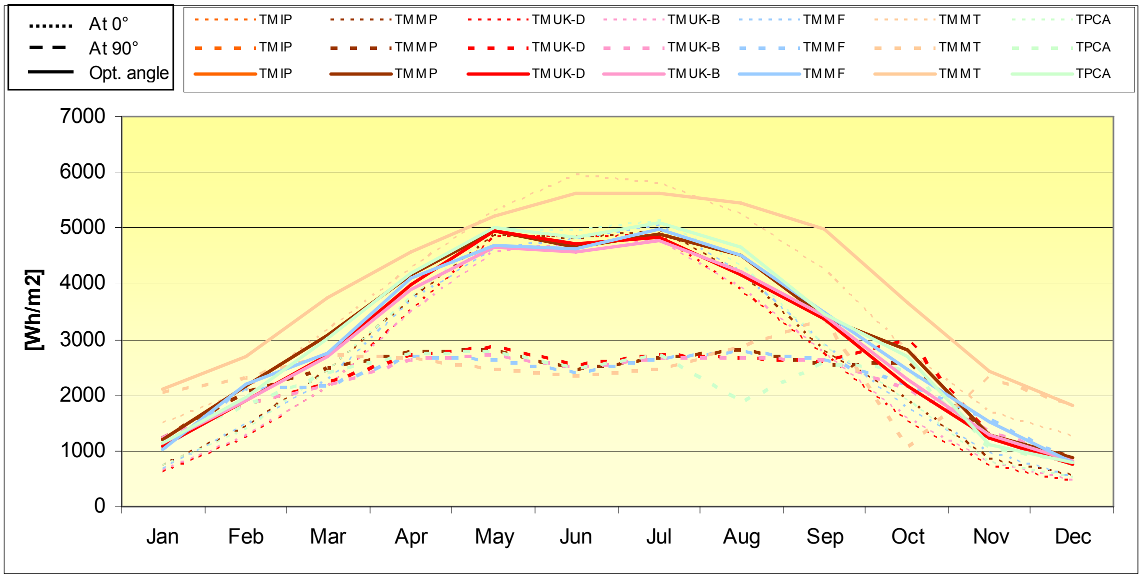


Figure 36: Monthly statistics for daily solar irradiation [12]

Ordinary solar collector can provide temperatures of 60-100°C (and concentrating collectors can reach 300°C). In the calculation below, water-based flat-plate collector are considered. The installed capacity is ~180 kW_{th} covering an area of 300 m^2 with a technical lifetime of 20 years. The turnkey investment cost is 150,000 € and the O&M cost is 2,250 € per year.

Table 21: Solar water heating performance

Solar heating	TMIP	TMMF	TMMP	TMMT	TMUKB	TMUKD	TPCA
Irradiation [kWh/m²/year]	1158.5	1131.3	1158.5	1461.9	1087.5	1094.6	1157.9
Heat generated [MWh/yr]	191.2	186.7	191.2	241.2	179.4	180.6	191.1
Annual avoided CO_2 [t/yr]	37.5	34.2	35.4	44.6	34.1	34.3	34.7
Annual benefits [€/yr]	3,082	2,804	3,077	880	3,130	3,244	2,528
Life cycle cost							
Baseline scenario [€]	68,411	64,844	68,345	40,164	69,024	70,488	61,309
With RE project [€]	178,868	178,868	178,868	178,868	178,868	178,868	178,868
Performance indicator							
Energy cost [€/kWh]	46.79	47.91	46.79	37.08	49.84	49.52	46.81
CO_2 cost [€/t CO_2]	238.22	261.80	252.90	200.42	262.32	260.63	257.77

As expected, the best results are obtained in Turkey where the weather conditions are best for the application of solar technologies. But as for ground-source heat pump, it also results an increased cost compared to the baseline scenario.

3.5.5 Wood biomass heating

In the following results, a modern 2 MW biomass CBF boiler technical data has been used. The turnkey investment cost is 1.2 M€. The annual energy output is 9,811 MWh and the O&M cost 207,960 €/year (including fuel cost = 15 €/MWh of fuel input).

Table 22: Biomass heating performance

Wood heating	TMIP	TMMF	TMMP	TMMT	TMUKB	TMUKD	TPCA
Annual avoided CO_2 [t/yr]	1,927	1,795	1,815	1,815	1,864	1,864	1,782
Annual benefits [€/yr]	65,449	57,673	65,711	-80,631	86,189	90,498	37,426
Life cycle cost							
Baseline scenario [€]	3,507,911	3,408,146	3,511,282	1,633,670	3,774,016	3,829,301	3,148,369
With RE project [€]	3,868,185	3,868,185	3,868,185	3,868,185	3,868,185	3,868,185	3,868,185
Performance indicator							
Energy cost [€/kWh]	19.71	19.71	19.71	19.71	19.71	19.71	19.71
CO_2 cost [€/t CO_2]	100.37	107.72	106.56	106.56	103.75	103.75	108.55

The life cycle cost and energy generation cost are the same in all EMCs since the power plants are assumed to be identical and used at maximum potential 5 days a week. In all cases, the energy cost increases but the gas price is what makes the difference. For instance, TMMT has the lowest energy price and thus the highest gap between baseline scenario and biomass project scenario.

3.5.6 Wood biomass CHP

The potential of biomass cannot be defined by the “resource available” or the meteorological conditions, since fuel is accessible from anywhere in Europe. The most common biomass fuel used is wood pellet which presents many advantages such as transport and storage. The main factor to determine the potential of biomass project is to look at the local incentives (mainly economic, see *Figure 37*).

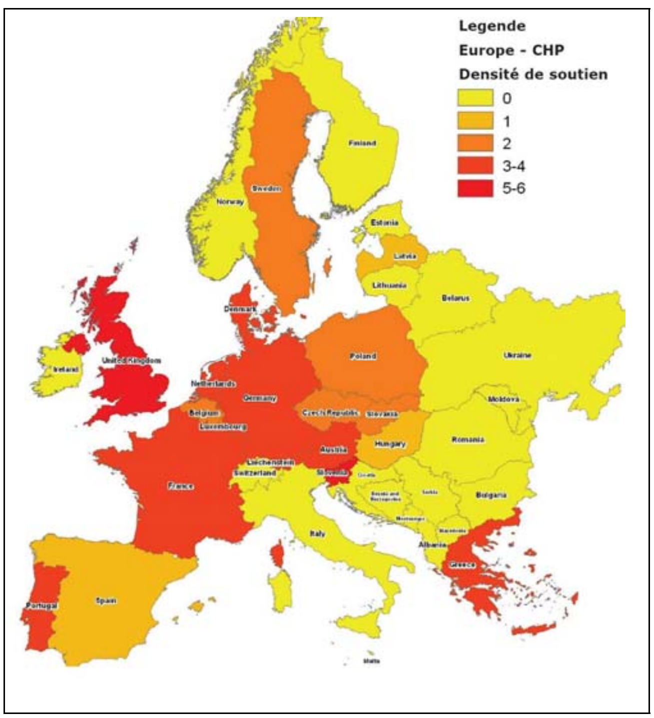


Figure 37: Map of CHP support level density in Europe [15]

In Czech Republic, the network operator contribute by ~20 €/MWh and the FIT is around 31 €/MWh (and additional profits are possible by selling electricity at peak time ~ 60 €/MWh). In France, the incentives are a 12-month tax exemption on natural gas and a feed-in-tariff of 6.1 to 9.15 €/kWh. In Poland, the Energy and Regulatory Authority is to set heat and electricity tariffs. Finally UK has the best level of incentive with Levy Exemption certificates given to CHP scheme that export electricity, 100% capital allowance on investment for the first year which can write off cost of investment on taxable profits, grant support from Community Energy Programme, License Exemption (but not required is electricity production < 2.5 MW).

In the following results, 2 MW biomass CBF boiler technical data has been used. Here it is assumed that a wood biomass gasification CHP system is used. The wood fuel price is assumed to be 15 €/MWh. The annual heat output is 7,358 MWh and the annual electricity output is 3,679 MWh. The turnkey investment cost is 2.04 M€ and O&M costs 265,560 €/year.

Table 23: Biomass CHP performance

Wood CHP	TMIP	TMMF	TMMP	TMMT	TMUKB	TMUKD	TPCA
Annual avoided CO_2 [t/yr]	3,892	1,549	3,808	3,061	2,980	2,980	3,187
Annual benefits [€/yr]	185,932	158,096	194,590	32,293	302,202	330,867	396,775
Economic incentive [€/MWh]		61		55			130
Life cycle cost							
Baseline scenario [€]	5,792,773	5,058,769	5,903,850	2,676,186	7,284,551	7,652,321	5,305,536
With RE project [€]	5,447,210	5,070,354	5,447,210	4,301,858	5,447,210	5,447,210	2,254,797
Performance indicator							
Energy cost [€/kWh]	24.68	22.97	24.68	19.49	24.68	24.68	10.21
CO_2 cost [€/t CO_2]	69.98	163.67	71.52	70.26	91.39	91.39	35.37

As for biomass heating, the conditions are identical in all EMCs and the difference is made with energy prices and the FIT police in France, Czech Republic and Turkey which obtains the best performances. But the life cycle cost of biomass CHP project would still be higher than in the baseline scenario. In TMMF, biomass CHP results in a very high abatement cost due to the low CO_2 benefit from electricity generated (86% of nuclear in electricity mix). UK has the highest energy prices and thus in the least increase in energy cost.

3.5.7 Waste-to-energy heating

In this part it is assumed that on-site generated wastes which are not recycled (those sent to incineration) are used as fuel for heat generation. On-site generated wastes are not considered as renewable energy sources. However, if a waste product from a process can be recovered and used as an alternative feedstock or recyclable input while retaining its value, this would certainly be considered renewable from a sustainability point of view.

In the following results, a modern 100 kW biomass boiler technical data has been used. It is assumed that only on-site generated wastes are used. The waste management unit cost is calculated from the sum of transport, treatment and incineration total costs divided by the corresponding amount of usable waste. Due to a lack of data from TMMT, the waste management cost is assumed to be ~18 c€/kg (180 €/ton) for this EMC. The annual heat generated is 460 MWh, the turnkey investment cost 100,000 € and O&M cost 7,245 €/year.

Table 24: Waste-to-energy heating performance

WtE heating	TMIP	TMMF	TMMP	TMMT	TMUKB	TMUKD	TPCA
Waste mgt cost [€/t]	268.67	208.15	234.22	180.00	198.84	147.51	152.49
Waste mgt savings [€/year]	74,135	57,436	64,630	49,669	54,869	40,704	42,079
Annual avoided CO_2 [t/yr]	-	-	-	-	-	-	-
Annual benefits [€/yr]	79,718	62,642	70,200	48,392	61,412	47,449	46,336
Life cycle cost							
Baseline scenario [€]	164,591	159,757	164,433	76,578	176,907	179,498	147,580
With RE project [€]	-758,217	-543,956	-636,258	-444,308	-511,021	-329,283	-346,918
Performance indicator							
Energy cost [€/kWh]	-82.43	-59.14	-69.17	-48.30	-55.56	-35.80	-37.72
CO_2 cost [€/t CO_2]	-	-	-	-	-	-	-

On-site generated wastes are not a carbon-neutral source of energy and data about the carbon content are not available, therefore the calculations about avoided CO_2 emissions are not applied. Furthermore, the economical analysis does not include the treatment cost of flue gas from the waste combustion. The major part of the benefits comes from the avoided waste management cost. As a consequence, the economic benefits are especially high and not comparable with the results of the RES options. The economic performance of WtE heating is hardly influenced by the gas price but is highly dependent on the waste management cost of the baseline scenario.

3.5.8 Waste-to-energy CHP

In the following results, a modern 100 kW biomass boiler technical data has been used. It is assumed that only on-site generated wastes are used. The waste management unit cost is the same as previously in waste-to-energy heating (chapter 3.5.7). The annual heat generated is 337 MWh and the annual electricity generated is 184 MWh, the turnkey investment cost 204,000 € and O&M cost 12,575 €/year.

Table 25: Waste-to-energy CHP performance

WtE CHP	TMIP	TMMF	TMMP	TMMT	TMUKB	TMUKD	TPCA
Waste mgt cost [€/t]	268.67	208.15	234.22	180.00	198.84	147.51	152.49
Waste mgt savings [€/year]	74,135	57,436	64,630	49,669	54,869	40,704	42,079
Annual avoided CO_2 [t/yr]	-	-	-	-	-	-	-
Annual benefits [€/yr]	83,281	63,745	74,207	47,125	69,763	57,018	49,413
Life cycle cost							
Baseline scenario [€]	-37,082	1,203,680	-119,579	325,601	432,000	432,000	211,066
With RE project [€]	-585,837	-371,577	-463,879	-271,929	-338,642	-156,903	-174,538
Performance indicator							
Energy cost [€/kWh]	-56.20	-35.64	-44.50	-26.09	-32.49	-15.05	-16.74
CO_2 cost [€/t CO_2]	-	-	-	-	-	-	-

For the same reasons as for WtE heating, environmental performance is not calculated for WtE CHP. Although the turnkey investment cost and O&M costs are higher than for WtE heating, the life cycle cost is lower due to higher energy conversion efficiency and to high electricity prices. But one must keep in mind that the flue gas from WtE energy generation plant must be treated and this additional cost is not included in those results.

3.6 Summary

The energy generation cost and the ranking for the selected technologies is summarised below in the *Table 26*.

Table 26: Average generation cost

	TMIP	TMMF	TMMP	TMMT	TMUKB	TMUKD	TPCA
Hydropower							
Energy generation cost [€/kWh]	38.58	6.83	38.58	23.01	38.58	38.58	20.85
CO_2 cost [€/t CO_2]	58.01	124.26	58.01	49.81	89.72	89.72	41.46
Wind power							
Energy generation cost [€/kWh]	321.52	10.82	28.88	635.08	46.66	32.58	25.91
CO_2 cost [€/t CO_2]	483.47	196.75	43.42	1,374.56	108.51	75.76	51.50
Ground-source heat pump							
Energy generation cost [€/kWh]	22.62	19.90	23.07	15.57	27.94	29.28	21.72
CO_2 cost [€/t CO_2]	-	119.66	-	346.10	468.02	490.53	744.75
Solar water heating							
Energy generation cost [€/kWh]	46.79	47.91	46.79	37.08	49.84	49.52	46.81
CO_2 cost [€/t CO_2]	238.22	261.80	252.90	200.42	262.32	260.63	257.77
Bio heating							
Energy generation cost [€/kWh]	19.71	19.71	19.71	19.71	19.71	19.71	19.71
CO_2 cost [€/t CO_2]	100.37	107.72	106.56	106.56	103.75	103.75	108.55
Bio CHP							
Energy generation cost [€/kWh]	24.68	22.97	24.68	19.49	24.68	24.68	10.21
CO_2 cost [€/t CO_2]	69.98	163.67	71.52	70.26	91.39	91.39	35.37
WtE heating							
Energy generation cost [€/kWh]	-82.43	-59.14	-69.17	-48.30	-55.56	-35.80	-37.72
CO_2 cost [€/t CO_2]	-	-	-	-	-	-	-
WtE CHP							
Energy generation cost [€/kWh]	-56.20	-35.64	-44.50	-26.09	-32.49	-15.05	-16.74
CO_2 cost [€/t CO_2]	-	-	-	-	-	-	-

The energy generation cost has been chosen as a criterion for the EMC roadmaps towards carbon-neutral manufacturing plant as the economic efficiency of the project is highly desirable. Legal aspects and security of supply are indirectly linked to this indicator: the more energy is produced with one € invested, the closer the EMC move towards the legal target of 20% of RES in final energy use, and the higher the energy security will be. Moreover, the energy price is assumed to be constant in the previous chapter. It is expected that the life cycle cost of the baseline scenarios will increase. Conversely the RE project scenarios' life cycle cost is will decrease in time.

But this criterion is not directly connected to the global aim of this study. Therefore the environmental performance is represented with a second criterion: the CO_2 abatement cost. Each of those 2 criteria used alone would not give a good overview of the energy option performance: for instance, GSHP option results in higher abatement cost than solar heating due to the additional consumption of electricity by the heat pump, but also in a lower energy generation cost due to very low O&M cost.

Important note: The economical performance of WtE options has be calculated only partially (only the cost for installing the boiler/steam turbine but not the pre-treatment of waste to increase dryness or combustion emissions treatment). And the environmental performance could not be evaluated at all. But the use of waste flow as a resource is an essential solution for the Sustainable Plant project. Further studies on WtE options are necessary to determine the environmental benefits and the requirements for their application, therefore WtE heating and WtE CHP will not be included in the roadmaps of this report.

To visualize the results, the *Table 27* summarizes the environmental and economical performance of the different options (WtE options are not included since the environmental performance has not been evaluated):

Legend:

- **O** = good environmental and significantly lower LCC compared to baseline scenario
- **Δ** = some environmental benefits but no or low benefits in LCC compared to baseline
- **X** = no environmental benefit or not applicable

Table 27: Feasibility indicator

	TMIP	TMMF	TMMP	TMMT	TMUK-B	TMUK-D	TPCA
Small hydropower	O	O	O	Δ	O	O	O
Wind power	X	O	O	X	O	O	O
GSHP	X	Δ	X	Δ	Δ	Δ	Δ
Solar heating	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Biomass heating	Δ	Δ	Δ	Δ	Δ	Δ	Δ
Biomass CHP	Δ	Δ	Δ	Δ	O	O	O

Both small hydro and wind power give good results in all plants, with the exception of TMIP and TMMT which are the sites with the least wind resource (average wind speed lower than 4 m/s). In TMUK-B, wind option gives positive but low results which explain its triangle condition. In TMMF, the CO_2 reduction from RES-electricity projects is quite small compared to the investment because the CO_2 emissions from electricity are already very low but the high FIT allows very quick payback and high cost benefits.

Ground-source heat pump and solar water heating give moderate results in all plants. The reason for Polish plants (TMMP and TMIP) to be in cross conditions for geothermal is a negative CO_2 performance since the kWh of electricity “contains” 3.5 times more CO_2 than a kWh of gas. To effectively reduce CO_2 emissions, the COP should be strictly higher than 3.5. The two British plants (TMUK-B and TMUK-D) have the highest energy generation cost due to the electricity consumption increase (additional power supplied to the heat pump). GSHP options give the reasonable energy generation cost in the other EMCs but they also are the option with the highest CO_2 abatement cost (except in France due to the low carbon content of electricity). Conversely, solar heating is the most expensive option in term of energy generation cost but performs better than GSHP in term of CO_2 abatement cost. Both those two options for RES-heating require lower initial investment costs to be competitive with current energy prices.

Biomass heating and biomass CHP options give better results than solar water heating and GSHP on the energy generation cost and CO_2 abatement cost, but in all plants the life cycle costs is not much lower (sometimes even higher) compared to baseline scenarios (gas price too low compared to wood fuel price) for France, Turkey and Poland. UK electricity prices and Czech Republic high FIT for electricity from biomass result in some economic benefits on a life cycle perspective.

4 ROADMAPS

In the beginning of the project, the expected outcome was a roadmap for Toyota Motor Europe energy-related CO_2 emissions in production activities. The analysis of the EMCs host country energy conditions has shown that not only economic and environmental aspect could instigate a move towards low carbon energy sources. New legislations are more drastic than before and challenging targets are set at the EU level. Moreover the fossil fuels scarcity raises the question of energy security, particularly on for natural gas in this study. Other aspect such as corporate social responsibility and corporate image also contributes to encourage manufacturing industries to take initiatives. In the second step of this project, some energy generation technologies were assess in order to identify opportunities to reduce CO_2 emissions from energy use in the most cost-efficient way.

In this third and last step, different ways to use the roadmap by combining both approaches will be discussed: the technology assessment gave an indicator of options' performance based on CO_2 reduction and cost-effectiveness whereas the EMC assessment gave an overview of the site-specific context for energy use and the areas which could be improved when applying the technology options. The final roadmap should provide an environmental solution to develop global performance of the plants.

A critical assumption which has been made from the beginning is the invariability of energy prices over the next 20 years. Energy price evolution would not modify the roadmaps but only make RES options more competitive compared to the baseline cases. Another critical point is the investment costs and O&M costs. They are assumed to be identical in all EMCs. A sensitivity analysis has been conducted to evaluate the influence of these costs on the final ranking of options and it appeared that the final roadmaps would not change significantly due to a large difference in abatement costs for each technology.

In this chapter, roadmaps based on strictly cost-effectiveness of CO_2 abatement will be presented. The performance indicators of the global roadmap for TME and the EMC-specific are given in *Table 28* and *Table 29*.

Table 28: TME roadmap

CO_2 abatement cost [€/ton CO_2 -eq]					
TPCA - BIOCHP	35.37	TMUKB - BIOCHP	91.39	TMMF - WIND	196.75
TPCA - SHP	41.46	TMUKD - BIOCHP	91.39	TMMT - SWH	200.42
TMMP - WIND	43.42	TMIP - BIOH	100.37	TMIP - SWH	238.22
TMMT - SHP	49.81	TMUKB - BIOH	103.75	TMMP - SWH	252.9
TPCA - WIND	51.5	TMUKD - BIOH	103.75	TPCA - SWH	257.77
TMIP - SHP	58.01	TMMP - BIOH	106.56	TMUKD - SWH	260.63
TMMP - SHP	58.01	TMMT - BIOH	106.56	TMMF - SWH	261.8
TMIP - BIOCHP	69.98	TMMF - BIOH	107.72	TMUKB - SWH	262.32
TMMT - BIOCHP	70.26	TMUKB - WIND	108.51	TMMT - GSHP	346.1
TMMP - BIOCHP	71.52	TPCA - BIOH	108.55	TMUKB - GSHP	468.02
TMUKD - WIND	75.76	TMMF - GSHP	119.66	TMUKD - GSHP	490.53
TMUKB - SHP	89.72	TMMF - SHP	124.26	TPCA - GSHP	744.75
TMUKD - SHP	89.72	TMMF - BIOCHP	163.67		

Table 29: EMC-specific roadmaps

CO$_2$ abatement cost [€/ton CO$_2$ -eq]													
TMIP		TMMF		TMMP		TMMT		TMUK-B		TMUK-D		TPCA	
58.01	SHP	107.72	BIOH	43.42	WIND	49.81	SHP	89.72	SHP	75.76	WIND	35.37	BIOCHP
69.98	BIOCHP	119.66	GSHP	58.01	SHP	70.26	BIOCHP	91.39	BIOCHP	89.72	SHP	41.46	SHP
100.37	BIOH	124.26	SHP	71.52	BIOCHP	106.56	BIOH	103.75	BIOH	91.39	BIOCHP	51.5	WIND
238.22	SWH	163.67	BIOCHP	106.56	BIOH	200.42	SWH	108.51	WIND	103.75	BIOH	108.55	BIOH
-	WIND	196.75	WIND	252.9	SWH	346.1	GSHP	262.32	SWH	262.32	SWH	257.77	SWH
-	GSHP	261.8	SWH	-	GSHP	-	WIND	468.02	GSHP	490.53	GSHP	744.75	GSHP

4.1 Example of application, European level

The global TME roadmap gives a priority order for the application of energy generation options. With this basic model, hydro electricity shows to be one of the most cost-effective ways to reduce CO_2. Wind power, biomass CHP and biomass heating come next but with CO_2 abatement cost slightly higher. And finally, solar heating and ground-source heat pump are the last options in the roadmap.

In the following example, all the installations in *Table 30* are considered as the long-term TME renewable energy project, the total investment would be 122.4 M€ to generate close to 357,250 MWh per year (~32.4% of the total energy use) and avoid 118,800 tons of CO_2 per year (~37.2% reduction of the total emissions and reduction by ~145 kg CO_2/vehicle). The results are given in *Table 31* and *Figure 38* below.

Table 30: TME roadmap application, size of the installations

		TMIP	TMMF	TMMP	TMMT	TMUK-B	TMUK-D	TPCA
SHP	kW	2500	2500	2500	2500	2500	2500	2500
WIND	kW	0	10000	8000	0	12000	8000	12000
GSHP	kW	0	1000	0	0	0	0	0
SWH	m²	0	0	0	500	0	0	0
BIOH	kW	0	10000	0	0	0	0	0
BIOCHP	kW	2000	0	2000	5000	10000	2000	5000
WH	kW	0	0	0	0	0	0	0
WCHP	kW	0	0	0	0	0	0	0

Table 31: TME roadmap application, monthly energy generation from RES

[MWh]	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	
Electricity use	40,629	42,990	43,612	45,412	30,793	42,359	45,511	43,677	35,806	45,251	42,939	41,761	**500,737**
RES-E	13,762	13,238	12,496	11,701	10,911	11,979	15,292	13,468	15,634	21,427	17,371	18,392	**175,671**
Heat use	49,502	41,479	33,277	34,079	19,763	37,827	51,202	67,105	62,519	76,808	69,515	60,653	**603,729**
RES-H	13,901	14,370	13,910	14,374	13,158	13,905	14,357	13,884	14,341	14,344	12,960	14,358	**167,862**
Enrgy use	**90,131**	**84,469**	**76,889**	**79,491**	**50,556**	**80,186**	**96,713**	**110,782**	**98,325**	**122,059**	**112,454**	**102,414**	**1,104,466**
RES	**27,371**	**27,136**	**25,926**	**26,075**	**23,531**	**25,287**	**28,888**	**27,352**	**29,054**	**30,842**	**29,596**	**29,613**	**330,671**

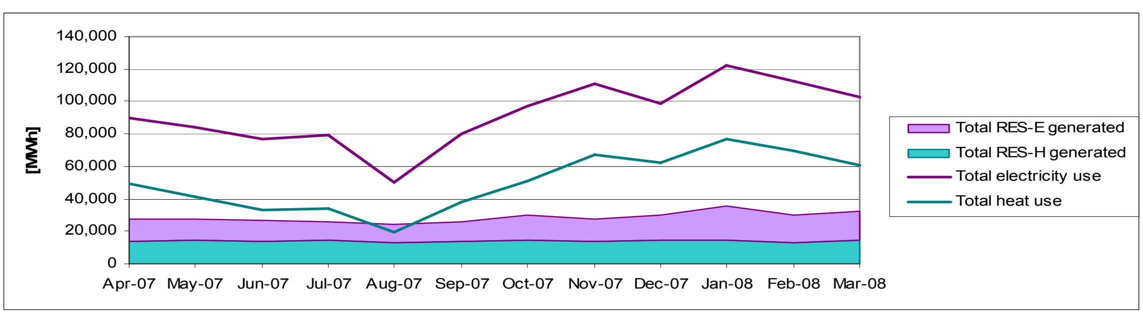


Figure 38: TME roadmap application, monthly RES energy generation vs. total use

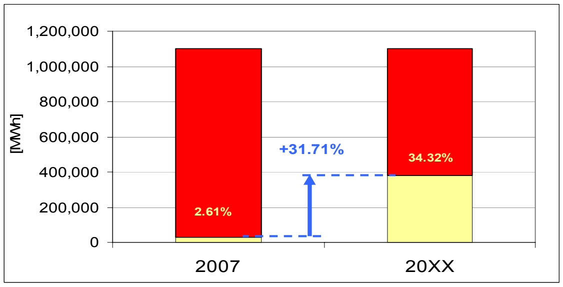


Figure 39: RES in total TME energy use

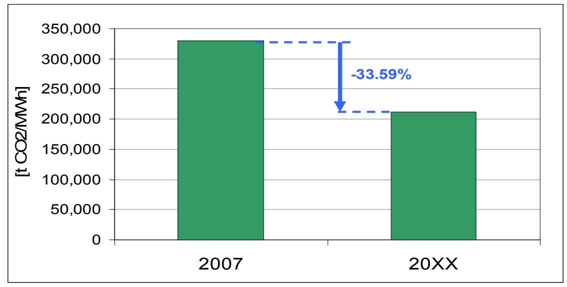
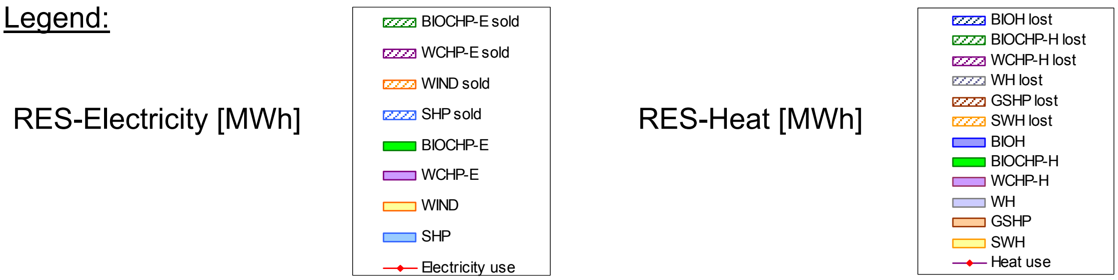


Figure 40: Total TME CO_2 emissions

The details of energy generation from RES for each EMC are plotted in the following 2 pages in order to visualise the contribution of renewables to total energy use.

Legend:



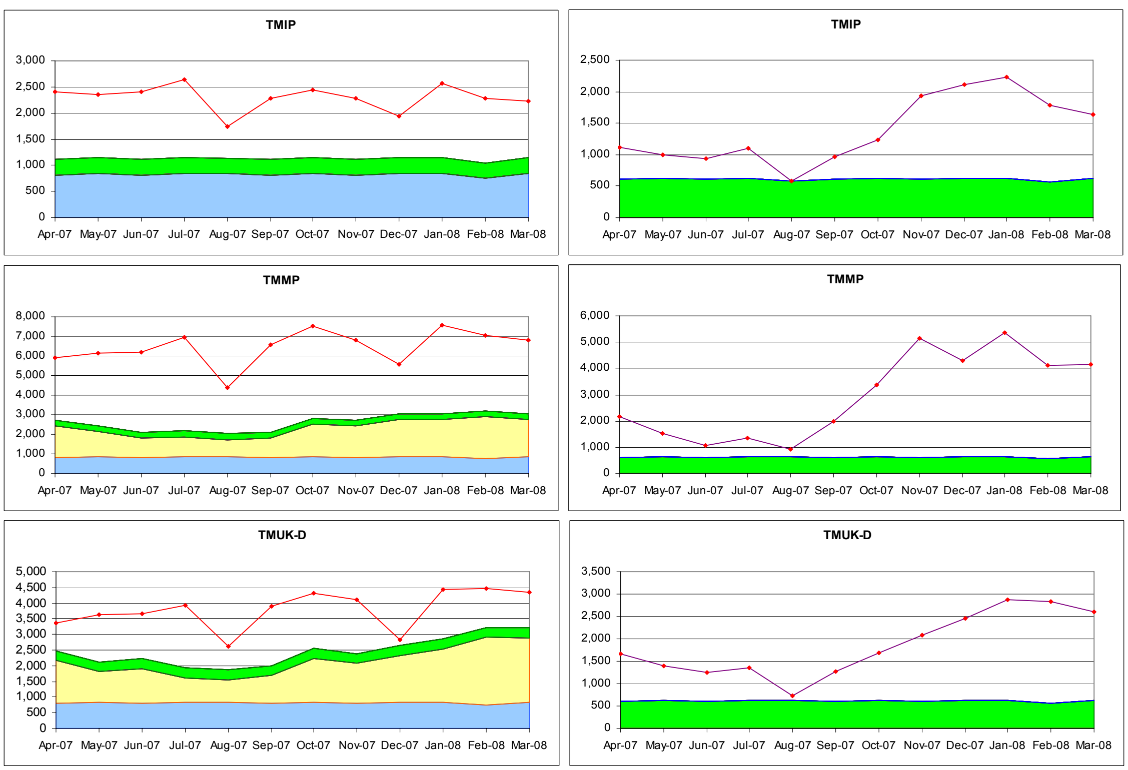


Figure 41: TME roadmap application - part production plants, RES energy generation

TMIP is the production plant with the lowest energy consumption. Consequently, achieving the *20-20-20 targets* is more reachable than for any other EMC. TMMP is in almost the same condition as TMIP but it is the largest unit production plant requiring a lot more effort to achieve significant changes relatively to its size. TMUK-D is a medium size unit production plant but with very different conditions: the energy prices in UK are higher and give a good economic incentive to invest in RES. But higher environmental benefits would result in the Polish EMC for the same amount of electricity produced due to the carbon content of energy.

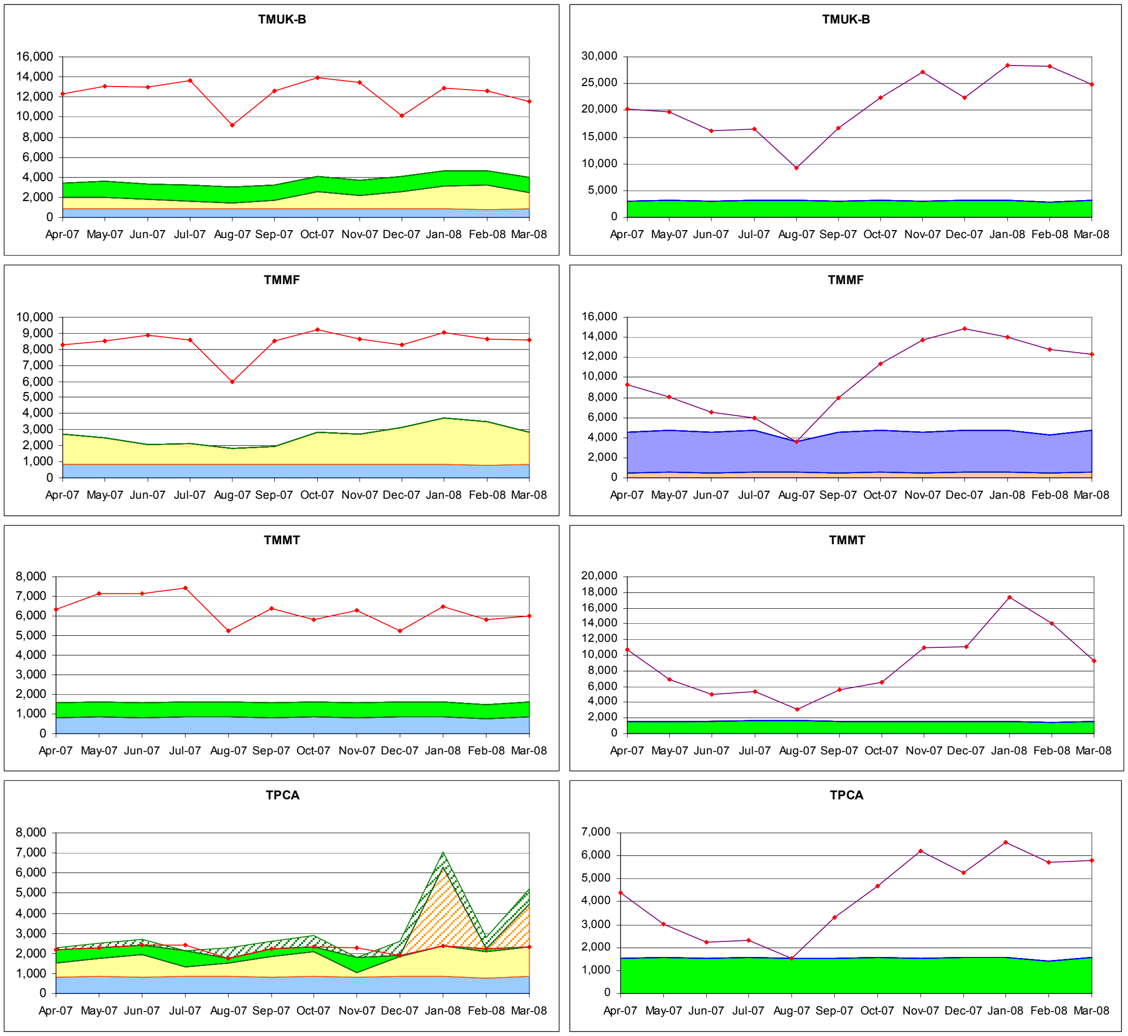


Figure 42: TME roadmap application – vehicle production plants, RES energy generation

TMUK-B is the largest production plant with the highest energy use per unit. It is the most challenging EMC if EU targets were to be achieved at the plant level: 20% of its total annual energy consumption is twice the one of TMIP. Major investment done in this EMC to reach any of the *20-20-20 targets* would affect the global TME performance significantly. TMMF is the second largest production plant and also one of the most efficient together with TPCA (which is about the same size as TMUK-B if including Peugeot and Citroën vehicle production). Both TMMF and TMUK (Burnaston + Deeside) have been selected for *Sustainable Plant* project which means that project done in those plants would have a higher impact on corporate image than any other EMC. In TMMT, the energy prices are very low which makes it harder to get economical benefits from investment in RES project. At the same time, it is also the plant with the lowest energy security (high dependence on natural gas and 44% of electricity is produced from natural gas). Finally, it is important to note that the energy use represented in the TPCA graphs are only Toyota fraction (1/3 of total plant energy use).

4.2 Example of application, TMUK-D

The EMC-specific roadmap can be used independently from the global TME roadmap. For instance, TMMF and TMUK are the European production plants selected for the Sustainable Plant project and therefore, implementing renewable energy project in those plants can considered as a higher priority than other more cost-effective options in other plants.

To demonstrate the application of EMC-specific roadmap, one of the selected EMC for *Sustainable Plant* project will be used as an example: TMUK-D is a part production plant with a total annual energy consumption of 67,823 MWh, annual CO_2 emissions of 23,827 tons of CO_2-eq and produces ~300,000 engines per year.

Given the abatement costs:

- WIND: 75.76 €/ton CO_2
- SHP: 89.72 €/ton CO_2
- BIOCHP: 91.39 €/ton CO_2
- BIOH: 103.75 €/ton CO_2

and assuming the following installations:

- WIND: 8.0 MWe
- SHP: 2.5 MWe
- BIOCHP: 5.0 MWth
- BIOH: 2.0 MWth

the total investment would be 19.74 M€, and result in a total energy generation of 63.7 GWh from RES (~93% of total energy use) and in a CO_2 emissions reduction of 19,346 tons (~86% of total CO_2). The remaining ~14% CO_2 reduction required to achieve carbon neutral manufacturing plant is mostly electricity and can be purchase from green supplier (100% of RES in electricity mix).

Table 32: TMUK-D-specific roadmap application, monthly energy generation from RES

[MWh]	Apr-07	May-07	Jun-07	Jul-07	Aug-07	Sep-07	Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	
Electricity use	3,366	3,640	3,663	3,929	2,612	3,885	4,302	4,106	2,833	4,447	4,457	4,349	**45,589**
RES-E	2,927	2,499	2,545	2,298	1,915	2,323	3,024	2,842	2,833	3,317	3,635	3,671	**33,834**
Heat use	1,666	1,392	1,259	1,363	720	1,280	1,687	2,091	2,467	2,875	2,826	2,607	**22,233**
RES-H	1,666	1,392	1,259	1,363	720	1,280	1,687	2,091	2,467	2,790	2,520	2,607	**21,842**
Energy use	**5,032**	**5,032**	**4,922**	**5,292**	**3,332**	**5,165**	**5,989**	**6,197**	**5,300**	**7,322**	**7,283**	**6,956**	**67,822**
RES	**4,593**	**3,892**	**3,804**	**3,661**	**2,635**	**3,603**	**4,712**	**4,933**	**5,229**	**5,714**	**5,799**	**6,067**	**54,643**

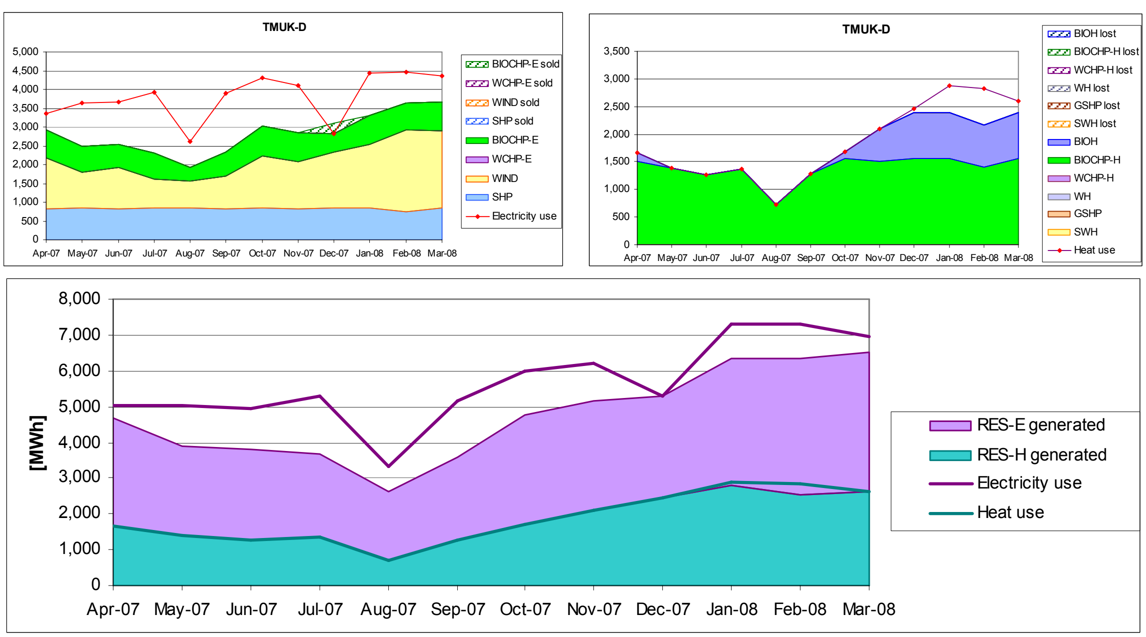


Figure 43: TMUK-D -specific roadmap application, RES energy generation vs. total use

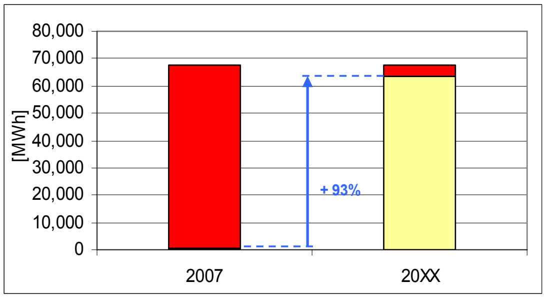


Figure 44: RES in TMUK-D energy use

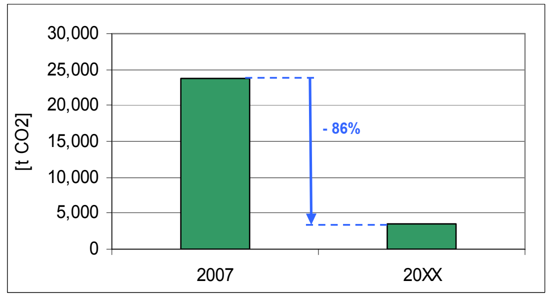


Figure 45: TMUK-D CO_2 emissions

In comparison with the examples given chapter 4.1 with the 5 hydropower projects (in TMMF, TPCA, TMMT, TMIP and TMMP) or with the global TME roadmap, the environmental performance cost-effectiveness is lower (higher cost for a ton of CO_2) but from a corporate image perspective, the results will impact more significantly public perception:

Table 33: Roadmap examples with comparable initial investment

	Initial investment cost	Total energy generated from RES	Total CO_2 abatement	**% of total emissions as the perceived outcome**
Global TME roadmap, 5 hydropower projects	30.00 M€	49,275 MWh	23,159 t CO_2	**4.5% of total TME**
TMUK-D specific roadmap, 4 RES projects	19.74 M€	54,922 MWh	18,622 t CO_2	**78% of total TMUK-D**

4.3 Other possible models

As previously mentioned, not only CO_2 abatement cost can be considered to make the roadmaps. Additional ranking methods could be used to increase the priority of options promoting different aspects than environment and economics. For example, if the roadmap was created with the aim to improve both environmental performance and energy security, it would become clear that the substitution of natural gas by RES-H options is highly desirable. A second criterion could be used together with the abatement cost to obtain a new indicator which would take into consideration the energy dependency and change the priority order.

Another alternative: If EU legal targets at national level were to be fixed as the minimum target for the EMCs in EU member state, then could be used as the new indicator. In this case TMMT would have the lowest priority since Turkey does not have any RES target.

Examples of alternative indicators:

- enhanced security of supply [€ / % of import reduction]
- distance-to-target reduction [€ / % of distance-to-target reduction]
- public perception of performance [€ / % of EMC-specific CO_2 reduction]

5 DISCUSSION

The highest priority is a quantitative optimisation: increase the output/input ratio by eliminating the material and energy which are not vital for the activities, then reducing these flows by increasing reuse/recovery/recycling rate and conversion efficiency. Toyota's strategy presented in introduction of this report clearly shows this hierarchy in environmental activities. The next priority is to improve the qualitative aspects: it is important to manage the inputs and the processes through which they will go before becoming the output (products, by-products, waste/emissions...). Therefore, using high quality input such as recyclable materials or renewable energy sources will result in better outputs such as less armful / hazardous waste and lower air emissions.

Design of processes and systems must include integration and interconnectivity with available energy and material flows. System components should be output-pulled rather than input-pushed through the use of energy and materials (Le Châtelier principle*): wherever there is a system in equilibrium, a design choice is available to take advantage of this principle to minimize the resource inputs necessary to generate the desired outcome. In this project, the energy flows are optimized through appropriate technologies in the context of site-specific flows.

A critical aspect of the study was the geographical location of Toyota's EMCs. The legal and natural environment varies greatly country to country and the roadmaps resulting from the same study in other European countries or other regions of the world would result in very different ranking of options to lessen the costs and environmental impacts of energy use, or even to increase the overall system efficiency. The resource inputs should be used at their highest economical and environmental value with BAT and local conditions (based on readily available inputs such as locally abundant renewable resources or waste generated on-site, and also considering the national economical incentives).

This thesis work has shown that renewable energy sources can be a major contributor to achieve the ultimate target of carbon-neutral manufacturing plant. Utilizing local resources in the production also increases the security of supply, helps to achieve national targets for RES share in final energy use and CO_2 emissions reduction, and may provide an opportunity for local economic growth.

* Henry Louis Le Châtelier (1850-1936), French chemist who worked on the principle to predict the effect of a change in thermodynamic conditions on a chemical equilibrium: *Lorsque des modifications extérieures sont apportées à un système en équilibre, l'évolution se fait de manière à s'opposer, en partie, aux perturbations qui l'ont engendrée et en modère l'effet afin d'atteindre un nouvel état d'équilibre*. [If a system in equilibrium is subjected to a stress, the equilibrium will partly shift in the opposite direction of the imposed change and minimize its effect.]

6 NEXT STEP

From a systems perspective, the manufacturing plant uses energy and materials (inputs) and generates products and waste/pollutants (outputs): systems are modelled in a very simplified way as a *black box* in this project. The next step in the *Sustainable Plant project – Carbon-Neutral Car Manufacturing Plant* should be to go for a *white box* approach to go in further details within the plants, to identify possible interaction or compatibility between two processes, or to match energy supply from alternative sources with the daily fluctuations of energy demand.

6.1 Global and seasonal energy trends

Although the energy consumption per unit has decrease each year from FY03 to FY07 (mainly due to gas consumption reduction), the global energy use increases every the year due to market development and higher production volumes (see *Figure 3* page 15). The contribution of the different processes/shops to the total energy demand is similar in all the EMCs. For instance, the paint shop will be the major contributor to total energy consumption (40-50% of the total electricity consumption and up to 80% of the total gas consumption) followed by plastic, welding, assembly and press shops, and at last facilities (light, heating/cooling…).

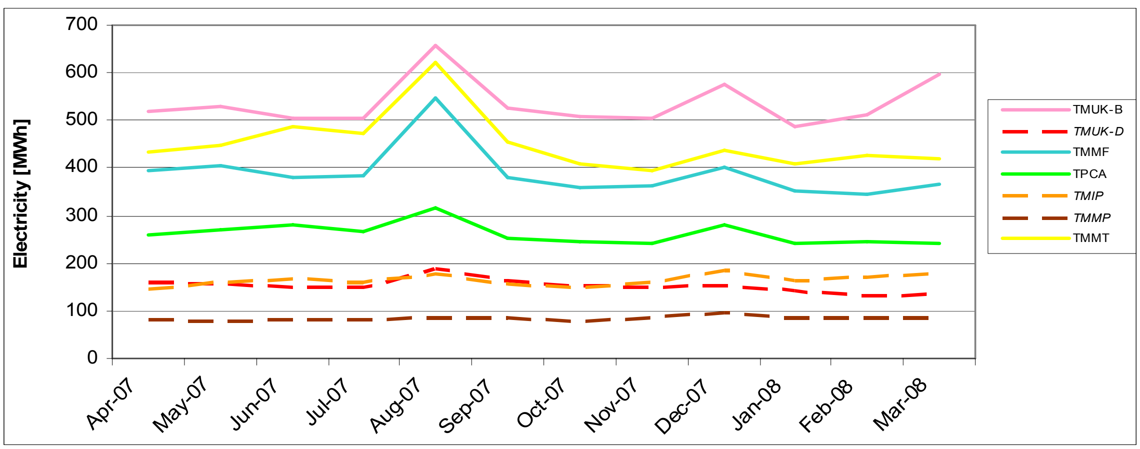


Figure 46: Electricity consumption per unit produced, FY07

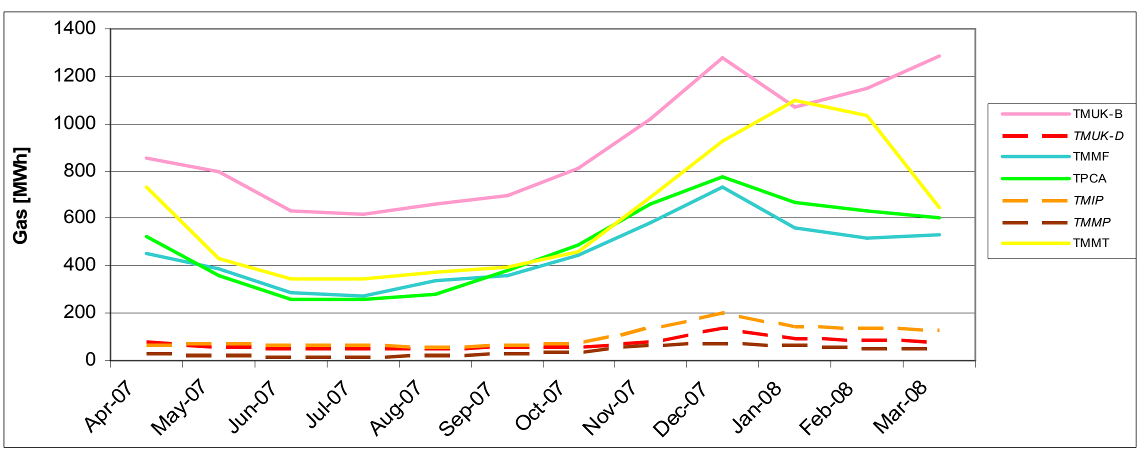


Figure 47: Gas consumption per unit produced, FY07

The general seasonal influence is observable with higher gas consumption (increased heat demand) in winter and stable electricity consumption all over the year. Those trends can be seen in *Figure 46* and *Figure 47*.

The peaks of electricity use in August and December are due to plant shut down or slow down in production: whether production is low or at its maximum capacity, there is a minimum amount of energy required to keep the plant in function; or when no vehicle or part is produced at all, there is still some energy consumed for maintaining the plant environment and security. This will be explained further in the next subchapter. The heat demand increases in winter as expected and the peak in December can be explained the same way as for electricity peaks (plant shut down for a week).

6.2 Energy demand variation at production level

To find the most adapted type of energy source and the most appropriate technology to match the consumption profile, one need to look at the energy consumption fluctuations at the process/machine level.

To match energy supply with the energy demand, one must consider the energy use sequences (continuous vs. batch production) and potential complementarities (use waste heat from a very high temperature process in another process requiring lower temperatures).

Energy generation technologies must be able to follow fluctuations (fast start-up and shutdown times) and fulfil 100% of the demand (supply all the power required when there is a peak demand). For instance, ground-source heat pump can provide a constant base load for heating and cooling or process water pre-heating, whereas wind power can only supply electricity intermittently, thus requiring a back-up system when wind is not blowing or when wind speed is not high enough.

In the graphs below is shown an example of energy use profile at plant scale*.

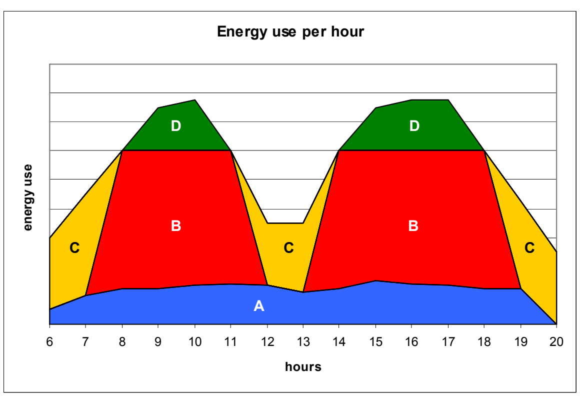


Figure 48: Example of daily energy use profile

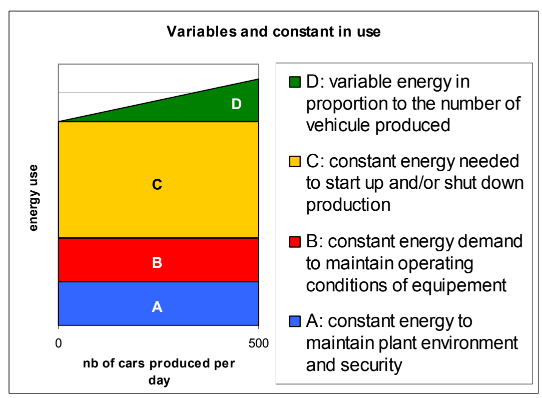


Figure 49: Energy variation as function of PV

* Energy Minimization Activities Manual for Automotive Manufacturing Plants, Toyota Energy Minimization Working Group

REFERENCES

Please note that the references used only once in the report are integrated in the footnotes report, only the most important and recurrent references are listed below.

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http://www.toyota.eu/

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[2] Corporation Global Site:
http://www.toyota.co.jp/en/index.html

CSR concepts:
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The Fourth Toyota Environmental Action Plan:
http://www.toyota.co.jp/en/environment/vision/plan/fourth_plan.html

Sustainability report:
http://www.toyota.co.jp/en/environment/report/index.html

[3] Carbon Trust:
http://www.carbontrust.co.uk/default.ct

[4] European Commission (EC):
http://ec.europa.eu/index_en.htm

Climate Action:
http://ec.europa.eu/climateaction/index_en.htm

SET Plan:
http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm

ATLAS Project:
http://ec.europa.eu/energy/atlas/home.html

Eurostat:
http://ec.europa.eu/eurostat/

Joint Research Centre (JRC), Institute for Energy:
http://ie.jrc.ec.europa.eu/

[5] Centrica, UK:
http://www.centrica.co.uk/

[6] EDF, France:
http://www.edf.fr/

[7] EnergiaPro Gigawat, Poland (in Polish):
http://www.gigawat.pl/

[8] Enerjisa, Turkey:
http://www.enerjisa.com.tr/

[9] ČEZ Group, Czech Republic:
http://www.cez.cz/en/home.html

[10] UNDP:
http://www.undp.org/

[11] IEA:
http://www.iea.org/

[12] Source of meteorological data for all production sites:

- IWEC Data - "Climate Design Data 2005 Ashrae Handbook"
- European Commission - Joint Research Centre
- Meteonorm

[13] EGEC (European Geothermal Energy Council):
http://www.egec.org/

[14] Center for Environmental Systems Research, Kassel university:
http://www.usf.uni-kassel.de/

[15] EUBIA (European Biomass Industry Association):
http://www.eubia.org/

[16] DWIA (Danish Wind Industry Association):
http://www.windpower.org/

[17] RETScreen, Engineering e-Textbook, Clean Energy Project Analysis:
http://www.retscreen.net/ang/12.php

APPENDIX I

Table 34: Toyota Earth Charter

I. Basic Policy	II. Action Guidelines
1. Contribution toward a prosperous 21st century society Contribute toward a prosperous 21st century society. Aim for growth that is in harmony with the environment, and set as a challenge the achievement of zero emissions throughout all areas of business activities. **2. Pursuit of environmental technologies** Pursue all possible environmental technologies, developing and establishing new technologies to enable the environment and economy to coexist harmoniously. **3. Voluntary actions** Develop a voluntary improvement plan, based on thorough preventive measures and compliance with laws that addresses environmental issues on the global, national, and regional scales, and promotes continuous implementation. **4. Working in cooperation with society** Build close and cooperative relationships with a wide spectrum of individuals and organizations involved in environmental preservation including governments, local municipalities, related companies and industries.	**1. Always be concerned about the environment** Take on the challenge of achieving zero emissions at all stages, i.e., production, utilization, and disposal (1) Develop and provide products with top-level environmental performance (2) Pursue production activities that do not generate waste (3)Implement thorough preventive measures (4) Promote businesses that contribute toward environmental improvement **2. Business partners are partners in creating a better environment** Cooperate with associated companies **3. As a member of society** Actively participate in social actions (1) Participate in the creation of a recycling-based society (2) Support government environmental policies (3) Contribute also to non-profit activities **4. Toward better understanding** Actively disclose information and promote environmental awareness **III. Organization in Charge** Promotion by the Toyota Environment Committee which consists of top management (chaired by the president)

Table 35: Environmental Chronological Table

1963	· Production Environment Committee established
1973	· Month of June designated as "Toyota Environment Month"
	· Environmental Product Design Assessment Committee established
1989	· Ozone-Layer Protection Subcommittee established
1990	· Recycling Committee established
1991	· "Toyota Environment Month" renamed "Global Environment Month"
	· "One Person, One Tree" campaign initiated to reduce waste of paper resources (completed at end of 1992)
1992	· "Guiding Principles at Toyota Motor Corporation" adopted
	· Toyota Action Plan for Global Environment (known as the Toyota Earth Charter) adopted
	· Toyota Environment Committee established
1996	· Takaoka Plant acquired ISO 14001 certification
	· Tsutsumi Plant acquired ISO 14001 certification
	· "Toyota 2005 Vision" announced
	· "Toyota Environmental Action Plan" established
1997	· "Guiding Principles at Toyota Motor Corporation" revised
	· LCA Subcommittee established
	· Motomachi Plant and Tahara Plant acquired ISO 14001 certification
1998	· Environmental Affairs Division established
	· ISO 14001 certification acquired in development and design areas
	· Toyota Environmental Pocketbook distributed to all employees to develop employee awareness of environmental issues
	· Toyota published its first Environmental Report
1999	· A computation model and a database for LCA evaluation software built
	· Toyota began including environmental specifications in brochures for all new products and products that undergo complete redesign
2000	· Second Action Plan Goals(FY2000 Goals) Achieved
	· The Toyota Environmental Textbook was distributed not only within the company but also to affiliated companies in Japan and overseas.
	· LCA Implemented at the Vehicle Development Stage
2001	· Action in Accordance with Third Toyota Environmental Action Plan Started and First Year Goals Achieved
	· "Customer Effects" and "Eco-efficiency" Calculated in Addition to Environmental Costs and Economic Effects
2003	· The Toyota Environmental Action Plan Interim Review
2004	· Eco-efficiency as indicated by CO_2 has improved 60% over 14 years
2005	· Toyota created its Fourth Toyota Environmental Action Plan

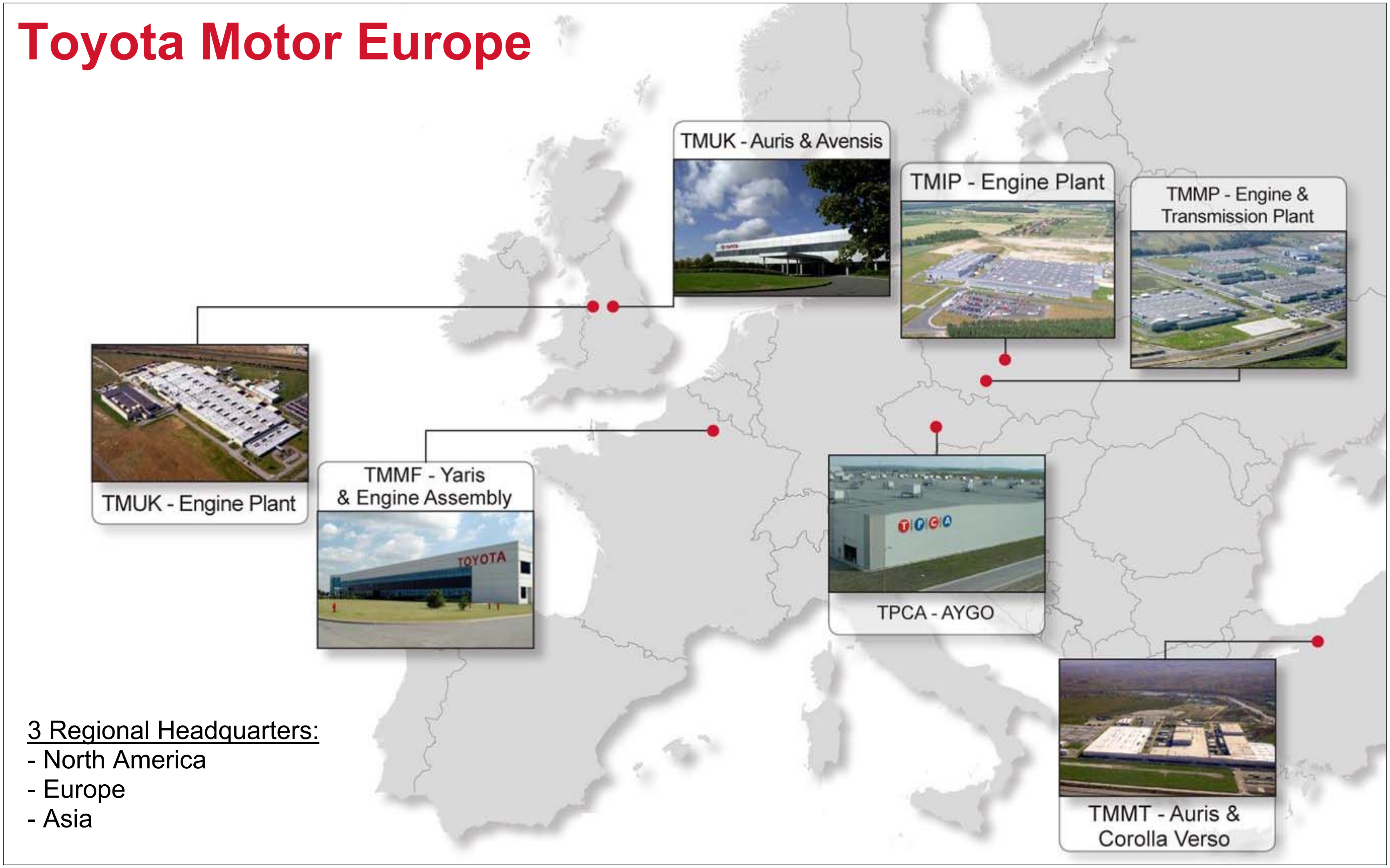

Figure 50: Map - Toyota Motor Europe production plants selected for the study

APPENDIX II

Table 36: EMC evaluation complete table (data + intermediate scores)

Size / Energy	**Production Volume [unit]**	Production Volume [vehicle]	Production Volume [part]	**Prod.**	**Energy use [MWh]**	Electricity [MWh]	Gas [MWh]	**Cons.**	**Energy use per unit [kWh/unit]**	Electricity per unit [kWh/unit]	Gas per unit [kWh/unit]	**Energy per unit**
TMUKB	**281,195**	281,195		**34.5%**	**400,292**	148,260	252,032	**18.5%**	**1,423.5**	527.2	896.3	**34.8%**
TMMF	**260,486**	260,486		**32.0%**	**219,432**	99,228	120,204	**10.2%**	**842.4**	380.9	461.5	**20.6%**
TMMT	**169,324**	169,324		**20.8%**	**181,331**	75,322	106,009	**8.4%**	**1,070.9**	444.8	626.1	**26.2%**
TPCA	**103,102**	103,102		**12.7%**	**77,825**	26,704	51,121	**3.6%**	**754.8**	259.0	495.8	**18.4%**
TMUKD	**304,038**		304,038	**21.8%**	**67,823**	45,588	22,235	**3.1%**	**223.1**	149.9	73.1	**36.8%**
TMMP	**923,090**		923,090	**66.1%**	**112,096**	77,442	34,654	**5.2%**	**121.4**	83.9	37.5	**20.0%**
TMIP	**169,128**		169,128	**12.1%**	**44,225**	27,582	16,643	**2.0%**	**261.5**	163.1	98.4	**43.2%**

CO_2	**CO_2 emission from energy [t CO_2]**	CO_2 emission from electricity [t CO_2]	CO_2 emission from gas [t CO_2]	**Plant CO_2**	**Energy emission factor [g CO_2/kWh]**	Electricity emission factor [g CO_2/kWh]	Gas emission factor [g CO_2/kWh]	**Energy CO_2**	**CO_2 emission from energy per unit [kg CO_2/unit]**	CO_2 emission from electricity per unit [kg CO_2/unit]	CO_2 emission from gas per unit [kg CO_2/unit]	**CO_2 per unit**
TMUKB	**111,637.9**	63,751.8	47,886.1	**23.3%**	**278.9**	430.0	190.0	**7.3%**	**397.0**	226.7	170.3	**38.0%**
TMMF	**27,454.9**	5,457.5	21,997.4	**5.7%**	**125.1**	55.0	183.0	**3.3%**	**105.4**	21.0	84.4	**10.1%**
TMMT	**54,412.1**	34,800.5	19,611.6	**11.4%**	**300.1**	462.0	185.0	**7.9%**	**321.3**	205.5	115.8	**30.8%**
TPCA	**22,716.3**	13,432.8	9,283.5	**4.7%**	**291.9**	503.0	181.6	**7.7%**	**220.3**	130.3	90.0	**21.1%**
TMUKD	**23,827.4**	19,602.9	4,224.6	**5.0%**	**351.3**	430.0	190.0	**9.2%**	**78.4**	64.5	13.9	**29.1%**
TMMP	**57,912.5**	51,501.6	6,410.9	**12.1%**	**516.6**	665.0	185.0	**13.6%**	**62.7**	55.8	6.9	**23.3%**
TMIP	**21,611.4**	18,342.7	3,268.7	**4.5%**	**488.7**	665.0	196.4	**12.8%**	**127.8**	108.5	19.3	**47.5%**

Table 36: EMC evaluation complete table (data + intermediate scores), continued

Cost	Total energy cost [-]	Electricity cost [-]	Gas cost [-]	Energy cost	Energy price [-/kWh]	Electricity price [-/kWh]	Gas price [-/kWh]	Energy price	Energy cost per unit [-/unit]	Electricity cost per unit [-/unit]	Gas cost per unit [-/unit]	Energy cost per unit
TMUKB	**0.11**	0.13	0.07	**67.2%**	**0.67**	0.66	0.92	**14.2%**	**0.18**	0.22	0.11	**48.0%**
TMMF	**0.29**	0.38	0.13	**26.6%**	**0.72**	0.68	0.92	**10.2%**	**0.09**	0.12	0.04	**20.5%**
TMMT	**0.24**	0.32	0.09	**11.5%**	**1.00**	1.00	1.00	**5.4%**	**0.22**	0.30	0.08	**13.6%**
TPCA	**1.00**	1.00	1.00	**9.2%**	**0.69**	0.93	0.99	**10.0%**	**1.00**	1.00	1.00	**18.0%**
TMUKD	**0.40**	0.37	0.44	**16.3%**	**0.50**	0.52	0.89	**20.6%**	**0.43**	0.40	0.47	**45.4%**
TMMP	**0.17**	0.16	0.18	**19.7%**	**0.26**	0.30	0.43	**14.9%**	**0.28**	0.27	0.30	**18.2%**
TMIP	**0.14**	0.12	0.17	**7.3%**	**0.48**	0.62	0.82	**13.8%**	**0.37**	0.32	0.47	**36.5%**

Note: For confidentiality issue, the energy cost values are not shown and the maximum value is set equal to 1.

Security	Energy dependency	Security of supply
TMUKB	13.9%	**6.5%**
TMMF	51.6%	**24.0%**
TMMT	71.9%	**33.5%**
TPCA	27.4%	**12.8%**
TMUKD	13.9%	**6.5%**
TMMP	18.0%	**8.4%**
TMIP	18.0%	**8.4%**

Legal	EU directive target 2020	Distance to target	Current RES-E share in final energy use	Share of RES in final energy use 2007	RES-E share by 2020	Share of RES in final energy use 2020
TMUKB	15.0%	**13.1%**	5.00%	**1.9%**	14.48%	**5.4%**
TMMF	23.0%	**18.9%**	9.00%	**4.1%**	16.88%	**7.6%**
TMMT	0.0%	**0.0%**	25.20%	**10.5%**	30.77%	**12.8%**
TPCA	13.0%	**12.3%**	2.00%	**0.7%**	17.56%	**6.0%**
TMUKD	15.0%	**11.6%**	5.00%	**3.4%**	14.48%	**9.7%**
TMMP	15.0%	**12.4%**	3.73%	**2.6%**	15.83%	**10.9%**
TMIP	15.0%	**12.7%**	3.73%	**2.3%**	15.83%	**9.9%**

primary indicator	secondary indicator	index for visualization		
EMC data, global values	relative to production	relative to energy	Eurostat / EurObserv'ER	data from other source

data for part production plants ranked separately from vehicle production plants

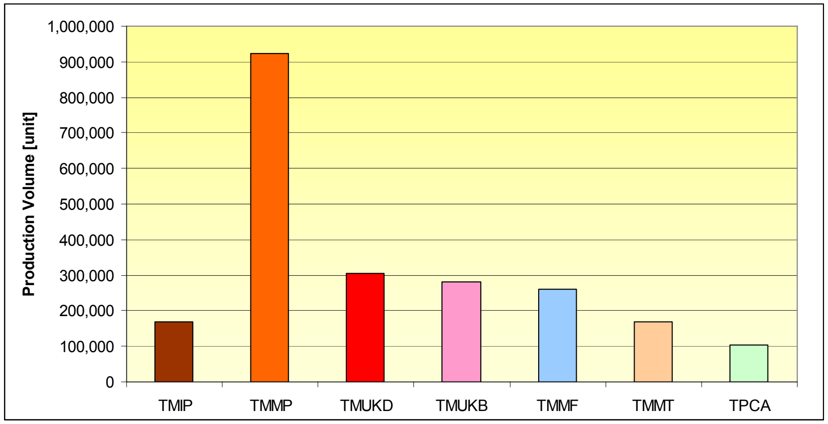

Figure 51: Production volume

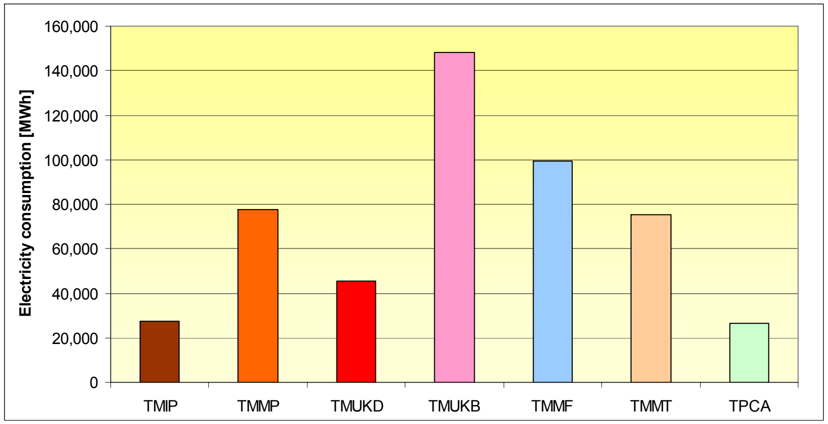

Figure 52: Electricity use

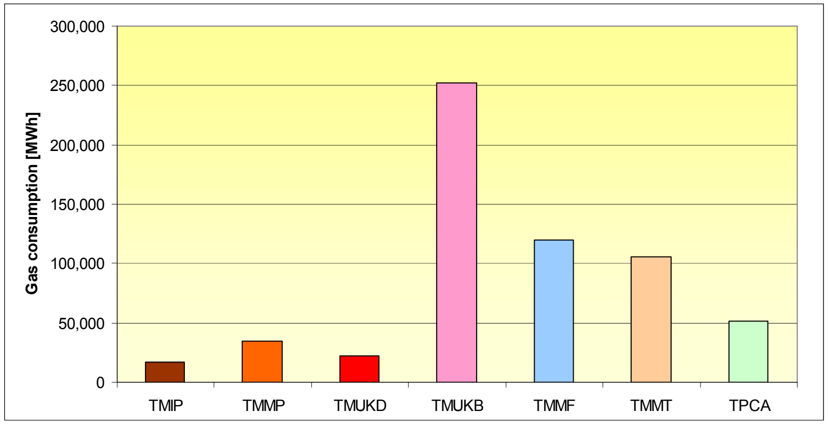

Figure 53: Gas use

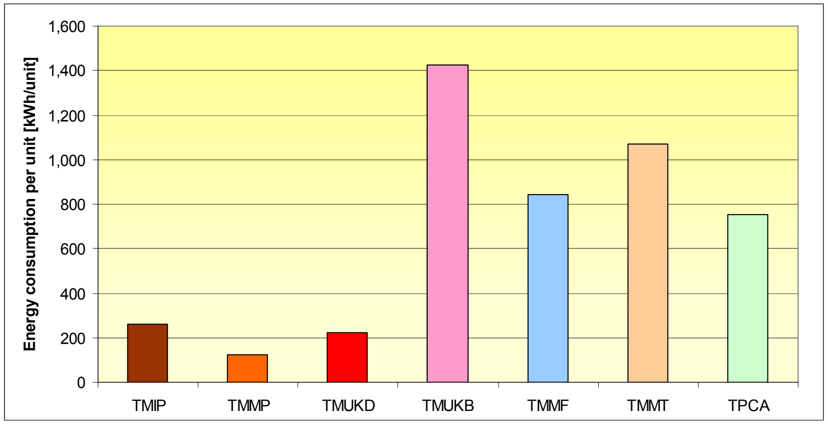

Figure 54: Energy use per unit produced

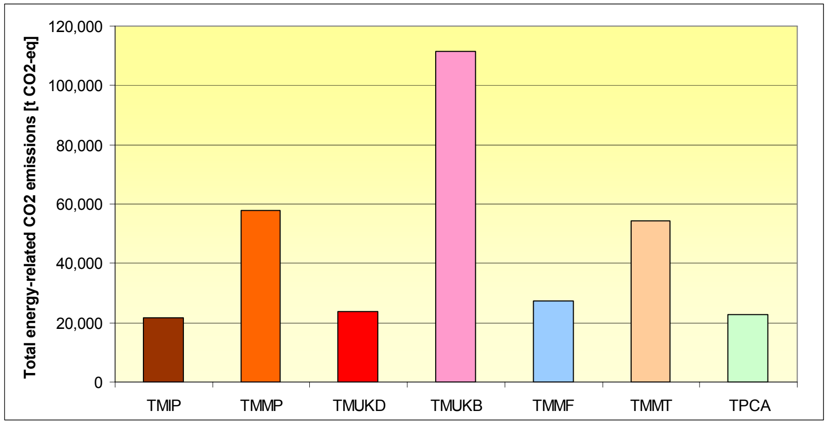

Figure 55: Total energy-related CO_2 emissions

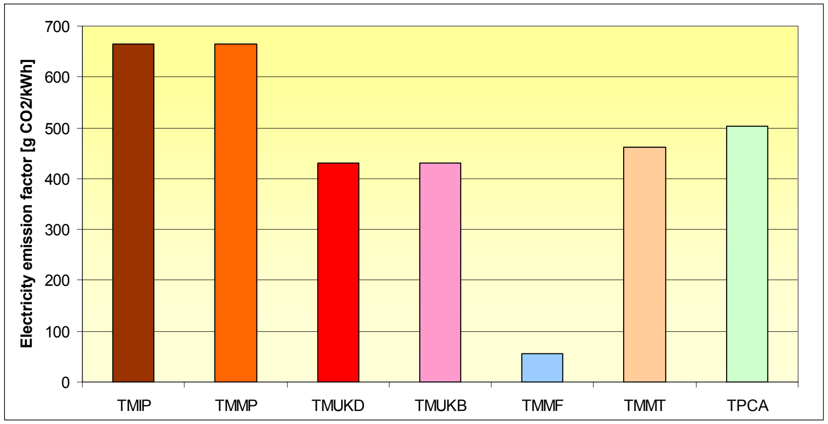

Figure 56: Electricity CO_2 emission factor

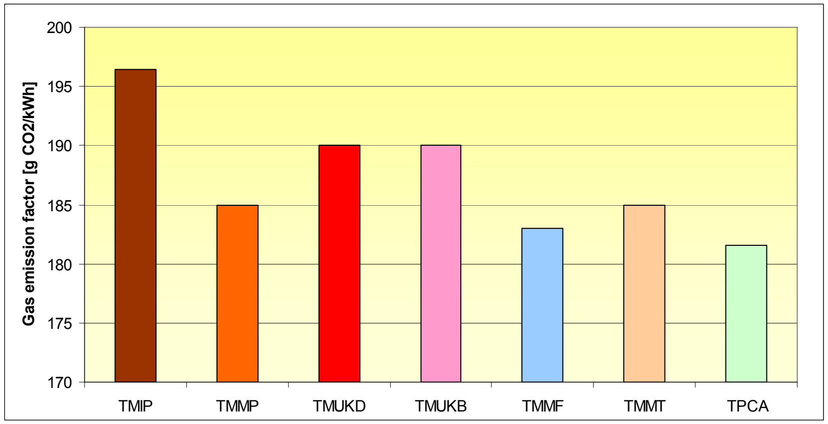

Figure 57: Gas CO_2 emission factor

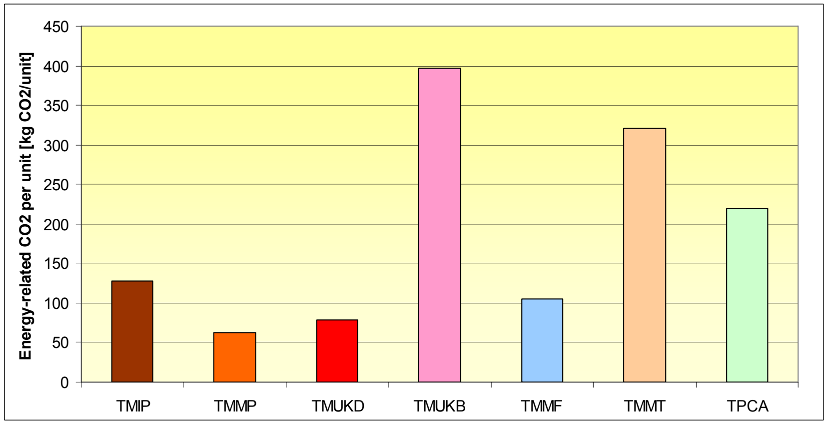

Figure 58: Energy-related CO_2 emissions per unit

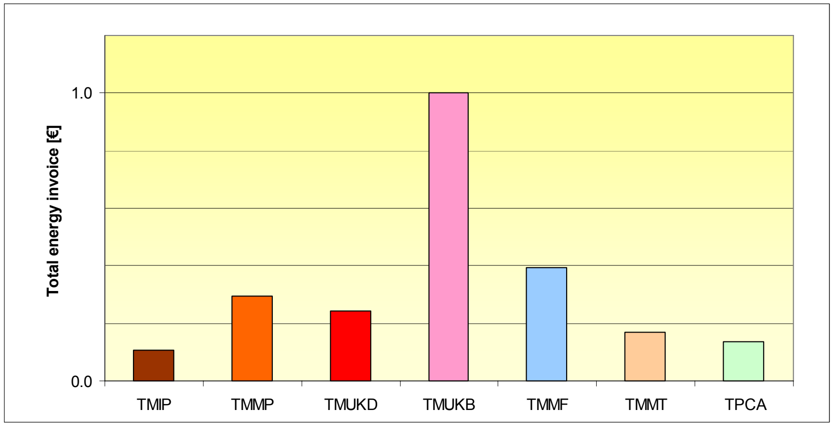

Figure 59: Total energy cost

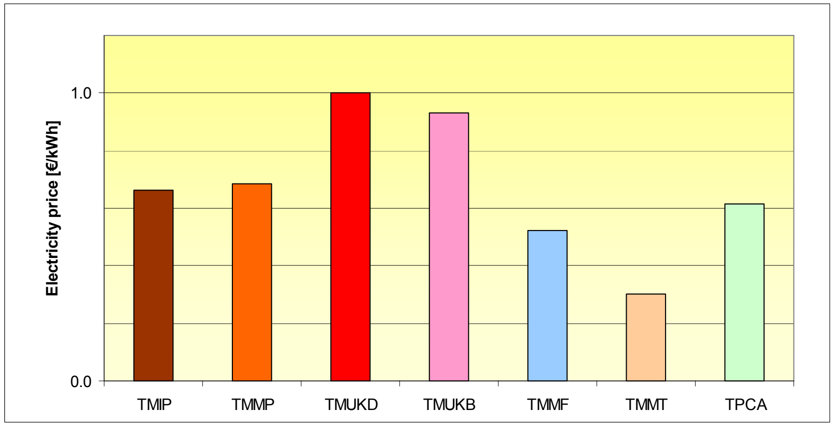

Figure 60: Electricity price

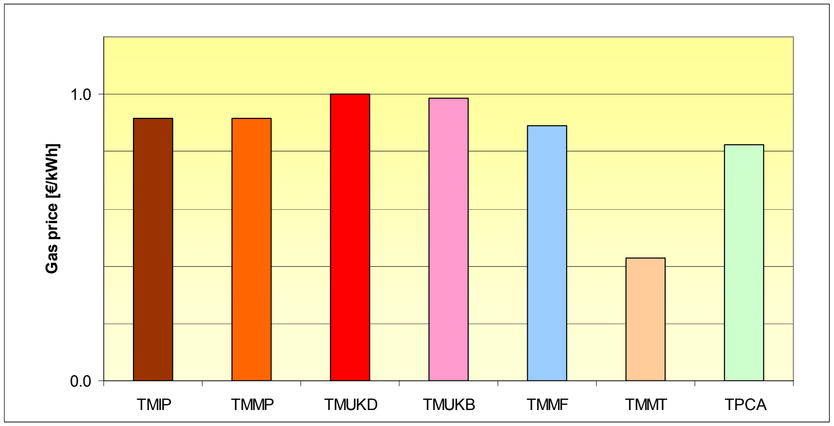

Figure 61: Gas price

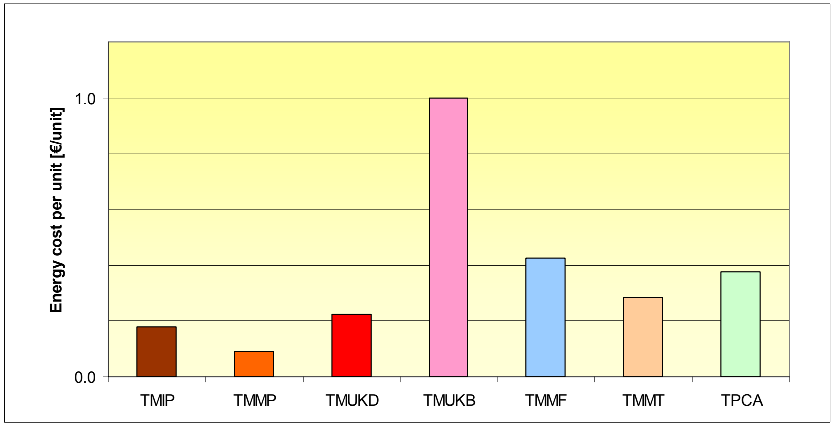

Figure 62: Energy cost per unit produced

Note: For confidentiality issue, the energy cost values are not shown and the maximum value is set equal to 1.

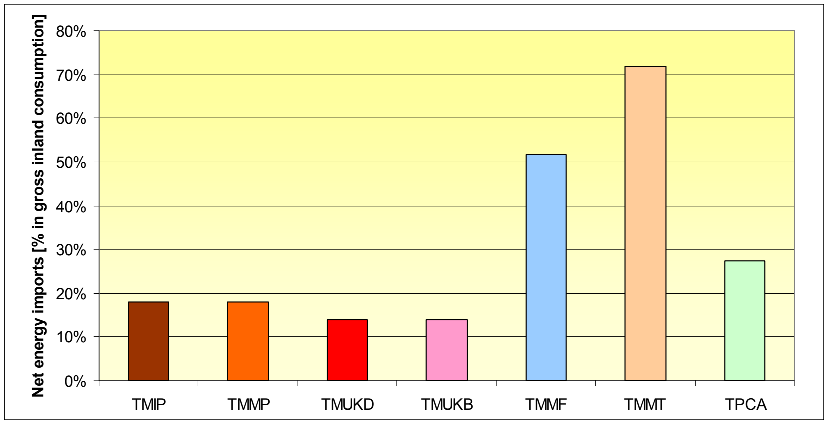

Figure 63: Energy imports

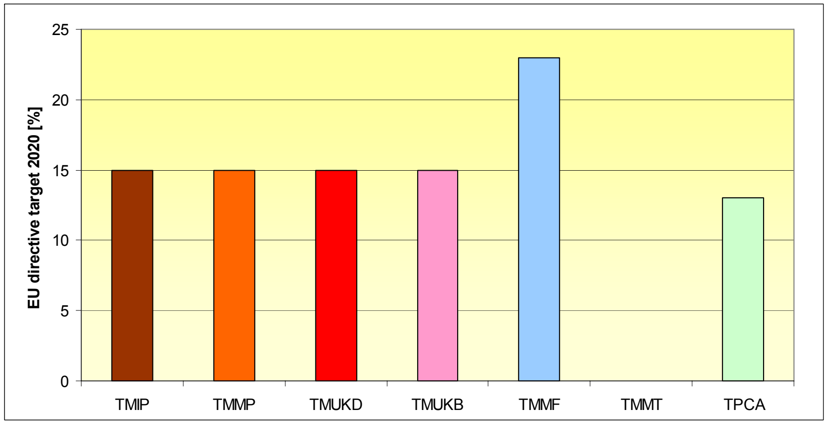

Figure 64: EU directive RES target by 2020

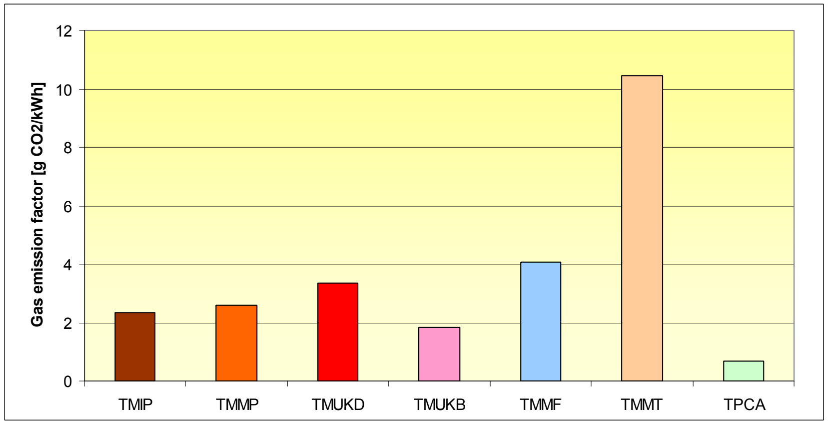

Figure 65: Actual share of RES in EMC energy use

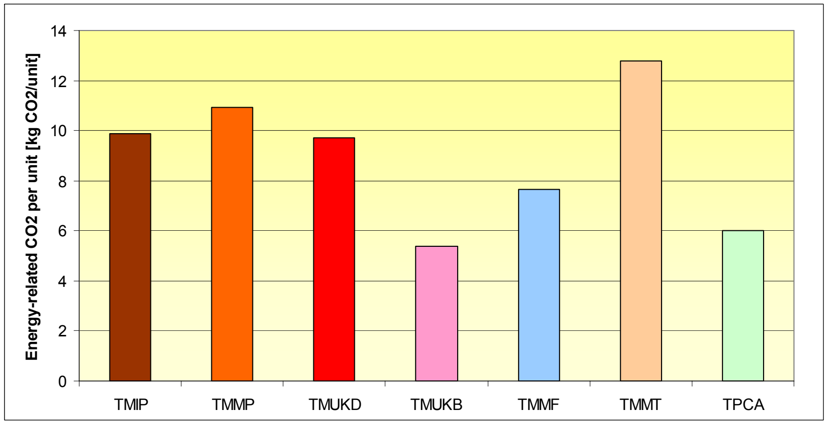

Figure 66: Estimated RES share in 2020