Technology Road-Mapping of Final-Energy Generator Technologies, for the Industrial Sector, in Developed European Economies

Kristóf Urbán[1,2], Szilvia Bíró-Szigeti[2] and Béla Pataki[2]

[1] Engineering System Configurator, Bosch Industriekessel GmbH, Nürnberger Str. 73, D-91710 Gunzenhausen, Germany
kristof.urban@de.bosch.com

[2] Department of Management and Corporate Economics, Faculty of Economic and Social Sciences, Budapest University of Technology and Economics, Magyar tudósok krt. 2, QA309, H-1117 Budapest, Hungary
szigeti.szilvia@gtk.bme.hu, pataki.bela@gtk.bme.hu

Abstract: The goal of this paper is to investigate the details of final-energy generation technologies for industrial energy systems. Currently, sustainable development, environmental aspects and economy are of paramount importance and these technologies play a very significant role in all of them. Moreover, the unpredictability of political, ecological and economic conditions poses a significant uncertainty for companies dealing with these products. To address this problem, a technology road-mapping framework was developed to facilitate the understanding of the environmental and technological maturity effects on these products, from the supplier companies' point of view. In the frame of this investigation, the macro- and micro-environments were examined, then summarized, with the resulting opportunities and threats for the manufacturing firms. Based on the concluding roadmap, mid- and long-term trends can be identified, which are then available to support company-specific research.

Keywords: technology roadmapping; energy; final energy generator; TRM

1 Introduction

The goal of this paper is to create a technology roadmap for final-energy generator technologies (techs) applied in the industry, focusing on the developed economies in the European Union (EU), in order to provide insight into the future trends of these technologies for product manufacturing companies.

The topic of industrial energy consumption, in general, is a globally important matter. As the World Energy Council's Issue Monitor [1] states, the subjects of "energy efficiency", "commodity prices" and "renewable energy", which are priorities in the industry, are all of paramount importance worldwide.

Focusing on the short-term and local interests, energy conversion system performance and efficiency for industrial decision-makers are also not topics to be neglected. In today's VUCA world (Volatility, Uncertainty, Complexity, Ambiguity) [2], product life-cycles are shortened, a more frequent change in processes and business models becomes necessary, therefore a need for energy systems being able to supply energy flexibly, efficiently, economically and in an environmentally friendly way, arises.

From the perspective of the energy conversion product manufacturers, the situation is also not easy. They face the same changing conditions in their own business, and they must predict which technologies to focus on. This paper deals exactly with this question: given the business environmental facts and information, a technology roadmap framework is created to facilitate the evaluation of existing and emerging technologies in terms of future market feasibility. Based on this, manufacturing companies can assess the considered technologies and create product roadmaps and strategies.

In the second section, some basic definitions and the applied method are introduced. The third part of the paper deals with technology road-mapping, first summarizing general assumptions, then introducing the research methodology and finally elaborating the process. The last part concludes the article by wrapping up the findings and drawing up potential further research topics.

2 Basic Concepts of the Final-Energy Industry

This section roughly describes the industrial final-energy generator market in developed European economies, based on the example of Germany. We classify the industrial sector into two sub-groups.

- "Normal" industrial sector: this includes every player where the goal of operation is a manifestation of some product. To be able to do that, they need various types of process-related final energy but there is also a need for comfort-related energy. The share of specific energy cost of the products is relatively low, meaning that the energy system has other requirements to meet as well. These requirements are related to production continuity/reliability, safety and flexibility. In several cases, the system design is first subject to robustness then to economy and ecology.
- Energy industry sector: to this sector, we assign the power plants, where the main goal of the operation is the final energy generation, that is the product of their processes. This is an important distinction from the previous sub-class because in this case, every slight system efficiency improvement is of paramount importance.

In this article, the target customer group belongs to the "normal" industrial sector, where the points of system reliability, flexibility, economy and ecology are all of paramount importance. Moreover, the technology road-mapping is going to be carried out for general products, meaning that the differences between products from different producers, but with the same technology are neglected. From now on, the term "industrial" is going to be used for the "normal" industrial sector.

3 Technology Road-mapping of Final-Energy Generator Technologies

3.1 Technology Road-mapping Fundamentals

Technology road-mapping (TRM) is a powerful management technique enabling the evolution of markets, products, technologies, and other significant perspectives to be explored, together with the linkages between the various perspectives. A technology roadmap is a multi-layer chart with time axis showing different types of information from the perspectives of the layers and also the linkages between those pieces of information at all layers. There are company level and industry level roadmaps as well.

In this paper we focus on the application of industry level road-mapping, nevertheless our roadmap can be used as the first base of company level road-mapping activities within the examined industry later on.

For a detailed review of TRM in general and its different versions and their applications see [3-7].

3.2 General Considerations and Assumptions

Normally, the focus of the technology roadmap defines its structure/layout/type, that is why some basic considerations are presented here in order to formulate it for the scope of this article.

- This work creates an industrial technology roadmap, which can be later expanded to company level roadmaps. The two topics of this investigation are the market and the technologies.
- As [8] points out, the "market" first layer fails to cover additional aspects in the environment, therefore in this work, "environment" is going to be investigated.

- Some authors include two market layers where not only the product but also the technology market is investigated [9]. In the scope of this paper, it is assumed that advanced technology know-how provides a serious competitive advantage, so this scenario is not taken into consideration.
- As previously discussed in Chapter 2, this article generalizes the products applied in energy systems, based on underlying technologies, so the "product" layer is left out of this work.
- Although one of the main advantages of technology road-mapping is to simultaneously consider market pull and technology push effects, this paper builds rather on the former one, since the technology assets of a specific company cannot be interpreted here.
- The time horizon of the evaluation aligns with the ones of the European Union's energy policy. Accordingly, 2050 is chosen to be the investigated period with respect to the EU long term energy strategies until 2050 [10].

3.2 Some Roadmap Layers of Final-Energy Generation Technologies

3.2.1 Environment Layer

Evaluation of the Macro Environment

The evaluation of the environment layer is started with the Macro Environment applying the STEEP analysis.

The *ecological aspects* are very important, since every endeavor, measure, political decision and the topic of this article can be traced back to them. Even though the effects of climate change are obvious even today, many people still deny the existence of this phenomenon. The right-now effects include continuous temperature rise [15] which caused the sea ice extent to decrease substantially since 1979 [16] and the sea level to increase with 9 cm since 1993 [17]. This is accelerated by the increasing level of CO_2 concentration [18]. Another negative effect of these processes is more extreme weather conditions [19]. The ecological results of this process could be elaborated more in detail in a separate study, but from the aspect of this paper it is more important to understand their reality since they are the trigger to to-be-expected human actions. Roughly speaking, if we look at potential future outcomes, we can think of many. As [20] summarizes, we can consider three different scenarios. The first and worst one is the "business as usual" scenario where we do not take any measures to mitigate our effects on the climate. This would mean to maintain our current CO_2 emission rate. The 2DS (2-degree scenario) scenario would mean to decrease our CO_2 emission rate to keep global mean temperature warming below 2°C. The best-case scenario is that we keep the temperature rise below 1.5 °C until 2050. Every one of them results in a major decrease in precipitation and an increase in temperature, which all initiate the above-mentioned ecological effects. To sum up, the effects of climate change are so severe that major social and political measures are to be expected over the long term. Our time frame immensely influences the final outcomes, so these changes are to be calculated with in the consideration period of this article too. This is also supported by the fact that the actions taken now are more effective than later actions. From now on, we will assume the so-called realistic scenario, which corresponds to the 2DS one[1].

The *social aspects* of the macro environment show promising trends in Europe. As discussed, it is hard to formulate objective and completely relevant indicators about them, nevertheless, some statistics are presented here to show the environmentally conscious behavior of EU citizens. The greenhouse emission per capita of the EU countries has been decreasing since 2003 [21]. This can be traced back to many factors, but environmental attitude change cannot be neglected. Although it is also a complex indicator, the expenditure on environmental protection is growing too [22]. This would most likely not be the case without social expectations. To sum up, the social factor of the macro environment supports environmental protection, let it be politically initiated or willingly performed by the companies.

A more tangible aspect is the *political environment* in the EU. As mentioned, it can be approached from various point of views, this article starts with a global one and zooms in to the specificities of the EU. One of the most important international agreement was the Kyoto protocol [23], adopted in 1997, entered into force in most countries in 2005, which aimed at decreasing the emission of greenhouse gases. A more actual international measure was the Paris Agreement [24] in 2015. It is the most effective agreement of all times, already resulting in ratifications in less than 11 months after adaptation and well before its validity in 2020. Its main target is to keep the global warming below 2°C, aiming for a maximum of 1.5°C increase, and reaching global emission as soon as possible. It strives for global CO_2 neutrality by. The measures ignited by this agreement are expected to align with climate change scenario 2DS [25].

Probably the most relevant and direct political influencers to the topic of this article are the EU's directives. The 2030 and 2050 environmental goals are summarized in its Green Paper [25] and 2050 Roadmap [10]. Other two relevant documents are the Energy Efficiency Plan [26] and the Strategic energy technology SET plan [27].

1 The optimistic scenario (1,5°C increase until 2050) would require immediate, very strong changes, which cannot be observed yet, so it would be unrealistic to take that as the most likely outcome.

Since the 2050 Roadmap [9] deals with a broader focal area, and it is also the base of the Green Paper [25], it is beneficial to investigate this one at first. The document mainly defines Europe's key challenges (i.e. keeping its 2020 goals, international collaboration) and formulates goals for this period. It states that in order to keep temperature change below 2°C until 2050, 80-95% greenhouse gas emission reduction is necessary, and it will largely need to be met internally.

The mentioned Energy Efficiency Plan [26] summarizes potential areas where energy efficiency can be increased. According to it, the low hanging fruit is the building sector, the second-largest potential is in the transport, and the third is associated with the industry. Since only the third is relevant from the perspective of this paper, bullet points connected only to this sector are summarized briefly: efficient generation of heat and electricity (replacing ageing equipment with best available technology (BAT)), energy efficiency in electricity and gas networks, energy efficiency as business sector, increasing the competitiveness of European manufacturing industry with energy efficiency, research and innovation.

The Strategic Energy Technology Plan [27] is a general document about the focus areas of the EU. The biggest emphasis is on renewable energy sources and hydrogen. In the section about the industry, it specifically mentions high-temperature heat pumps as a key technology.

According to the Green paper [25], the EU is on track to achieve its 2020 goals, but it is necessary to define new, further plans for the upcoming period [28]. It was created to ensure the long-term reachability of climate objectives, taking into consideration challenges the EU has to face with (e.g. economic crisis and budgetary problems of member states). The Green paper builds on the other roadmaps, where the following key figures to be reached until 2030 were defined: 40% greenhouse gas reduction, energy efficiency improvements, 30% renewable share, energy system modernization. Mentioned instruments to reach these goals are the renewable support schemes, energy and CO_2 tax and energy performance standards [29].

Besides the listed roadmaps, one can look at available statistics, to inspect the ongoing changes in connection with the political agenda. One such source is the Eurostat [30]. We can conclude based on the information from this source that both the goals on greenhouse gas emission and energy efficiency / energy productivity are backed by the statistics, so the EU and its members are committed to reaching the above-mentioned goals.

The last topic inside the political aspect is the governmental incentives and policies. It is important to summarize and understand them since as of today they play a key role in the economy of certain technologies (renewable energy technologies are expected to outperform conventional technologies regarding economy until 2020 [25]). A good summary of this topic can be found in Fruhman and Türk [31]. Among others, the most popular policy measures are Feed-in tariffs, Feed-in premiums and quota obligations. Several countries apply the combination of the aforementioned (e.g. German, France, Italy), many use only one (e.g. Hungary, Austria, Sweden) [31]. An overview of nation-specific incentive systems can be found in RES Legal Europe [32]. To sum up, over the long term, the decrease of governmental incentives is expected due to the competitiveness of renewable technologies and the result of market behavior.

Within the last, *economic layer* of the STEEP analysis, the availability of primary energy resources is going to be summarized, to be able to draw a conclusion with respect to the potential long-term applicability of technologies building on a certain energy source. This is an especially sensitive issue in the EU since it is one of the strongest economies globally, meanwhile lacking its own natural resources in a magnitude like China or the USA. No EU countries are counted as a major power when it comes to energy resource reserves [33]. Although the tendency change of energy dependency does not show any major increase alone, one can draw up the following conclusions.

- Most of EU’s oil is imported, its stagnating trend can be traced back to the outbalancing of efficiency increase with an increase in vehicle numbers. Because of the high dependency on imported oil [34], endeavors for decreased emission [10] [25] and globally platooning demand for this resource (Global Energy Perspective 2019, 2019), a strategy to leave oil-based technologies is justifiable.
- The EU has certainly a more significant gas reserve as for oil, still the increasing demand [35] and its dependency [34] (the biggest supplier of natural gas to EU countries is Russia [36]) would indicate cautiousness for this resource. On the one hand, the EU reserves are moderate and exhausting, on the other hand, gas is the best fuel-like non-renewable energy source in terms of specific CO_2 emission. Its price is fluctuating and highly dependent on global market conditions. As this energy source provides a good alternative against other conventional fuels, its usage in the industrial sector in the EU is not expected to decrease in the considered time interval. Another important and favorable aspect is that renewable gas products and hydrogen provide valid and (in mid-term) competitive alternatives for this energy source, in fact applying the same technology. This provides flexibility in energy utilization.
- Solid fossil fuels are mainly relevant for bigger than industrial-scale systems (i.e. power plants), where coal and uranium are utilized for final energy generation.
- As for renewable energy sources, the effects of the environmental aspect are hard to predict. On the one hand, higher solar radiation can be expected in the region. The wind potential would theoretically also increase because more extreme weather conditions are accompanied by more intense airflow. Current technologies, however, can hardly handle increased wind

speed, which could result in more often and longer safety stop periods. Biomass production is threatened by less precipitation.

To sum up the edifications of the previous sections, two main statements can be made. On the one hand, renewable energy sources are expected to play an increasingly significant role, therefore technologies building on them are more favorable in the long term. As for conventional energy sources, on the other hand, natural gas-based technologies are the most preferable ones because of the longer competitiveness and availability of this resource (e.g. compared to oil) and potential substitutes, i.e. biogas and hydrogen.

Evaluation of the Microenvironment

The microenvironment of a "general" company acting in this environment is evaluated with the "customers" aspect of the Porter five forces method. Focusing on the customer segment of western European countries, the following trends must be calculated with.

Industry plays a key role in developed economies. According to the European Commission's statistic database, the total final energy consumption is slightly decreasing [37], industrial energy consumption is stagnating.

Another important aspect is the structural change of the industrial customers' energy demand:

- One of the to-be-expected effects of climate change is more extreme weather conditions. In the mid-term, this primarily means increased temperatures in the European region. Because of this, areas previously not requiring air conditioning will do so in the future, so the cooling demand is expected to increase. In parallel, heating demand is expected to decrease.
- A very important tendency nowadays is the electrification of the industries [38]. It primarily means, that processes previously powered by heat/steam/high pressure/etc. are replaced with technologies utilizing electricity. This can be traced back to several reasons: more advanced technologies, investment reasons and flexibility.

Finally, the previously considered social aspects drive companies to pursue an environmentally friendly operation. Apart from the listed points, investment decision-makers have more positive sentiment for renewable and sustainable technologies.

Threats and Opportunities

In this last part of the environmental evaluation, the previously collected information is going to be summarized for a "general company". Since not every discussed layer has a direct effect on the business environment, some of them is going to be ignored in this evaluation and was only used to support the understanding of other layers.

Regarding *threats*, some obvious factors can be seen on the technology roadmap in Figure 1. A general sentiment from the ecologic and social layers of the evaluation is that renewable and "sustainable technologies"[2] are going to be favored against conventional ones. The latter is generally the cash cow of today's companies since they are more economical and more frequently applied nowadays than the former technologies. On the one hand, this carries a risk, because the cash cow technologies are expected to "die out" from the portfolio if they are not taken care of. On the other hand, the long-term processes are somewhat predictable, so portfolio management techniques can be applied to slowly put the emphasis on renewable and other "sustainable" technologies. Supplier companies need to evaluate their portfolio, technology pipeline and research & development activities to prepare themselves for the long-term changes in their business.

Another one of the main uncertainties is the political environment which, in parallel, carries threats and opportunities to the companies. As discussed, the EU is generally dedicated to supporting the 1.5D and 2D scenarios, and it created its roadmaps and strategies also along with these ideas. This can normally materialize in two main forms[3]. On the one hand with compulsory regulations (e.g. defining CO_2 tax, technology audits and stipulation of the installation of best available technologies [BAT]), on the other hand with voluntary measures (e.g. renewable incentives). Although these actions influence mainly the end customer of the products, their investment decisions are based on competitiveness, so supplier companies must consider these by all means. This carries a major threat: although compulsory regulations are more predictable, governmental incentives change often and greatly, with that influencing the economy of products. The short-term competitiveness depends heavily on these financial support systems [31], which effects research and development of given technologies in a negative way. Nevertheless, the long-term success of renewable and "sustainable" technologies is dependent very much on the maturity of the technology, which can be improved only over time.

As it was discussed in the economy layer, the fossil fuel dependency of the EU is significant. This mostly affects the energy policy of the member states and the EU, but through market mechanisms it is a very important fact for the final energy generator supplier companies as well. Two aspects must be considered: first, (un)expected political conflicts can lead to sudden and very significant changes in the product demand. This phenomenon is still actual nowadays. Second, fossil fuel prices are expected to increase over the long-term, making current fossil-based technologies less competitive.

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2 Under „sustainable technologies" it is referred to conventional technologies (e.g. burners) which are capable of utilizing renewable (e.g. natural gas) and unconventional resources.

3 The differences in the realization of the EU directives in the member states are not considered here.

As for the microenvironment, several threats can be noticed from the side of customers. First, customer energy demand is expected to stagnate, meaning that the potential market is not growing significantly in Europe. This means that companies must increase their market share if they strive for growth in the local markets. Since this topic is complex and other international aspects could have been investigated for a specific company, given that this article is only dealing with a “general company”, more detailed evaluation is not presented here.

A more relevant phenomenon can be traced back to the ecological layer, namely the shift in building energy demand. Most of the market leader companies in Europe have been focusing on heating appliances so the decrease in heating demand and increase in cooling demand carries a threat because the demand against their products shifts to other technologies. If a company wants to stay in the frontline, it must consider this aspect in its strategic plans.

Probably the most important transformation process is the electrification of the industry. This is a serious threat since industry sized final energy generator technologies are seldom capable of electricity generation.

The evaluated aspects, however, also carry many *opportunities*. Since the general geopolitical intentions of the EU are calculable, companies can prepare themselves for focusing on not-yet-economic technologies. It is straightforward that fossil-based technologies are not going to be incentivized and – because of the fossil fuel price increase and alternative technology maturing – becoming less and less competitive over the long-term. Strategic technologies are clearly announced by the EU so focusing on these minimize the risk of not lucrative research & development investments. Another support for these companies is the endeavor of the EU to ensure the instalment of BAT. This helps developing companies to maintain a market demand against their new products since in new projects only these new technologies can be implemented. With the intention of increase of renewable energy share in the energy mix, technologies utilizing such energy sources are destined to be looked for over the long-term. As this also stands for “sustainable technologies”, companies dealing with conventional technologies are able to shift their long-term focus in this direction without requiring substantially new technological know-how in completely new fields.

Although the fast-changing incentive system is hard to be calculated with, agile companies are able to utilize this support system and invest in promising. This is an important point, since companies in difficult periods tend to focus on short-term success instead of the long-term, although it is clearly less successful [39]. If one is able to support the financial competitiveness of an investment of an immature technology with these incentives, short-sightedness can be avoided.

Despite the risk from long-term changes, some opportunities can be noticed as well. The trends in building energy shift and process energy change are known so companies can exploit them by focusing on these phenomena and investing in this direction. With an acquisition or in-house development, the portfolio can be expanded so that it can cover both heating and cooling demand. Parallel, companies must assess the long-term demand against conventional technologies and allocate resources towards investments accordingly. Even with the high pace of electrification, not every process can be exchanged with electricity-based technologies.

Table 1 summarizes the above-discussed threats and opportunities from the environmental layer. As it can be seen, generally speaking, the threats can be derived from the expectable changes of the evaluated aspects, but opportunities arise as well from them, since the processes are mostly calculable (not every point is known for sure, but at least the directions are presumable.

Table 1
Threats and opportunities from the environment

Layers	Threats	Opportunities
Social	1. change in favoured technologies over the long-term	1. the known direction of preference change
Political	2. possible emission taxes and quotas 3. continuously stricter technology regulations 4. fast-changing governmental incentives 5. decreasing renewable incentives 6. potential political conflicts	2. known EU wide geopolitical intentions 3. supporting BAT 4. incentivized renewable and “sustainable” technologies
Economy	7. increasing fossil fuel prices and decreasing supply	5. calculable changes in energy source availability and prices
Customer	8. stagnating energy demand 9. decreasing heating- increasing cooling demand 10. expansion of electricity-based processes	6. known transformation of building energy demand from heating to cooling

3.2.2 Technology Layer

There exist several technologies to cover a specific energy demand with and picking one is by no means a trivial task. In the frame of this article, some of the most significant final energy types are going to be considered.[4]

[4] Information and statements regarding the technologies, specific market conditions and other such topics are based on the industrial experience of the author in the German industrial energy market.

Available Technologies by Final-Energy Demand

One of the two most fundamental final energy demands is the *heat demand*. As discussed above, in industrial plants it consists of comfort-related and process-related parts. The two can be differentiated in temperature level as well. Generally speaking, technologies being able to cover process heat are also capable of covering the heating demand, since their temperature is higher. Accordingly, the applicability of certain technologies for process heat generation is limited (for example, solar thermal modules and high-temperature heat pumps cannot generate enough heat for the metal industry). Technologies, which are suitable for such purposes are: burner-based, electricity-based, and electro-chemical process-based technologies. Technologies, which are suitable for lower temperature heat generation are: reciprocating and rotating engines, solar thermal technologies[5], heat pumps, thermal compressor-based heat pumps. These latter technologies are also less conventional, but serious energy savings can be achieved by utilizing them correctly. Another remarkable attribute of most of the technologies in this second class is that they can be applied for combined energy generation (either heat plus electricity or heat plus cold). This makes them especially economical in suitable applications.

Cold energy can be classified to comfort-related and process-related parts too. The former is external temperature-dependent and generally requires a moderately cold temperature. The temperature level of the latter is very dependent on the application – from climatized storage to deep cooling. In case of the available technologies, we can generally speak about compressor chillers and absorption chillers in industrial applications. The former is very flexible and can generate various temperature levels, although it utilizes electricity. The latter is an alternative technology, where a heat-driven compressor is used, but it is mostly applicable for climatization.

In industrial applications, *electricity* is most commonly purchased from the grid. Its price is generally complex, so several potential improvement possibilities arise at companies. (E.g. in Germany the total price consists of performance price and energy price – the former is dependent on the maximum performance value a consumes; the latter is based on the consumed energy.) One possibility is the utilization of a battery. Since this technology does not generate final energy, only stores it, it is not dealt with in this article in detail. As for generator technologies, a substantial amount of money can be saved when utilizing a generator machine. Most of these technologies (except the photovoltaic) are applied for combined energy generation.

As can be seen, unconventional technologies are hard to evaluate because they normally generate various forms of final energy in parallel. That is why a general

5 With concentrating solar power technology, several hundreds of degrees can be reached but its application in industrial scales is hardly imaginable yet.

evaluation method is necessary in order to be able to compare them. This will give the basis of the operational evaluation. Before diving into the technologies, some assumptions and considerations must be mentioned. In the frame of this work only conventional technologies will be summarized because of the following:

- Nowadays, they represent the majority among installed appliances
- Most of the leading final energy generator product supplier companies deal with these technologies as their main business
- Unconventional technologies are technologically less mature and diverse, so company-specific evaluations are necessary to select and evaluate the relevant ones in a proper way
- The primary and secondary energy sources powering these technologies vary significantly depending on country and region, so a generalization would be too undetailed

Because of these reasons, only burner-based technologies (boilers), internal combustion engines (combined heat and power module), heat pumps and solar thermal modules are going to be discussed more in detail. Similar to the technologies, only specific energy sources are going to be considered because:

- Although alternative powering (e.g. with hydrogen) would be possible, the selected conventional energy sources are used in today's appliances
- Renewable and alternative energy sources are highly varying based on country and region

Only natural gas, "heat" and electricity are considered here.

Final-Energy Generator Technologies

In this subsection, the above-mentioned technologies are going to be discussed more in detail to be able to evaluate them, based on the aforementioned environmental predictions. The investigation is primarily based on the technologies, and the applicable energy sources are considered separately.

Boilers are the most common products to generate final heat energy. It is in the 4th stage of the S-curve of the technology life cycle[6] [40] [41]. Its basic operation is to apply a burner where different types of fuels can be burned to generate heat for warming up the water. Common fuels nowadays are natural gas and heating oil. Lately, heating oil lost popularity because of its emission and additional costs. An alternative is the biomass boiler, which has a significantly different burner technology. As the operating cost (fuel cost) takes up to ~96% of the total life-cycle cost [41], the investment cost and its trend are neglected. This assumption

[6] About the S-curve and the detailed discussion of the whole theory of the technology life cycle see e.g.: Twiss, Goodridge [39] or Cetindamar, Phaal, Probert [40].

can be further supported by the consideration that the technology is fairly mature, so breakthrough inventions are not expected. Consequently, the competitiveness of the technology depends on the fueling energy sources and on their prices. The efficiency of a modern boiler is approximately 93% [41] boilers can generate only heat as output.

Combined heat and power modules (CHP) are an alternative for heat and electricity generation. It is between the 3rd and 4th part of the technology S-curve. They consist of an internal combustion engine (ICE), a generator and heat exchangers. The electric efficiency is approximately ~ 30. This constellation is used as a back-up generator, but CHPs are extended with heat exchangers to be able to utilize the waste heat for heat demand coverage. CHPs can be operated with any commonly used fuels ranging from diesel to natural gas. Nowadays, the standard version is the natural gas-based variant, which is used to cover the base load, while a boiler is operated in peak periods. A fuel alternative is biogas, although special treatment and increased maintenance are. CHPs cost significantly more than boilers because of the technology and the necessary additional components. Because of this, one also must take into account the investment costs. The investment cost of CHPs is approximately 12 times higher than for boilers [44]. Although it must be noted that CHPs can generate electricity which is a substantially more valuable energy form than heat.

Heat pumps are a complex technology where the performance, efficiency and economy all depend on the use-case. It is on the 3rd part of the S-curve. Generally speaking, a heat pump consists of an evaporator (heat source), compressor, compensator (heat sink) and throttle valve. In this thermodynamic process the energy from the heat source and heat sink can be utilized as well, generating cold and/or heat energy. The most beneficial situation if we can utilize both sides of the cycle, in that way very high efficiency can be reached. The issue with these machines is that their efficiency (coefficient of performance, COP) is highly dependent on the heat source and heat sink temperatures [45]. As for the investment cost, heat pumps are also significantly more expensive than boilers: 5000 kW machine – 250 €/kW, 800 kW machine – 475 €/kW [45].

The last technology this article deals with more in detail is the *solar thermal* collector. It is between the 2nd and 3rd part of the S curve with a steep incline. It is a renewable energy-based technology, where the thermal energy of the sun is utilized with collector panels. Because of this, one can neglect the fuel costs. By this technology, as more and more products are applied, unit-cost drop over time can be expected, because the product technology and the process technology evolve.

As it could be seen, various technologies are not easy to compare because they utilize and generate different energy forms, and their life cycle cost structure differs significantly as well. As for fossil fuel-based technologies, mostly the fuel costs have to be considered, meanwhile renewable-based technologies depend on the investment cost. The competitiveness of the former, will be shaped by the change of fuel prices – which are expected to grow over the long term – and the economy of the latter is highly dependent on the technology maturity. For the purposes of this article, primarily the former technologies were examined, due to of the above-mentioned reasons.

Conclusions

In the frame of this article, an industrial technology roadmap was presented for final-energy generator product manufacturing companies, that supply the Industrial Sector. The main target was the evaluation of the environment and the technology landscape.

The conclusions of this paper can be summarized in the following points.

1) The justification of the topic points out important facts about industrial energetics, which might wake the attention of researchers to focus on this topic more thoroughly.
2) Since this area is complex, it is important to create some classifications and segmentations, to be able to distinguish between research fields and the articles' research focus.
3) To the best of the authors knowledge there has not been any such industrial technology roadmap generated, for the topic of industrial final-energy generator technologies. The investigation herein includes an environmental and technology layer that provides a good basis for further discussion and company-specific technology roadmaps.
4) With the application of different management and evaluation tools, a basic framework is drawn up, which can be used as a basis for further evaluations.
5) Apart from collecting topic relevant information, the work presented suggestions and edification summaries based on the performed research. Such results were the summary of threats and opportunities from the environmental layer, where the collected information was processed, and its relevance to the supplier companies was formulated.

In addition, this work can be the basis for various further research directions. One possibility could be to limit the scope for a specific country, doing that, the political landscape (regulations, incentives and country-specific roadmaps) can be further elaborated. This is supported by the summary of EU politics herein.

Another topic could be the expansion of the connection between the ecological, social, political and customer aspects, from a marketing perspective. In other words, the effects of the first three, on the last one, could be investigated, to explore the possible reactions and trends, for example, in the form of CSR.

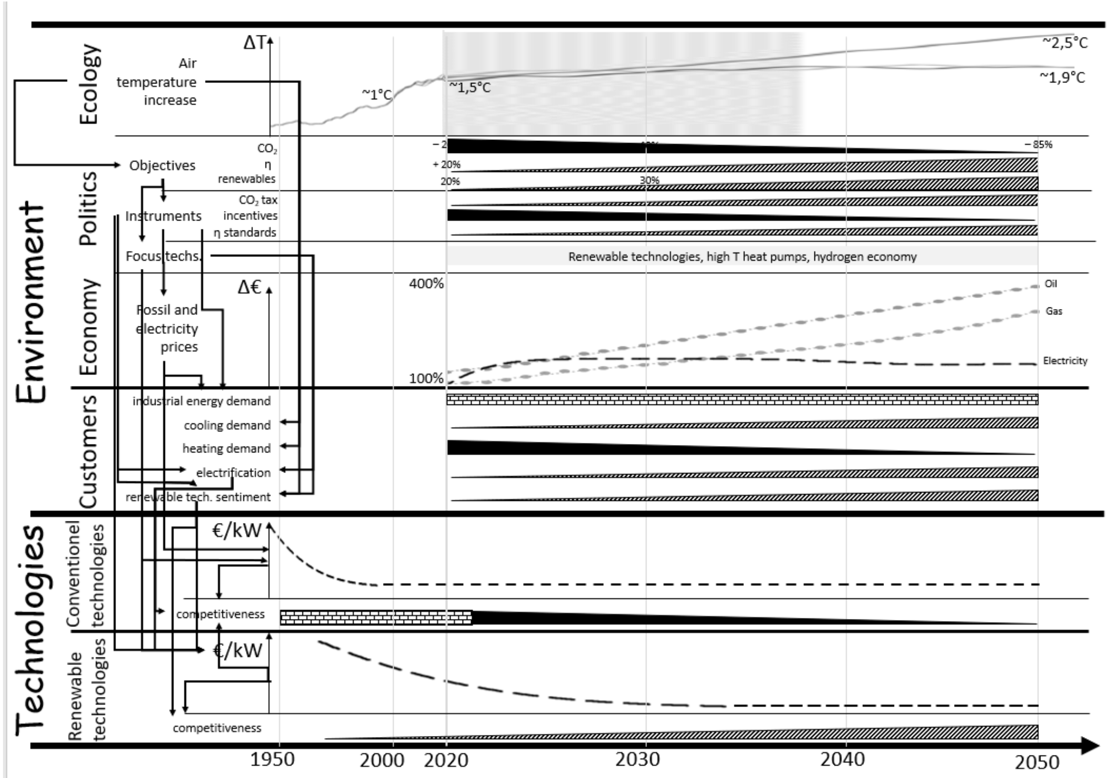

Figure 1

Some Technology Roadmap Layers of Final-Energy Generation Technologies with Effect

Since this article dealt mainly with conventional technologies, a potentially novel research area could be the inclusion of unconventional (renewable and sustainable) technologies, although this would probably be most beneficial for a given company and a specific country. In the frame of this evaluation, a further classification of technologies should be performed (differences and proper definition of conventional, unconventional, renewable and sustainable technologies).

Probably, the most natural follow-up research direction would be to include company-specific information and create a company technology roadmap, with clear strategic suggestions.

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