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Presentation of the 5Ds in Energy Policy: A Policy Paper to Show How Germany Can Regain Its Role as a Pioneer in Energy Policy

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Abstract: The widely recognised Energiewende, ("energy transition") in Germany has lost its original momentum. We therefore address the question of how the transition process to a new energy system can be reignited. To do so, we developed the "5Ds approach", which lays the groundwork for a process analysis and the identification of important catalysts and barriers. Focusing on the five major fields required for the energy transition, we analyse the effects of: (1) Decarbonisation: How can efficiency and renewable energies be expanded successfully? (2) Digitalisation: Which digital solutions facilitate this conversion and would be suitable as sustainable business models? (3) Decentralisation: How can potential decentralised energy and efficiency opportunities be developed? (4) Democratisation: How can participation be strengthened in order to foster acceptance (and prevent "yellow vest" protests, etc.)? (5) Diversification of service: Which services can make significant contributions in the context of flexible power generation, demand-side management, storage and grids? Our paper comes to the conclusion that German policy efforts in the "5D" fields have been implemented very differently. Particularly with regard to democratisation, the opportunities for genuine participation among the different social actors must be further strengthened to get the Energiewende back on track. New market models are needed to meet the challenges of the energy transition and to increase the performance of "5D" through economic incentives.

Keywords: energy policy; energy transition; decarbonisation; digitalisation; decentralisation; democratisation; diversification

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1. Introduction

Industrialised countries are tasked with reducing CO_2 emissions by at least 80–95% by 2050, according to the Intergovernmental Panel on Climate Change (IPCC), which requires almost zero-carbon electricity generation. This underscores the special role of the electricity sector to lead the low-carbon energy transition [1]. As the fourth-largest economy in the world and an export-oriented nation, Germany is (or rather was) perceived internationally as a powerful role model. If energy policy fails in Germany and Germany's climate protection targets remain unmet or lead to social upheaval, other countries might conclude that a turnaround in their energy systems is even less possible. Conversely, many will follow the example if Germany succeeds in converting its energy supply efficiently, economically and responsibly. Germany was long considered a pioneer in the expansion of renewable energies, above all because of its progressive feed-in tariff regulation. Many observers expected that other countries would follow the German example [1]. In recent years, however, Germany has lost its position as a leading role model and was only ranked 23rd in the 2020 Climate Change Performance Index (CCPI) [2]. The 2020 World Economic Forum Energy Transition Index (ETI) did not rank Germany much higher, in 20th place with a score of 63.9% [3]. The highest scores were obtained by Sweden (74.2%), Switzerland (73.4%) and Finland (72.4%).

The reasons for this development are manifold. There is a lack of faith and ambition among some politicians and industry representatives [1,4] but also among the general population when, for example, electricity grids need to be expanded [5].

A look at the past makes it clear that change is necessary to achieve success in the future energy transformation. The first Renewable Energy Sources Act (EEG), which entered into force on 29 March 2000, started the promotion of electricity from renewable energy systems in Germany [6]. Section nine of the EEG laid down the payment of a minimum remuneration for a period of 20 years. For all systems that were commissioned before the Act entered into force, the year 2000 is generally considered the year of commissioning. Consequently, first renewable energy plants that were operated before or around 2000 lost their entitlement to subsidies as of 31 December 2020 [7].

Following the expiry of the EEG remuneration claims, renewable energy systems are now confronted with free market competition. Business models are therefore possible only via freely accessible market segments, and the market values on the electricity exchange serve as the basic assumption for the possible revenues. In addition to Germany's so-called "subsidised direct trading", in which plant operators still receive a reduced price premium, so-called "other direct trading" is the counterpart for plants not entitled to remuneration anymore. With "other direct trading", a service provider must be contracted that sells the electricity generated. Alternatively, the electricity can also be sold to a buyer or trader under a "power purchase agreement" (PPA). With both latter options, no additional subsidies or premiums are paid. However, in contrast to subsidised plants, electricity traded this way retains its "green electricity" attribute, which could make it suitable for special premium "green" or "regional" electricity products. However, appropriate business models must be developed and offered to provide an economic perspective for the growing number of such plants.

Another aspect that provides pressure for change has to do with acceptance. Although general acceptance of renewables is very high in Germany, wind energy, for instance, has become a controversial topic, with emotional debates on shade, noise and potential negative impacts on the landscape [8]. Accordingly, one current evaluation of energy policy implementation efficiency in the EU shows that Germany has lost pace compared to other EU member states in the last 25 years [9]. If Germany is to advocate for sustainable and courageous energy policies worldwide, it must therefore reclaim its status as a pioneer in energy system transformation and climate protection. In this context, Germany has started numerous policy initiatives and programmes, such as using digital technology to facilitate its energy transition, including replicable solutions developed and demonstrated in model regions. Against this background, we investigate the relevant policy framework and efforts in Germany and hypothesise that more concerted policy action is needed for the country to become an inspiring role model again.

Energy transitions are typically characterised as transformations of physical infrastructure, accompanied by wider social, organisational and political changes [10]. In this context, the following aspects of system transformation are of major importance:

- A transition from conventional energy systems to renewable energy sources;
- An industry-wide low-carbon transformation;
- A shift from centralised large-scale to decentralised small to medium-scale generation infrastructure;
- Growth in the demand for energy efficiency, sufficiency and flexibility;
- An industry-wide change towards greater service orientation;
- Business model transformations;
- Company-level transformations.

Based on this, we structured the necessary system transformation into a total of five major sub-trends, which we refer to as "the 5Ds".

2. A Systematisation of the Drivers of Energy System Transformation into Five Key Dimensions of Change—The 5Ds

It is quite obvious that the process of the energy system transformation has considerable impact on the energy industry in Germany. The transformation process of other countries has already been structured several times. In many cases, terms with a "D" have been used. Asif, for example, has determined the 4Ds of a sustainable energy transition. These are: decarbonisation, decreased use of energy, decentralisation and digitalisation [11,12]. Dash has identified 5D words to describe the transformation process, namely democratisation, decarbonisation, decentralisation, deregulation and digitisation [13]. Since the process of deregulation has already been completed in Germany in the course of a very far-reaching liberalisation of the energy market at the end of the 1990s, this aspect is no longer relevant for Germany. Like Asif, we are of the opinion that the aspect of democratisation has increased in importance and will become more important in the future, especially in the context of acceptance issues. For this reason, our five dimensions mentioned above are relevant for Germany. Since our consideration is primarily about the process of leveraging digitalisation to improve business processes, we use the term "digitalisation" instead of the term "digitisation" used by Dash (which is often used in a solely technical context). We go into detail in the following and describe the drivers.

The "5D" processes of decentralisation, digitalisation, decarbonisation, democratisation and diversification of services (to decrease use of energy) not only have substantial impact on the energy industry's actors and the sociotechnical structure but also change the core business of the established energy companies and their self-image. The intended division of selected business fields between Germany's two most powerful energy companies, E.ON and RWE, illustrates the ongoing disruptive processes in the national energy industry [14]. It is also becoming increasingly apparent that traditional business models no longer work in such transitions, and new service-oriented approaches are necessary to take advantage of economic opportunities and therefore successfully conduct business [15].

2.1. Decarbonisation

A look at the figures shows that Germany can certainly claim success in climate protection (see Figure 1). Since 1990, annual greenhouse gas emissions have fallen by around 42 percent. In 2019, however, it still looked as if Germany would not achieve its 2020 climate target of a 40 percent reduction compared with 1990. By then, emissions had fallen from 1251 to 810 million metric tons, a 35 percent drop. Ultimately, only the unexpected massive restrictions associated with the fight against the coronavirus pandemic led to the 2020 target being achieved after all.

However, a look at the details also shows that the sectors have made very different contributions to the development. In 2019, for example, more than 40 percent of electricity already came from renewables, and in the summer of 2020 even more than 50 percent, making them the most important energy sources in the electricity generation sector. In the areas of heat and mobility, on the other hand, the switch to renewables is proceeding rather slowly (see Figure 2).

The development so far is a first small step, and further measures are needed, which becomes quite clear when one looks at the defined political goals. Originally, Germany had defined a target of reducing its national greenhouse gas (GHG) emissions by 40% by 2020 and by 80% to 95% by 2050 (compared to 1990 levels). These targets were already key points of the German government's Integrated Energy and Climate Programme (IEKP) in 2007. The IEKP defined a "top-down" target corridor and political framework for the energy system transformation in Germany. In doing so, targets corresponded with the respective measures of the European Union for the European level. An overview of all relevant climate protection goals until 2020 is provided in Table 1.

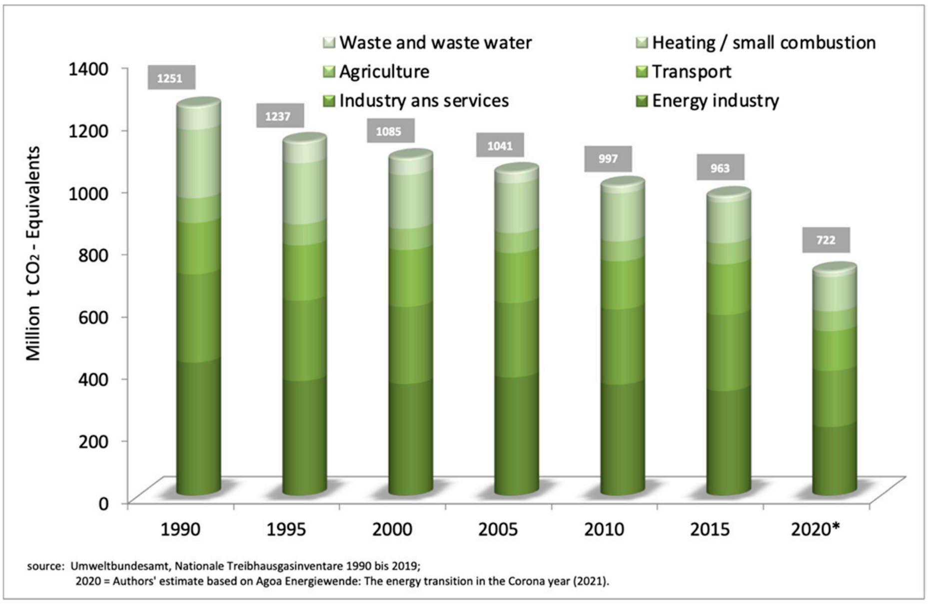

Figure 1. Development of greenhouse gas emissions by sector in Germany from 1990 to 2020 (Own presentation based on data from the German Federal Environment Agency 2020: https://www.umweltbundesamt.de/ (accessed on 9 June 2021) and Agora Energiewende 2021).

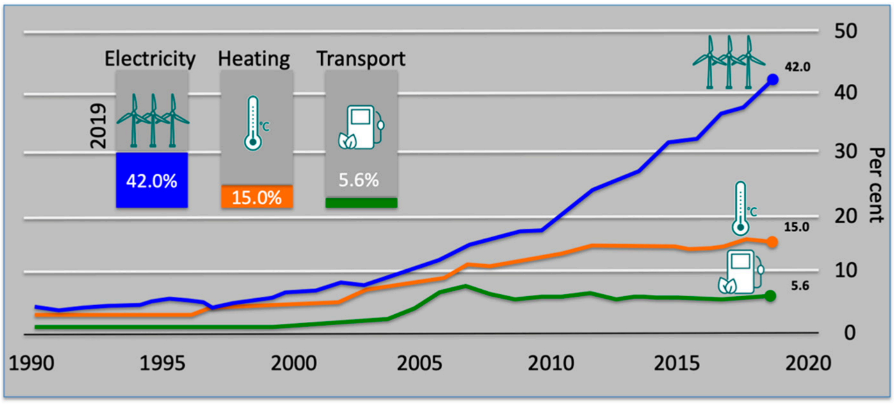

Figure 2. Shares of renewable energies in Germany in the areas of electricity, heat and transport from 1990 to 2019. (Own presentation based on data from the German Federal Environment Agency 2020: https://www.umweltbundesamt.de/ (accessed on 9 June 2021)).

Table 1. Energy and climate policy objectives of the German government in the 2010 Energy Concept.

Target	Base Year	2020	2030	2040	2050
Reduction of GHG emissions	1990	−40%	−55%	−70%	[−80%, −95%] [1]
Share of renewable energy in final energy consumption		18%	30%	45%	60%
Share of renewable energy in gross electricity consumption		35%	50%	65%	80%
Primary energy consumption	2008	−20%			−50%
Power consumption	2008	−10%			−25%
Final energy consumption Transport sector	2005	−10%			−40%
Nuclear phase-out	2010	−60% (in 2019)	−100% (in 2022)		

[1] Original range was specified in the German government's energy concept. In meanwhile, this target was adjusted several times.

As the table shows, the goal of decarbonisation has been on the political agenda in Germany for a long time. In addition to politically driven reduction targets for CO_2 emissions, the programme brought together the instruments of technology promotion (Renewable Energy Sources Act) into an integrated overall concept.

Following a decision by Germany's highest constitutional court, the targets just recently had to be further adjusted. During the review process of this publication, with the Climate Change Act 2021, the political decision was made that Germany should be climate neutral already by 2045 [16]. However, other countries were faster in this regard, as Figure 3 shows.

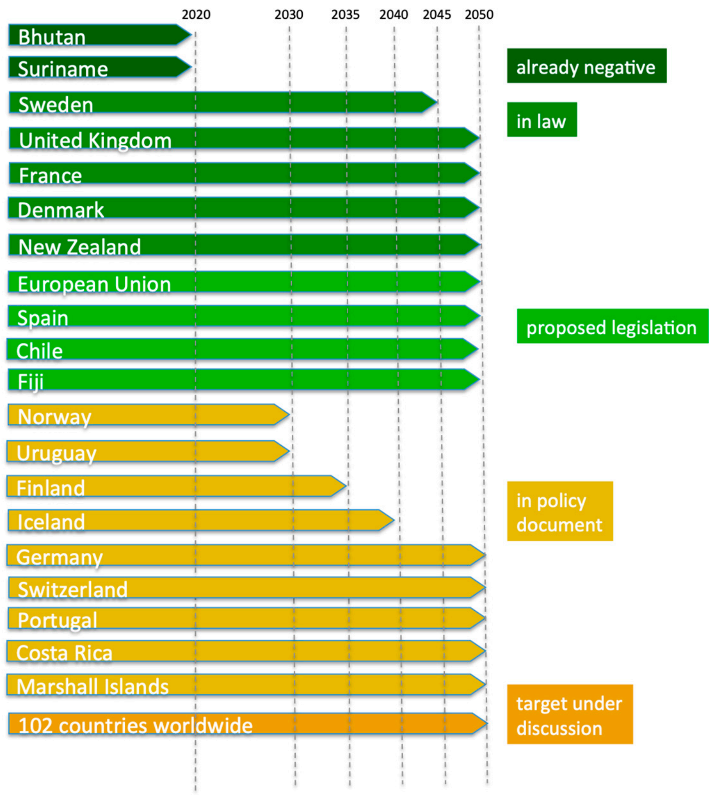

Figure 3. Decisions on climate neutrality (authors' illustration based on Energy & Climate Intelligence Unit [17]).

Furthermore, the German policy package announced the introduction or amendment of other legal requirements, especially for the sectors of space heating and transport. It covers a total of 29 measures designed to increase energy efficiency and renewable energies. The reduction of CO_2 is therefore linked with a much faster increase in renewable energy sources in combination with energy efficiency. To achieve decarbonisation in Germany by 2050, e.g., extensive electrification of industry, transport and heating markets are needed [15]. Thus, large-scale centralised power plants fired by fossil fuels need to be phased out much sooner than anticipated in traditional business plans. In addition to more renewable energy generation such as (offshore) wind power and power-to-gas approaches, new solutions such as photovoltaic (PV) systems combined with (vehicle) battery storage as well as demand response and flexibility measures will become increasingly important.

This raises key challenges for the energy industry and for political bodies: How can efficiency and renewables be expanded more rapidly and successfully? How can the amount of renewable energy be added with fast-track measures, and how will companies manage this complete transition to renewable energies? In order to deal with these questions later on, a few central aspects are listed below, which are of great importance for the energy industry in general and for the German energy industry in particular.

Decarbonisation is a central challenge because:

- The energy industry has a key role in contributing to global, national and regional climate protection goals for GHG neutrality 2050 or earlier;
- The energy industry must provide an answer to international dynamics (e.g., European Green Deal) and related targets on the national level (Climate Protection Act);
- The coal phase-out strategy is politically decided and enjoys widespread support in society: Gas and renewable energy sources align with the "Commission on Growth, Structural Change and Employment" (the so called "Coal Commission") proposal for the phase-out of coal-fired power generation is to be achieved by 2038 at the latest [18];
- The energy industry must provide an answer to corporate responsibility (expectations of customers and society);
- Technical developments pose a challenge for infrastructure, for example in the field of green (synthetic) gases and liquids or the conversion to "green" district heating [19].

An increased number of organisations are setting corporate climate protection targets, and therefore the energy industry has also been called upon to do so. For example, thyssenkrupp Steel has declared the goal of becoming climate-neutral by 2050 through a combination of carbon capture and usage (CCU) and hydrogen-based direct reduction of iron ore. Establishing a green hydrogen infrastructure is also therefore crucial for this transformation.

Catalysts and Barriers with Regard to Decarbonisation

The biggest challenge is that companies must culturally redefine themselves in a very short time. Especially incumbents whose corporate history has been closely linked to the use of fossil fuels and capital-intensive nuclear power plants through large-scale plant engineering must completely revise their mission statement and redefine their business model. However, strong social support for the Energiewende shows that there are also customer expectations to be met. In addition, the Paris Agreement and other climate protection efforts make it clear that fossil fuels will no longer be a viable business area in the future.

2.2. Digitalisation

The key question behind digitalisation in the energy sector is, "Which solutions will be able to facilitate the Energiewende and sustainable business models at the same time?" In this context, digitalisation—like any new technology or technical development—is neither fundamentally positive nor negative per se, and should always be seen as a tool and not as an end in itself. Accordingly, the environmental consequences of broad-spectrum digitalisation can be positive or negative alike. For example, the production, operation and disposal of an ever-increasing number of networked devices may also lead to an increasing consumption of energy and materials. For example, net electricity consumption for information and communication technology (ICT) was already 10% of Germany's total electricity consumption in 2017 [20].

On the other hand, digitalisation is the key "catalyst" technology for an energy system transformation and the restructuring of the overall energy infrastructure. Instead of a small number of centralised large-scale power plants, in the future Germany will be supplied by a diversified mix of renewable energy generation plants. Electricity will no longer flow only to consumers; instead, consumers might become producers or "prosumers" themselves. This means a significantly growing number of active market participants, e.g., through decentralised PV and wind generation combined with storage and flexibilities, such as electric transport or heat pumps. Thus, the fluctuating nature of renewables requires restructuring energy networks and increasing their flexibility, as energy production and consumption must be coordinated intelligently in real time. Digitalisation is the essential tool to master this challenge efficiently and cost-effectively [21].

According to Doleski [22], the energy sector has already gone through three phases and is now at the beginning of its fourth phase. It all began with energy distribution companies (Utilities 1.0); after liberalisation of the energy market in the 1990s, networks and energy distribution were separated, and the classic energy supply companies (Utilities 2.0) were created. Around 2011, utilities increasingly started to transform into energy service companies (Utilities 3.0), selling distinct services to their customers. Today, the energy market and information technology are merging, resulting in digital energy service companies (Utilities 4.0), which offer more networked products to address flexible generation and demand response (see Figure 4).

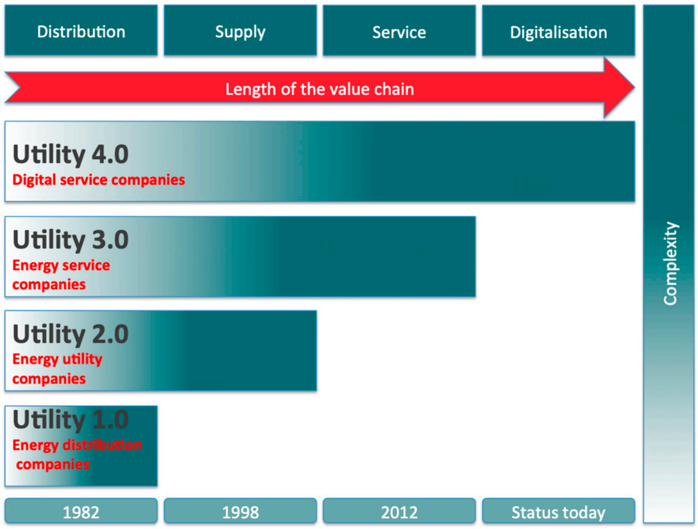

Figure 4. Changes in the roles of energy supply companies over time (authors' illustration based on Doleski [22]).

In the smart energy grids of the future, technologies such as digital market platforms, smart metering systems and adjustable transformers will coordinate the interaction between generation plants, networks, consumers and storage facilities. In this way, plants and grids can be automatically regulated even in complex, highly decentralised energy systems with intermittent renewable energies.

The continuously acquired energy data can also be analysed and used to make forecasts of power generation and consumption patterns and thus ensure that the individual components of the energy system work together in an optimal way, e.g., for charging electric cars. So-called "virtual power plants" will allow aggregation and flexibility in multiple generation and storage facilities to react to dynamic changes in energy supply and demand. Such means would allow many small and medium-scale plants (such as wind farms or battery storage systems in private households) to be bundled and used much more effectively. Network operators will be able to use available grid flexibility to optimise network operation in case of network bottlenecks, which would also contribute to cost efficiency and stabilisation of the power grid. Other examples of intelligent solutions may include system approaches, such as smart homes with its inhabitants as "prosumers" in demand-side management activities, as well as integrated smart-city concepts, smart factories with advanced energy management systems or smart transport, combining electric transport and other sustainable means of transport in dedicated hubs.

Overall, besides new technologies, new digital processes and business models are also needed to create viable solutions for the technical, economic and regulatory challenges in the energy sector, based on the consolidation, processing and evaluation of energy-related data. Automated digital trading and market platforms (e.g., blockchain or cloud-based) can facilitate the efficient allocation of energy and flexibility services and also ensure that the costs of matching energy generation and consumption are kept as low as possible. In the context of such systemic approaches, it also has to be considered that regulatory norms and standards will have to be amended so that they can be applied to new technologies and processes in the intelligent energy system of the future [21]. A comprehensive cost–benefit analysis is of particular importance in this context [23] in order to have a sustainable and long-term business model. To achieve this long-term perspective, it makes sense to look at more than just the direct and short-term economic effects. Multiple impacts play a major role in energy supply. For example, energy efficiency measures lead to a large number of multiple impacts that can be integrated into a long-term economic perspective. These include, for example, economic effects on labour markets, aggregate demand and energy prices or on energy security [24]. If these preconditions are fulfilled, based on new technologies and adapted business models, significant opportunities may arise from the digitalisation of the energy sector also for the other areas of the "5Ds". For instance, this could mean increased visibility and proximity to customers on the part of platform operators, or customer- and sector-specific, tailor-made energy services (See examples in "Decentralisation" section).

In sum, we have identified the following central theses:

- Digitalisation is a key catalyst technology for overall system efficiency improvements, based on a largely renewable energy system.
- Digitalisation is not an end in itself but needs a clear orientation toward sustainability.

Catalysts and Barriers with Regard to Digitalisation

The most prominent barriers to digitalisation are linked to data protection or security concerns and potential distrust in the reliability of technologies and business models. The biggest catalyst is related to the huge, and mostly still untapped, opportunities for the energy system. Therefore, all efforts to foster digitalisation in the energy sector must take into account such concerns by clearly addressing potential risks and strategies how they can be prevented or mitigated.

2.3. Decentralisation

As an essential part of the *Energiewende* in Germany, the increasing use of, e.g., wind, photovoltaic or combined heat and power (CHP) plants, is continuing the trend towards decentralisation of electricity generation capacities. The safe, reliable and affordable transmission and distribution of electrical energy will therefore require new technologies and solutions. This will further expand the range of technological developments required in the field of smart electricity grids. Intelligent load management is one important solution for the integration of fluctuating energy sources. This means that electricity will be consumed or stored in a targeted manner when a large amount of renewable electrical power is available, e.g., during sunny and highly windy periods [21].

For this purpose, the distribution networks in particular must be redeveloped into much more flexible and active networks if they are to integrate a high proportion of local and decentralised renewable energy and demand from consumers. To complement the reorganisation and further development of these energy networks, storage facilities will play an increasingly important role in the future for balancing short and long-term fluctuations in energy supply and demand [25].

Examples of business models in a decentralised energy system in all sectors (transport, households/buildings and industry) and all relevant energy-related areas (power generation, grid and retail) are given below [15]:

- Rollout of public infrastructure for electric vehicles (transport);
- Supply of system solutions, such as PV with storage (buildings);
- Dynamic electricity pricing for companies and homes (industry/households);
- Digitalisation for the demand side: smart homes (households);
- Digitalisation for the supply side: virtual power plants (industry).

As illustrated, there is clearly a close link to the topic of digitalisation, which is a precondition for any decentralisation approach. In this context, it is of major interest how decentralised energy and efficiency potential can be further developed and how the energy industry will manage the process to develop efficiency and feed-in potential into a profitable new business segment. In this context, blockchain technology in particular may provide a promising basis for digital decentralisation approaches by directly linking regional producers of green energy and consumers by means of a secure and reliable system. This is relevant, as easily transferable business models, especially for older existing generation plants, have yet to be found in Germany after the end of support by initial feed-in tariffs. Today, it is still necessary for each operator to conduct a very complex and expensive assessment of the specific circumstances to find a niche for further economic operation [7]. Accordingly, much more regulatory support from the federal government is needed for owners of renewable energy plants after the expiration of the feed-in tariff mechanism, especially by introducing less complex administrative solutions.

Another essential key factor for the implementation of the energy system transformation is related to ecological and acceptability restrictions concerning the availability of sufficient space for the installation of renewable energy facilities. In other words, converting the electricity system to renewable energy sources has the consequence that, with regenerative power generation, a new economic use case competes with current land uses. For photovoltaics in particular, the supply can be covered either with open field or building-integrated PV systems. According to current reference scenarios for the energy system transformation, building-integrated PV systems in particular should be a central element of any future expansion strategy for renewable energies from the perspective of an environmentally sensible space efficiency strategy [26]. This development could be supported by exploiting rooftop PV potential in combination with battery storage systems and very high proportions of self-consumption, in part so that electricity transfers via the grid are minimised for the groups of actors involved. Assuming an ambitious "Focus Solar" scenario [26], PV systems in Germany may contribute 288 TWh to annual energy generation in 2050, which corresponds to a required increase by a factor of 7.2 compared to 2017. To achieve this, an installed PV capacity of 313 GW is necessary. Assuming a realistic potential for building-integrated PV to be almost completely exploited in 2050, 67% of this total PV capacity in Germany could be available from (mainly) rooftop systems.

However, realistic expectations of PV expansion are strongly related to the creation of sufficient incentives and the removal of regulatory barriers for PV and battery storage systems. Since the investment behaviour of homeowners is crucial, appropriate measures must be taken by the federal government to make the operation economically viable. In order to now move the *Energiewende* into city areas in particular, it is essential to develop, e.g., tenant electricity models, which would generate, sell and use the electricity mainly on-site within the same building. Additionally, instruments under building codes, such as obligations to install PV systems for new buildings or in case of major structural changes/renovations of the roof, should be investigated. Furthermore, the general reorganising of urban rooftops (e.g., concerning ownership and structural aspects) should be analysed for the comprehensive use of such areas in the construction of PV systems.

In contrast, the alternative "direct consumption" option for the generated electricity on-site or nearby locations offers the possibility to save individual government induced electricity price elements, such as taxes and levies. The concept of self-consumption in German law requires strict personal identity between the plant operator and the electricity consumer. If this, as well as the spatial proximity, is given and the use of the public grid is excluded, only 40% of the EEG levy is currently due for self-used electricity quantities. In addition, there are no grid usage fees and, if the plant is no larger than 2 MW, no electricity tax. "Self-supply" is therefore currently the economically most interesting way of using own-generated electricity in Germany. However, due to the strict and very complex legal and administrative requirements, this option is still used very rarely and much less than needed for the energy transition. The so-called "direct supply" approach, on the other hand, offers a broader scope in German law. In this defined application case, a direct spatial connection is sufficient to save the electricity tax. If the consumer and the generation system are so close to each other that a private and direct electricity connection can be installed, the grid fees are also waived. In such supply relationships, the plant operator becomes the electricity supply company, which, however, also comprises some energy-related legal and administrative obligations.

Other promising examples for building energy efficiency measures include multi-stage outreach advice on building refurbishment, as implemented in Germany, e.g., in the "Innovation City Ruhr" project. In this context, a multi-stage consulting concept for energy-related refurbishment has been established, as for many building owners already the general topic of "energetic refurbishment" is still a major barrier. However, renovation measures are a key element and precondition for successful climate protection and for reducing energy costs. That is why, e.g., InnovationCity Ruhr has developed a consulting concept to help interested parties in the project area to identify and implement the right measures for their specific buildings.

Step 1 comprises a free 60 to 90 min initial consultation and the setup of a general energy inventory of the building. A qualified energy consultant shows the possible renovation measures and explains how to use possible subsidies. In Step 2 more targeted implementation advice is given, which is accompanied by a German Federal Office of Economics and Export Control (BAFA) and Kreditanstalt für Wiederaufbau (KfW, the German promotional bank) accredited energy consultant from the project's partner network. The accomplished energy saving measures must be verified mathematically and confirmed to KfW in the application procedure to receive funding. The KfW efficiency status, which may well reach KfW 55 standards (using only 55% primary energy compared to the reference building) through comprehensive refurbishment measures, is determined by a BAFA assessment. For this purpose, the legislator grants appropriate promotional funds. This third step is subject to a fee (direct fee agreement between interested parties and energy consultants of the partner network). These and other costs (e.g., for construction supervision and quality control) can later be subsidised by a KfW programme up to EUR 4000 [27]. Overall, this promising approach shows that regional engagement with actors is essential for effectively overcoming implementation barriers and for the success of the energy transition, in particular in the challenging building sector and considering also heating and domestic hot water energy savings.

Cities consist of quarters, which according to the definitions of KfW and the German Federal Office for Building and Regional Planning (BBR) are units below the district level, in which the spatial proximity also supports close actor relationships [28]. It is therefore possible to implement small-scale projects, which contribute to the achievement of climate protection objectives and may serve as role models for other quarters and actors. However, the preconditions for such local initiatives are secure and reliable energy transactions, as demand and capacities must be matched in real-time. Appropriate digital tools are already available to meet such requirements. At the same time, however, it has to be noted that at the level of planners and decision-makers there is still a lack of knowledge, and therefore prerequisites in form of sufficient planning or contract law capacities are still missing and cannot adequately support a wide range of different cross-neighbourhood solutions for heterogeneous actor groups [29]. Accordingly, further research, stakeholder information and implementation support are necessary.

Examples of future topics, which are relevant preconditions and examples in this context, are smart home gateways, local storage solutions in the smart grid, blockchain technology in the energy network, long range wide area network (LoRaWan), real-time data processing and visualisation, availability of low-ex networks [30] and the integration of the water–energy nexus in municipal infrastructures.

In Germany, there are demonstration projects that successfully use at least some of these applications, e.g., in the technology park Berlin Adlershof [31]. Berlin Adlershof is the location of Germany's largest science and technology park. From start of developing the area until the year 2020 and beyond, the built-up area, the number of employees and the resident population and thus energy consumption will have multiplied if no countermeasures are taken. Therefore, several projects for an integrated energy concept were implemented in the neighbourhood with the goal of achieving 30% primary energy savings by the time the site is fully occupied, equalling to a consumption of only 308 GWh/a compared to the "business as usual" scenario of 441 GWh/a. This makes Adlershof the only large residential technology and science quarter in Germany with such a project. The location is thus a role model for other large technology and business locations on a national and international level. Additionally, the Adlershof energy project is an important component of Berlin's overall energy strategy as Germany's capital [32].

Beginning in 2011, the first focus has been on measures for electricity efficiency. From 2011 to 2013, an energy concept was developed in the joint project "High Tech—Low Ex: Energy Efficiency Berlin Adlershof". From 2013 to 2017 the follow-up project "Energy Strategy Berlin Adlershof 2020" was implemented, which applied the efficiency measures in concrete terms. With the project "Heat optimisation in non-residential buildings", since 2017 additional efficiency potential of heating systems has been identified and developed. For example, the heating systems of non-residential buildings at the site were evaluated in order to subsequently optimise them on the utility and building side. In addition, the project addressed the so-called tenant–lessor dilemma, which typically means that the landlord invests in energy efficiency, but the benefit is passed on to the tenant. Here a process is determined that enables efficiency measures and creates a win–win situation in terms of costs for all parties involved.

In addition, a future model for the overall energy infrastructure in Adlershof is developed, which maximises the use of renewable energies for electricity and heat generation and its decentralised feed-in. The project results will be used for further science and technology quarters, e.g., within the framework of the D-A-CH cooperation with partner institutions in Austria and Switzerland to exchange knowledge and develop joint projects for energy efficiency [29]. By this means, such projects illustrate that cities, quarters and smart neighbourhoods are the essential nucleus of the successful digital, decentralised transformation of the energy system and thus the energy transition overall.

Catalysts and Barriers with Regard to Decentralisation

The essential catalyst for decentralising the energy system of the future is the overarching digitalisation of the related infrastructures and services. On the other hand, the continued lack of such digital infrastructure, suitable to manage a large number of active participants in a flexible energy system, is still lacking. The greatest challenge is therefore closely linked to solving the challenges mentioned in the "Digitalisation" section to provide the preconditions for a broad rollout of decentralised energy solutions and related business models.

2.4. Democratisation

The democratisation of the energy industry covers a very broad field. This includes the possibility of many individuals becoming electricity producers themselves [33]; however, this also requires addressing the desire for social participation in energy issues [34]. The founding of numerous public utilities, the re-municipalisation of many electricity distribution networks [35], the establishment of hundreds of energy cooperatives [36] and the great interest in bio-energy villages, energy-autonomous municipalities, etc. are an expression of a change in social awareness [37] that can be observed not only in Germany [38]. It is also an expression of growing distrust of large energy supply companies and a system for the provision of services of general interest that is predominantly based on shareholder value.

With the expansion of renewable energy sources in Germany, the aspect of acceptance is also increasingly the focus of attention. Acceptance is often strongly linked to participation. The willingness to pay higher energy prices and to accept changes in the landscape can be encouraged if people have the opportunity to participate financially or politically in the processes. The connection between the social, technical and resource-based side of the energy system is seen as mutual [39]. Framing the issue properly is therefore important for supporting acceptance. In health care measures, references are often made to the harmful consequences of smoking, obesity, etc. Such negative references are referred to as "loss framing". For prevention measures, however, messages that are embedded in a "gain frame", i.e., those that emphasise the positive consequences of the desired change in behaviour, are generally more successful [40]. In the expansion of renewable energy sources, opportunities for financial participation and improvements in community income can constitute such a gain frame.

A central question for energy system transformation is therefore, "How can participation be facilitated or strengthened in order to foster acceptance?" Political decision-making regarding climate protection must also correspond with feelings of social justice and social acceptance. If the population is not sufficiently involved in the processes, protest movements such as the so-called "yellow vests" in France may emerge [41].

How can energy companies or municipal utilities succeed in making their decisions transparent, and how do they manage to actively involve customers in shaping the transformations (discussion formats, prosumer approaches)?

- Transparent information about strategies and goals, including milestones;
- Customer empowerment, e.g., by supporting prosumer approaches;
- Participation models for customers to invest (e.g., local wind farms);
- Establishment of discussion formats on site with relevant social groups such as Fridays4Future, customer advisory boards, etc.;
- Active involvement of customers in concept development and implementation, e.g., through joint implementation of neighbourhood concepts, living laboratories, co-creation of solutions, etc.;
- Establishment of municipal full service companies (to meet all needs of customers in a service-oriented manner).

Catalysts and Barriers with Regard to Democratisation

The greatest challenge is to achieve lasting acceptance for an energy system transformation. In this context, opportunities for participation in renewable energy systems are essential. Experience to date has shown that acceptance can be encouraged if affected stakeholders are involved in decision-making processes and they benefit from revenues. For example, the Rhine-Hunsrück rural district shows how this can be achieved in Germany, where solidaristic citizen participation in the economic success of wind power has been a cornerstone of the programme's high acceptance level [42].

2.5. Diversification of Service Orientation

The development of new services is of great strategic importance for energy companies. Energy services play an increasingly important role when it comes to promoting and developing private, commercial and industrial efficiency potential and/or the development of renewable energy. According to Article 2(7) of Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC [43], "energy service" is defined as "the physical benefit, utility or good derived from a combination of energy with energy-efficient technology or with action, which may include the operations, maintenance and control necessary to deliver the service, which is delivered on the basis of a contract and in normal circumstances has proven to result in verifiable and measurable or estimable energy efficiency improvement or primary energy savings." Against the background of an increasing expansion of renewable energy systems, the question arises which role energy services can play in the future.

In particular, the *Energiewende* poses major challenges for distribution and transmission system operators. The task of transmission networks is to balance the generation and consumption of electricity over long distances and to transport the electricity to where it is needed. In Germany, wind power from the coastal areas in the north must be transported to the inland industrial centres of consumption in the south. It is already apparent that both the required number and volume of feed-in management measures (which means the active regulation or power-down of electricity from renewable energy sources) and redispatch measures (input reductions or increases by other power plants) have increased significantly and will continue to increase in the future. In 2018, grid operators took 5.4 TWh of feed-in management measures and requested 14.9 TWh of other redispatch measures [44]. In addition, 0.9 TWh of electricity was generated from grid-reserve power plants. The grid operators' expenses for these complex adjustment measures are considerable [45]. Expansion and optimisation of the existing electricity grid are therefore important measures for the *Energiewende*, but they are also capital-intensive [15]. From the perspective of the energy industry, the following question therefore arises: "Which services can make significant contributions in the context of flexible demand, energy, storage and grids?" The challenges for distribution system operators are also significant. Over 90% of renewable energy in Germany is fed into local distribution networks, which have to absorb these fluctuating loads [46]. Local distribution networks are therefore already the infrastructure basis of the *Energiewende* and the foundation for service business and energy-economic optimisation. Future developments in smart grids and electric transport will require considerable additional investment in the performance of distribution networks (e.g., adjustable local network transformers, etc.), but this also promises to open up new business areas and additional sales.

But how does an innovative business model differ from a conventional business model? As described above, Doleski (2016) [22] divided the transformation of the energy industry into four historical stages that illustrate the epochal change from monopolistic utilities to digital energy service companies. In the first stage, extensive electrification was established with the implementation of transmission and local distribution grids, mostly under monopoly conditions. This phase lasted for around 100 years in Germany, from the discovery of the electrodynamic principle and the beginning of electrification in the 19th century to the liberalisation of the market in 1998. The following second stage, which lasted until 2012 according to Doleski [22], focused mainly on price competition. These first two stages form the core of a conventional business model in the German energy sector. At the heart of the strategy was the ability to generate electricity at low cost by exploiting economies of scale in large power plants to possess a competitive price advantage. Beyond that, Doleski suggested two additional stages post-2012. The third stage, characterised by a stronger service orientation, changed utility companies into service companies, with a stronger focus on customer needs. The ongoing post-2015 fourth stage extends this service orientation by integrating dedicated digital solutions [22]. In our understanding, the last two stages are now the basis of every innovative business model. It is apparent that large companies have an advantage over their smaller competitors, especially in conventional business areas where size and financial capacity are the key factors [4]. In contrast, customer knowledge and customer proximity are becoming advantages in innovative business fields, and decentralised structures are now more advantageous than centralised approaches.

The necessary further transformation process towards a low-carbon energy supply is increasingly characterised by a pronounced interaction between the electricity, heating, gas and mobility sectors. It is therefore crucial for the success of the energy transition that the possible options arising from new technological developments are used locally in a decentralised manner in the sense of a cross-system supply strategy.

The variety of new technological options also leads to a diversification of the grid-bound heat supply. The integral and cross-system elements are [47]

- Cogeneration;
- Energy source substitution and load optimisation through power to gas/PtX;
- Electric heat supply/power to heat through electric heat pumps, resistance heating;
- Flexibilisation through control of electricity generation (increasing importance of CHP balancing energy) or control of loads (load-dependent operation of heat pumps).

In order to assess the extent to which various services are offered by energy suppliers, it makes sense to examine a specific region in detail. This was done for the Ruhr metropolitan region. There, an analysis showed that energy services are offered by many energy companies. The following figure (Figure 5) shows which service is offered by how many of the energy companies located in the study area (n = 26).

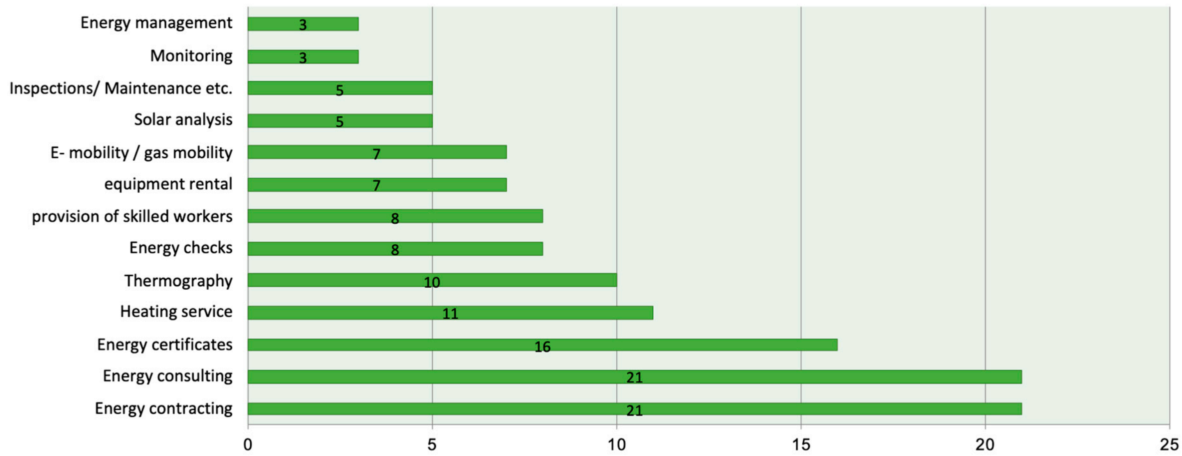

Figure 5. Services offered by energy companies (own illustration based on Berlo et al. [47]).

One promising regional approach in Germany relates to business models for public utilities on a blockchain basis. For example, with the so-called "Tal.Markt 2.0" the municipal utility in the city of Wuppertal (WSW) marked in 2018 the beginning of a new era for energy sales in Germany by the introduction of Europe's first green power distribution approach on a blockchain basis. The underlying platform, further developed under the brand name "Blockwerke", can be used by a nationwide partner network for creating various innovative products. Each partner can build their own business models on basis of the platform developed in Wuppertal or use the Tal.Markt for their own market as a rebranded white label product with local green power producers. In addition, the platform represents a central marketplace for producers. In practical terms, this means that any producer registered on "Blockwerke" can supply to all connected markets. By this means clients can purchase electricity from regional green electricity producers throughout Germany, even without smart meters, but with any approved electricity meter [48].

Catalysts and Barriers with Regard to the Diversification of Service Orientation

The main challenge is to anticipate technical possibilities at an early stage in order to develop beneficial services with added value. The fact that there are many innovative small companies that are developing creative, customer-friendly solutions supports this thesis. However, the German regulatory environment has not kept up to make these new services financially attractive, or even legally possible. For example, due to state-induced tax and levy structures, it is often still more economically sensible to power down electricity from renewable energy generation plants than to store it.

3. Discussion

Germany already possesses enormous knowledge due to its many years of experience derived from the first phase of the energy transition, based mainly on the rollout of various renewable energy sources in the power sector. The targets with regard to climate protection are also well known and largely settled and accepted by politicians at the national and international level. Transformation knowledge was built up, and people's experience is clearly and increasingly used in science, civil society and the corporate sector. However, after this first phase of the *Energiewende* and a well-founded analysis of persisting barriers and challenges, a broad and clear vision for the next phase must be drawn. This has to be done through further development of the regulatory framework and related sustainable business models considering and integrating the 5Ds as described in this paper.

This vision requires further specific scientific experiments as well as the assessment of actual policy and business developments. For example, new approaches or policies should be tested and created together with affected stakeholder groups. From the experiences gained in this process, lessons can be learned and policies as well as business models can be adapted at an early stage and (if successful) rolled out much faster to start the process of actual diffusion. This means that the generic 5D approach described in this paper is useful in supporting and guiding policy makers and scholars through the transition process from abstract knowledge to real-life policies and business models (see Figure 6). If the above-mentioned criteria are met, many new opportunities for business models compliant with energy transition targets may arise.

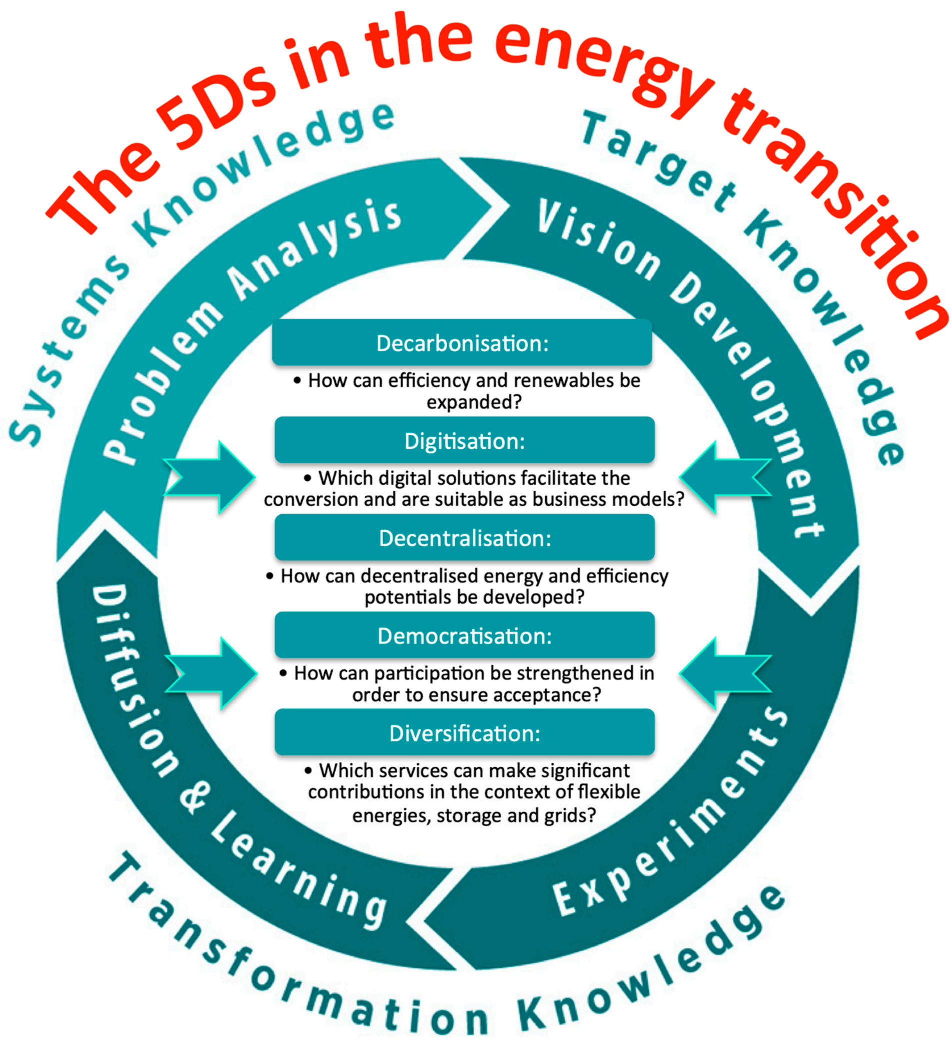

Figure 6. Overview of a results-oriented transition process (authors' illustration).

A transdisciplinary concept of knowledge creation illustrates the opportunities of the 5D strategy outlined here: It does not only serve to generate "systems knowledge" (e.g., technological or resource-oriented systems analysis) but also integrates stakeholders in the process of generating "target knowledge" (visions and guiding principles) as well as "transformation knowledge" in concrete settings of urban or sectoral transitions to sustainability. Transformative research approaches and innovative methods of assuring scientific quality must be developed in this context. To better understand the transformation process, it is useful to conduct a problem analysis, to develop a vision of the future and to gather experience in experiments from which to learn. Successful models can then diffuse, but mistakes can also be made, and targets can be missed. A new problem analysis then becomes necessary. In addition, new technical opportunities and societal challenges are constantly emerging, which means that new solutions must always be found for transformation research.

In this context, market models will play a central role in the future. This is because investments and service offerings require very good knowledge of how the market will develop in the future. For example, it is conceivable (and likely) that an increased number of viable services will develop that enable the production and storage of power to heat (PtH), power to gas (PtG) or power to liquid (PtL) products from surplus electricity from renewable energies. Whether the development of such products and related services is worthwhile, however, depends very much on market models that take these flexibility options into account. The most important driving forces are illustrated in Figure 4. This variety of integrated approaches, combined with (still very rare) best practice examples from Germany, will support further discussions on which measures have to be combined and added successfully as part of a comprehensive and adequate policy package for the future.

4. Conclusions

In this paper, we argue that the major challenges facing energy companies in the course of the energy transition in Germany can be systematically categorised by the "5Ds". These are decarbonisation, digitalisation, decentralisation, democratisation and a diversification of service orientation. It became evident that these 5Ds are nowadays also very closely related to each other. For example, increasing decentralisation and the growing importance of decarbonised generation requires the development of digital solutions and services. Decentralisation and decarbonisation are drivers for the development of new market actors, who often relate the energy system transformation to hopes for greater democratisation of the energy supply. As a consequence, doing business in the energy sector has generally become more complex and diverse. Accordingly, based on our analysis, the following requirements must be addressed by political and business decision-makers:

- The Energiewende requires a clear positioning (expectations from inside and outside) and a convincing narrative. In other words, the *Energiewende* is not a pre-accepted end in and of itself. Furthermore, it provides not only benefits for the overarching target of climate protection but also incorporates many other social and economic benefits that must be highlighted and ultimately harnessed.
- The Energiewende requires an innovative and "catalysing" regulatory framework and related business approaches, not only at the technical level (business fields, cooperation formats), but also in a service-oriented manner in all related areas and for society as a whole.
- Implementing specific business models or developing actual services requires successfully shaping (internal) change. For policymakers as well as business leaders, this increasingly requires, e.g.,:
    - A comprehensive discussion with social groups for "co-creating" resilient solutions and best possible results for all stakeholder groups;
    - An integrative and holistic approach for organising such transition processes effectively and rapidly for the society as a whole;
    - Appropriately qualified personnel, empowered with the necessary education and skills to successfully cope with the upcoming opportunities and challenges.

Overall, our approach describes what is needed to foster the best possible results for all of the stakeholder groups involved so that Germany can regain its role as a leading innovator in energy policy, technology and business and reclaim its role as a pioneer in the next phase of the Energiewende for other economies worldwide. Now it requires much more visionary and creative entrepreneurship to implement successful business strategies rather than just generating and selling kilowatt hours, as practiced by the energy industry in the last century in the absence of competition or service orientation [15]. To support this, also a more ambitious government policy to adapt the regulatory framework to correspondingly catalyse new business models is urgently needed, as well as digital energy service companies (Utilities 4.0) actually willing to take up the new opportunities.

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