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Concept Paper

A Transdisciplinary Approach and Design Thinking Methodology: For Applications to Complex Problems and Energy Transition

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Abstract: In this paper, we outline a transdisciplinary approach and design thinking methodology (TADTM) to tackle complex problems. Our premise is that these problems need a fundamental understanding of technological solutions and those for human interactions, business operations, financing, socioeconomic governance, legislation, and regulations. They must be approached by different decisionmakers from different disciplines to establish seamless interactions and structured teamwork. In this regard, we emphasize the need for a transdisciplinary framework that accounts for personal preferences based on human behavior as well as the traditional interdisciplinary frameworks. To test and prove our hypothesis, three case studies are discussed. Case Study 1 is based on our studies at a major medical establishment, and Case Study 2 is about the integrated engineering and architecture approach we used at our university campus. Case Study 3 is based on an ongoing project to lead industrial corporations to change their energy policies with practical energy efficiency measures and by adapting renewable/alternative energy adaptations for their operations. Developing creative solutions and strategies to decrease atmospheric greenhouse gas emissions requires such an energy transition framework and should involve every person, company, entity, and all governments. It can only be achieved with efforts on both local and global levels, which needs to convince (a) industries to change their traditional operation modalities, (b) people to alter their consumption behaviors, and (c) governments to change their rules, regulations, and incentives. The complexity and magnitude of this enormous task demand the coordination and collaboration of all stakeholders, as well as the need for technological innovations.

Keywords: energy transition; climate change; transdisciplinary; design thinking; energy efficiency

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Citation: Ozsoy, C.M.; Mengüç, M.P. A Transdisciplinary Approach and Design Thinking Methodology: For Applications to Complex Problems and Energy Transition. *World* **2024**, *5*, 119–135. https://doi.org/10.3390/world5010007

Academic Editors: Throstur Olaf Sigurjonsson, José Manuel Ruano de la Fuente, Ortwin Renn and Manfred Max Bergman

Received: 4 September 2023
Revised: 16 January 2024
Accepted: 25 January 2024
Published: 1 March 2024

1. Introduction and Conceptual Definitions

There is a definite need for innovative holistic approaches to solve and strategize complex problems. Our statement is based on and supported by a significant number of scientific papers aiming to find ways to embrace complexity and complex transition efforts. Two examples that are similar in thinking are cited here. In the work by Scholz et al., a Swiss waste management system's transition was handled with transdisciplinarity and structuring for complex transitions (SCT) [1]. In a special edition of *Public Management Review*, public management and complexity theory was discussed at length, and approaches to solve and strategize complex problems were discussed in depth [2]. In our understanding, the approach to complex problem solving should be based on scientific methods and understood and implemented by society, individuals, corporations, governments, and global organizations. Every detail of such problems to establish long-lasting solutions must be examined, including their human (behavioral) aspects,. These problems are everywhere, including the climate crisis we are currently facing. One of the major drivers of the climate crisis is the use of fossil fuels to meet the insatiable need for energy by the increasing population and the rapid industrialization around the globe. To help this problem, we need to find ways to shift energy production from fossil fuels to renewable energy technologies and emphasize energy efficiency in industry, buildings, and transportation. Thus, the entire energy value chain also needs to be re-examined, from the source to how it is refined and processed, transmitted and distributed, all the way down to the consumers, and how electric and heat energies are eventually used by individuals, corporations, buildings, and industrial manufacturing sites. Several organizations have reported in their recent publications that they recognize the importance of this issue and have made various suggestions for solutions to different, albeit limited, aspects of these problems [3–7]. In their 2022 reports, the United Nations Intergovernmental Panel for Climate Change (IPCC), International Energy Agency (IEA), and the UNCC mention similar risks and challenges. One common urgent theme is that we are globally behind in reaching goals set for net zero emissions by 2050. The second common theme is that society needs to be fully engaged with the behavior change, starting with consumption habits, particularly with more emphasis on energy and resource efficiency [3–5]. The IEA defines energy efficiency as the "first fuel" and estimates that 55% of emissions reduction will be driven by consumer choices. Currently, there are many studies, from the electrification of mining operations to green steel, and from electrical transportation to energy-efficient buildings. However, there is still a need for new technologies and a stronger need to change consumer behavior.

Developing countries and developed countries have different needs and ways to address the challenges we face due to the climate crisis [7]. However, no well-established and unambiguous international/global road maps or regulations are available to provide a structure for this overreaching goal. McKinsey, in its Energy Transition 2022 report, states that at a time of global macroeconomic and geopolitical turbulence, the impact of transition efforts is not bearing the results expected, and that while the momentum toward renewables is increasing, there is not a corresponding decrease in global emissions. As energy represents 80% of global emissions of carbon dioxide, impactful energy transition strategies become even more critical [6].

In this paper, we argue that these problems need a fundamental understanding of not only technological solutions but should also be developed considering human behavior, along with business operations, financing, socioeconomic governance, and legislations and regulations. The strategies developed and the solutions produced should include the active involvement of many people from different disciplines to show a long-lasting impact. Similarly, in recent times, several studies pointed out the need to focus on challenging and complex problems, such as the "food-water-energy" (FWE) nexus, and they argue that the FWE nexus can potentially support the integrated accomplishment of sustainable development goals if a transdisciplinary approach is taken. The existing literature on the FWE nexus shows that increasing research interests have been directed toward understanding, identifying, and qualifying the interrelationships among diverse stakeholders to inclusively involve nexus actors in the process and to identify new and supporting governance solutions [8].

We intend to introduce an effective process to approach such problems and to come up with better and transdisciplinary strategies for their solutions. Our premise is that no such problem can be solved by a single person or group from the same discipline. These problems are multifaceted, and only an interdisciplinary team of experts can comprehend their complexity. On the other hand, most problems involve the human element. In a sense, they either affect society, and the outcome becomes important for societal aspects, or the irrationality of humans makes problems nonlinear. The dynamic nature of experts from different disciplines, from technology to social to finance, and even to end users, is needed, as they should provide input to develop strategies and possible solutions to these problems.

As one may guess, coordinating such an effort will not be easy. For that reason, there is a need for a leader or a leading team with a keen understanding of the issues. This leader should gather the opinions and ideas of stakeholders from different disciplines and lead the team along a dynamic path toward the optimum solution at a given time with the available resources. We have shown in two separate case studies that the authors of this paper were able to lead different teams to implement effective solutions to two quite complicated and intertwined problems. With that understanding and based on our experiences, we outline how the TADTM approach can be adapted to tackle energy transition at the national level.

1.1. Multidisciplinary, Interdisciplinary, and Transdisciplinary Approaches

Teamwork involving more than one discipline has been increasingly used in research and development efforts since the beginning of the 20th century. The terms multidisciplinary and interdisciplinary are quite different, although they are sometimes confused and used interchangeably. This confusion requires further explanation of these terms. On the other hand, transdisciplinary approaches involve the impact of human behavior, which will be the key focus area, and again, a clarification backed by the literature is necessary [9–15]. All three terms refer to the involvement of numerous disciplines to varying degrees.

The multidisciplinary approach utilizes knowledge from different people, yet these researchers from different disciplines stay within their boundaries and do not necessarily learn the intricacies of the other disciplines. The interdisciplinary approach allows researchers to analyze, synthesize, and harmonize links between disciplines in a coordinated and coherent way. These researchers usually learn different aspects of cross-cutting disciplines and analyze the requirements of different disciplines in tandem. The objectives of interdisciplinary approaches are to resolve real-world or complex problems, to provide different perspectives on problems, to create comprehensive research questions, to develop consensus definitions and guidelines, and to provide comprehensive solutions [10–12].

Transdisciplinary research involves people from different disciplines working jointly to create new conceptual, theoretical, methodological, translational, and behavioral innovations that integrate and move beyond discipline-specific approaches to address a common problem [10,14]. The term "transdisciplinary" connotes a research strategy that crosses many disciplinary boundaries to create a holistic approach [12]. Meanwhile, Wikipedia's definition can be considered the lowest common denominator, not necessarily as the ultimate expression [9]. Transdisciplinary approaches integrate knowledge and experiences by accounting for the variations in human behavior. As it likely relates to many individuals' thought processes, we consider this definition the starting point for our discussion. Our premise is that, as we mentioned above, the complex problems, including energy transition, need a fundamental understanding of not only engineering solutions, but also business, financing, socioeconomic factors, governance, and regulations, which constitutes our emphasis on a transdisciplinary approach. Such an approach should focus on humans and attempt to regulate individuals' irrational choices for the betterment of society and the environment.

As the world's problems become more complex, even large corporations consider a transdisciplinary approach in their top management for better decision making and approach problems holistically and inclusively by sharing top executive positions in a co-leadership approach [16]. This way, leaders who are in touch with different people outside the structured corporate life can bring the opinions and priorities of other groups to the table and constructively impact the decision-making process. When working with different groups of people and various disciplines, there will be a need for facilitation, and tensions and negotiations among parties must be carefully managed. In that sense, the flexibility and openness of researchers to new ideas and different approaches, as well as to irrational decisions by people, need to be considered together [10–14]. These facilitators can be from the academic world or thinktanks working with different stakeholders [15].

1.2. Design Thinking Methodology

Design thinking methodology (DTM) can be explained as a nonlinear, iterative process that emphasizes (a) understanding the potential users, (b) challenging the assumptions made, (c) redefining problems, and (d) creating innovative solutions to prototype and test. Involving five phases, namely empathize, define, ideate, prototype, and test, and it is most useful to tackle problems that are ill-defined (wicked) or unknown, as defined by the Interaction Design Foundation on its website [12]. There are other models of design thinking, such as Stanford d. School 5-step design thinking, the Design Council double diamond, IDEO human-centered design, etc. Our focus is inspired by the Stanford d. School 5-step design thinking model [17]. The first and second steps of DTM, namely empathize and define, are to understand and clearly define the question, frame the problem, and identify all stakeholders involved in forming teams. During the ideation phase, which is step 3 of the model, the team tackles the issue from multiple perspectives based on different points of view and different fields of expertise. The team then identifies possible solutions, constraints, and impacts on other parts of the value chain. The next two steps include forming a solution to test a prototype form and testing, which will allow exploring the impact of the procedure and its potential strong and weak aspects. The team then has further discussions to adjust the intermediate action steps as necessary [17].

During the last two decades, the design thinking approach has been used in education, embraced by leading universities, and is at the core of many large global corporations [17,18]. Through active engagement of all stakeholders and moving from a consumption focus to a participation focus, it allows user to tackle complex issues for better outcomes. Particularly during times of change, there is a greater need for wide-based participation, out-of-the-box thinking, and new choices. At this stage, it may be better to discuss comprehensive and "right" questions rather than trying to come up with answers with limited impact.

Below in Figure 1, we show our interpretation of the methodology inspired by the methodology described by the Stanford d. School DTM, which helped us to shape our TADTM approach and which is discussed in more detail in the Methodology section later. To explain the interaction between different stakeholders discussed in TADTM, we used abbreviated symbols (α, β, γ, δ, ε, and ϴ) for different groups. In that sense, we identified the common people (alpha α), small organizations (NGOs, families, societies) and businesses (SMEs) (beta β), corporations (gamma γ), governments (delta δ), and multinational global organizations (epsilon ε) as contributors to the TADTM approach. Thinktanks and university centers are denoted as theta (ϴ), and they provide the essential framework for the interaction of all stakeholders. The functions of each of these groups are further evaluated below.

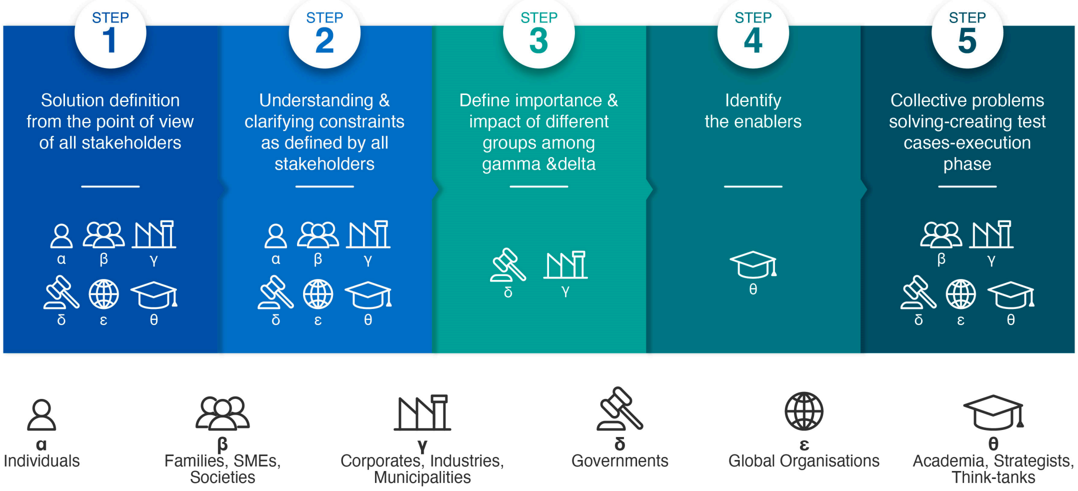

Figure 1. A new approach to complex problem solving—illustration of the design thinking model inspired by the Stanford d. School 5-step model [17]. The importance of different groups defined in the text (α, β, γ, δ, ε, ϴ) for each step is shown explicitly.

To be able to achieve this objective, there is a need for either a template or a facilitator who will lead the discussions to customize a template for the creative solution of the complex problem. The expertise of participants, a shared and well-defined common problem, and extensive discussion will help reach an applicable solution. This approach can be applied to different complex problems, as later discussed in Case Study 1 and Case Study 2. On the other hand, one of the most challenging issues we face today is the climate crisis, which needs fundamental energy transition at a multitude of levels. That problem constitutes Case Study 3, discussed last.

2. Methodology

A General Discussion to Tackle Complex Problems

Below, we present the essential steps of the proposed methodology. To develop an effective strategy, we chose to identify different stakeholders based on their different circles of influence. Then, we discuss how we can make them interact based on intuition and experience gained by the leaders. Ultimately, we give some examples from our past efforts to show that we can implement the proposed methodology.

(1) The first step is to identify and group stakeholders. We grouped stakeholders into five vertical groups and one cross-cutting group. This is to set a simple sandbox for the understanding of the proposed transdisciplinary approach. First, we outline the structures of different stakeholders, briefly named alpha (α), beta (β), gamma (γ), delta (δ), epsilon (ε), and the cross-cutting layer of theta (Θ) scale.

Alpha (α) refers to every individual, any person on the street. We are all consumers of energy. Every change and every energy decision is directly impacting all these individuals. Alpha (α) is the biggest group in society, usually with the smallest voice toward potential solutions and strategies that must be developed for complex issues. However, their cumulative contribution is likely to be significant, and this requires a thorough understanding and implementation of behavior change, which is much more complex than many other technological developments.

Beta (β) refers to families, neighborhoods, small to medium-sized enterprises (SMEs), and nongovernmental organizations (NGOs). Although they may have a small voice and are mostly overlooked, their combined efforts can also send shock waves around the globe, like in the case of climate activist Greta Thunberg and the organizations she established over the years.

Gamma (γ) refers to the large (and multi-national) corporations, industries, and large municipalities (e.g., Istanbul, London, Mexico City, New York City) that have loud voices and are likely to have significant impacts if they want. However, they usually make decisions with near-term goals and often focus on short-term profits to survive (votes, balance sheets, etc.). They communicate well with governments (delta δ) and global organizations (epsilon ε), as discussed below; however, they do not always have the same goals in mind. This causes a clash of the clans, which can be resolved only with effective leadership.

Delta (δ) is for governments. They deal with many challenges at once, are elected for a term, plan for the term they are in office, and have different values and priorities than all other groups identified here. They have a different local, regional, and global focus on their endeavors and do not necessarily care for the overreaching problems of the climate crisis. Their alliances with other governments and with other pacts may push them to come up with actions that may jeopardize energy transition and the resulting fight against the global climate change challenge.

Epsilon (ε) refers to global organizations, from international finance organizations (the World Bank, International Monetary Foundation, etc.) to the United Nations, including the IPCC and the IEA. They are global, and they are considered the key agencies providing extensive programs and suggesting roadmaps to avoid the future problems we will face due to complex problems, such as energy transition and, of course, climate change. They have the best view of the global landscape and have a significant amount of data and experts. They also influence governments (delta δ) through their effective leadership.

Theta (ϴ) is the last group, comprising global academic leaders, thinktanks, and strategists. They can be very influential as they usually innovate, devise effective solutions, integrate different disciplines, and test different approaches. There is an acceptable amount of collaboration among them, but with limited conversations between them and the others, especially with the corporations (gamma γ), governments (delta δ) and global organizations (epsilon ε), and a very scarce connection to people (alpha α) and NGOs and small companies (beta β). We must discuss the interconnectedness of these layers and propose increased communication to establish action plans between them. Working on different priorities set by them is essential for structuring a well-functioning society marching together against the significant consequences of the climate crisis we are facing in the world.

Figure 2 demonstrates a schematic showing the relationships among the six groups mentioned. For example, alpha (α) is directly related to beta (β), gamma (γ), and delta (δ) through relationships, memberships, consumerism, and votes. In a similar approach, it can be said that beta (β) is linked to gamma (γ) as their suppliers, and gamma (γ) is linked to delta (δ) from policies, regulations, incentives, and other forms of support. Delta (δ) and epsilon (ε) need to have a healthy dialogue, ideally, although sometimes there are conflicts between them related to special local issues. However, the effective interaction between governments and international agencies, favoring their national and international interests while protecting the world from future challenges, is not always clear. Such interactions will require leadership and the cross-cutting work of the academics and thinktanks (theta, ϴ), as discussed below.

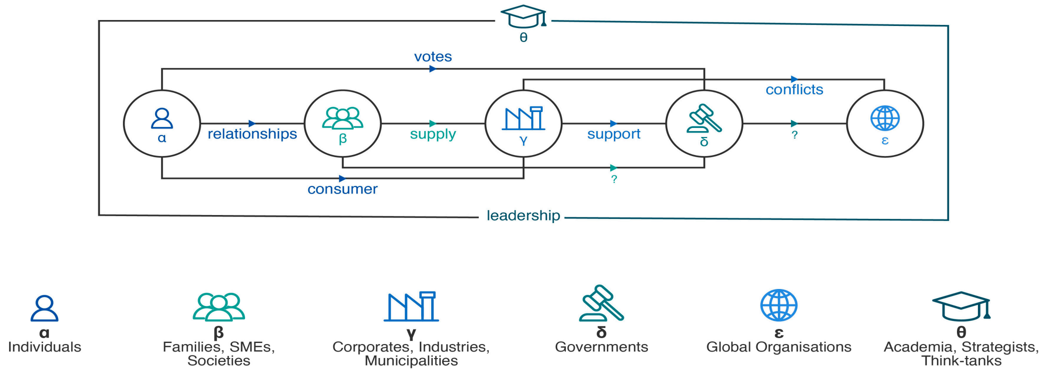

Figure 2. TADTM: concept of connectedness—demonstrating the interactions among defined groups.

(2) The second step is to prototype with small, manageable, and measurable samples to identify the problem and the bottlenecks and to facilitate solution-based transdisciplinary discussions for design thinking. The reason for this is to first understand why each stakeholder is unaware of the problems and why they are not attempting to establish a seamless connection between different scales of operation. The required steps for a given complex problem include empathizing, defining, ideating, prototyping, and testing. In our context, the complex problem of energy transition is to be streamlined, and these steps need to be defined clearly.

Within the present approach, we find it safe to assume that increasing communication among the groups defined above is necessary to create a holistic action plan with anchors in the global public opinion, thus organizing and accelerating the global clean energy transition by 2030. The current additional global challenges mentioned above make public and private collaboration even more critical. Creating genuine collaboration by governments and multilateral institutions has a leading role in developing novel policies, incentives, and investments, issues of financing and directing, as well as funding research and development of clean technologies and making them more affordable [6].

(3) The third step is to create meaningful case studies, working with a combination of all stakeholders on one part of the problem. An important goal should be to reach a "proof of concept" level focusing on one measurable part of a complex problem (e.g.,

energy transition for designing effective strategies to minimize its adverse effects on climate change and different societies).

Once the case studies are outlined, we can start to generate findings from the comments and contributions of the transdisciplinary working groups. These observations are likely to lead to finding creative, out-of-the-box solutions. It may be safe to assume that changes in the understanding and behavior of stakeholders based on collaborative discussions may start to bear different results, making certain transformations easier and/or faster, leading to incremental improvement. One must also remember that this is not a one-step process but an iterative process that needs to be continuously fine-tuned.

The complex problems we face cannot be solved by a single group of people or stakeholders, including governments, businesses, NGOs, and citizens, or even by academics and thinktanks. Understanding and solving complex problems requires collaboration with different groups of scientists, including technocrats, academics from many fields of physics and engineering, architects, and a variety of social scientists, as well as people who will be at the receiving end (execution) of these solutions. Therefore, we envision theta (ϴ) as the cultivating medium in which alpha (α), beta (β), delta (δ), and epsilon (ε) bring different perspectives of needs, solutions, and constraints as per their points of view and connections when solving complex problems, especially energy transformation, where every individual on the planet is part of the problem as well as part of the solution. In addition to solving technological constraints, additional issues surface, such as system change issues and societal acceptance.

One of the most necessary requirements for a transdisciplinary approach would be the relationship among the technical people, end users, financial mechanisms, and the human element, including behavior and culture. Most of the time, people dealing with technological or financial mechanisms do not understand the rational/irrational desires of those using the products. Because of this, these additional features would find a way to hinder the potential impact of new technologies for solving any critical problem, such as the climate crisis. For example, buildings need to be energy efficient or carbon neutral and attractive, comfortable, and affordable enough for the occupants. This means that they should not be simply built by the engineering and architecture firms straightforwardly following government directions, regulations, and incentives, but should be planned and built following integrated engineering and architecture principles. They should be integrated to account for occupants' needs and desires and coupled with environmental efforts, including local city planning and urban/national transportation development ideas. These latter concepts influence the habits of the citizens using their houses with the minimum waste of energy, materials, and time and cause the least amount of stress. Only then can we follow sustainable practices for both society and the environment. We should note that sustainability in all its shapes and forms is a transdisciplinary concept [15].

The "network of relations" of our above-defined stakeholder groups is given for any complex problem, and, of course, they will be applicable to energy transition. In our model, also based on our experience, bringing in all our above-mentioned stakeholder groups has challenges. Alpha (α) and beta (β) are unorganized big groups of people or companies (SMEs). Once included and managed effectively, they have a large collective power of transformation and impact on the desired outcome. However, the challenge lies in informing, educating, and motivating them in meaningful, large numbers. As for gamma (γ), delta (δ), and epsilon (ε), they are well-known structured entities, but they have different priorities, often conflicting with each other, and their focus is more on short-term rather than long-term impacts. Our last group of stakeholders is theta (ϴ). They are experts in narrow fields and may lack the insight to understand the other stakeholders' points of view. Therefore, they need to be put in contact with all the others to consider the impact of technical solutions on real life. While working on the framework and methodology, this is the picture we have in our minds in designing the framework of the "Transdisciplinary Approach and Design Thinking Methodology" (TADTM).

(4) The fourth step is to communicate extensively to expand the scale of impact. Once a proof–of-concept study bears the desired outcome, it is critical that the case is widely communicated on all platforms. Clear communication of the ideas at expert levels is essential, which needs to be disseminated in traditional ways. Furthermore, organizing workshops and roundtables, including representatives from all groups, namely alpha (α), beta (β), gamma (γ), delta (δ), and epsilon (ε), is needed to have seamless interaction between them. This step can be best achieved with the help of the theta (Θ) group, that is, thinktanks, academics, and strategists. The third phase is the impactful use of social media to reach out further to people (alpha α) and society through small groups and NGOs (beta β). As one can imagine, without such a step, impactful and sustainable energy saving and energy efficiency cannot be considered by alpha (α) and beta (β) alone. SMEs (beta β) and large corporations (gamma γ) are relatively easy to target and communicate with, but alpha (α) is the biggest and most diverse group among our stakeholders. The use of social media will be important and critical in achieving the desired impact in both collections of inputs as well as delivering the output of solved issues to alpha (α).

3. Energy Transition and Climate Crisis as Complex Problems

Energy use and transition are directly related to the enormous challenges faced with climate change, and they can also benefit from the TADTM structure we put together. As mentioned above, our goal is to present the foundations of such an approach starting from our experiences and to suggest a methodology that can be implemented easily under effective leadership.

Emissions of carbon dioxide and other greenhouse gases (GHGs), mostly due to the use of fossil fuels, continue to increase at an alarming pace around the globe, causing the climate crisis we currently face. The resulting environmental impact is undeniably one of the world's most pressing issues [3,4]. The term climate change refers to changes in temperatures and weather patterns that happen over a long period. Its causes are many, starting from natural events, such as changes in solar cycles and volcanic eruptions, but are also closely tied to human activities. With the start of the Industrial Revolution in the late 1700s, the increasing use of fossil fuels for energy generation has contributed to this crisis. With more industrial progress and increasing population and urbanization, human activities will likely have a more significant impact unless we take some urgent actions [5].

In today's world, one of the main drivers of increasing carbon emissions is due to the increased demand for energy. Carbon dioxide-emitting hydrocarbon-based fuels still account for 80% of the global energy mix, and the IEA expects that this ratio will not be less than about 70% in 2030 [4]. How we generate, exchange, transmit, distribute, and consume energy shapes our lives and the concentration of GHGs in the atmosphere. The increase in population, changes in lifestyle, expansion of urbanization, advances in technology, and many other changes in society make us consume more energy than ever. New strategies are needed to take radical measures to overcome these problems, use less energy, and decrease the energy intensity in industry, buildings, and transportation.

The methodology we present in this paper, TADTM, can be adapted for achieving effective energy transition at multitudes of scales. We define a framework to implement the concept based on teamwork to contribute to the overarching task of minimization of carbon emissions. Obviously, energy efficiency measures and the use of clean energy sources need to be considered toward this goal. Solar, wind, geothermal, and hydro, as well as newer technologies, such as hydrogen, small modular nuclear reactors, battery storage devices, and electric vehicles, will all have a pivotal role to play. The need for energy security, climate commitments, and the new era of manufacturing powered by clean energy is a powerful combination for governments to set aside significant funds to enable this transition [4].

The 1997 Kyoto Protocol, the 2015 Paris Agreement, and many other regular Conference of the Parties (COP) meetings have allowed many countries, corporations, scholars, and individuals to contribute to solving different sub-problems related to the climate crisis.

These decades-long efforts have also emphasized how effective energy transition and other climate actions must be put on the global agenda. Unfortunately, the COVID-19 pandemic and increased geopolitical tensions resulted in a significant setback in these attempts. The IEA predicts that the world will not be able to reach targets set for 2030 and 2050 [3–6]. In particular, energy efficiency measures and the transition to clean energy technologies will not be enough to reach the carbon emission targets set for 2050 at the current rate of implementation [4].

The discussions held at COP 27 in November 2022 in Sharm-El Sheikh, Egypt, and at COP 28 in December 2023 in Dubai, UAE, indicated that global energy transition is more challenging and difficult to achieve than ever before. Economic turbulence and rising inflation in almost every country in the world following the global COVID-19 pandemic and the war in Ukraine constitute the reasons for this outcome. The resulting surge (and sudden drop) in energy costs with the accompanying disruption in energy security can be considered the perfect storm we face as humanity, which has slowed us down in achieving an effective clean energy transition and fighting against the climate crisis. Even sudden decreases in energy prices in recent weeks cause concerns of instability. We observe that a short-term reliance on fossil fuels comes back and challenges global collaboration and coordination to fight against climate-related problems as the world becomes polarized once more [6].

As mentioned in several reports, the focus is usually put on decreasing the use of fossil fuels, increasing the shift to renewables, and experimenting with newer technologies to explore if they can be integrated into the existing system cost-efficiently. In addition, the importance of energy efficiency is emphasized in several recent reports [7] and studies [9]. There is no question that the widespread implementation of innovative energy efficiency measures is an essential aspect of future strategies to achieve a decrease in global carbon emissions. However, for carbon emission reduction to reach an acceptable level, more efforts are needed to coordinate the actions of individuals, NGOs, corporations, and governments, and also to coordinate the interaction between them.

Through the efforts of many international organizations and some leading countries, awareness and a clear picture of the problem seem to appear better now than a decade ago (see, for example, [6]). Due to many factors, however, the impact of these initiatives is not encouraging. We still need to understand the reasons why people, companies, and countries are increasingly irrational in their thinking and actions regarding energy and climate change. The behavioral aspects of energy transition obviously need to be established seamlessly by the contributions of many different stakeholders to achieve the desired impact [12].

To further clarify why we need a different and effective approach, we would like to mention Germany's long journey with energy transition, often referred to as "Energiewende". Germany's energy transition efforts are well known and well researched as it had the most ambitious goals; however, the outcome has not yet been justified from a GHG reduction point of view and it has also had a high cost for the German people as well as the government, and the cost was not sustainable to reach the 2030 and 2050 goals. Germany's Energiewende program has been focused on electricity, and little investment has been made for heating and transportation. Many programs have been tried but have failed regarding energy efficiency. Germany's dependency on energy imports did not decrease. Despite significant investment and the increasing cost of energy, it may be concluded that the lack of a holistic strategy explains why carbon emissions did not decrease meaningfully. The example of Germany, in our understanding, underlines the importance of a holistic vision for sustainable energy transition and the importance of an all-inclusive strategy [19–21].

In a recently published study, Jakimowicz and Rzeczkowski also discuss the importance of government (gamma γ) to consumer (alpha α) discussion when implementing new measures to improve energy infrastructure and transition [22]. They argue that the success of energy transition relies on what happens in the contact zone, the area between citizens and municipality governments in two districts in Poland. Their approach and findings are supportive of our hypothesis and the TADTM model. Another study by Tushar et al. integrated the DTM into improving building energy efficiency using a university campus, similar to our work described in detail below as Case Study 2 [23]. Similar to our approach, they have demonstrated, through two case studies, the application of the proposed design thinking approach in improving the energy efficiency of both residential and commercial buildings. They state that the 4D framework has effectively guided the process of developing smart energy solutions by discovering opportunities, defining needs, developing concepts, and delivering solutions in the smart energy domain [23].

The discussions at COP'28 in Dubai, UAE, did not help to create more solid solutions and strategies, given that working on a holistic approach involving all stakeholders in the conversation is more important than ever. The methodology we have developed, the TADTM, may help identify some overlooked challenges or roadblocks and to increase the pace of the implementation of the necessary measures. In addition, it allows a coherent discussion between many decisionmakers and the public and streamlines the transition with the help of overlooking thinktanks.

4. Case Studies

In this section, we have opted to share three case studies to support our premise that a transdisciplinary approach combined with DTM may help expedite and solve complex problems. Our forward-looking vision is to help enhance the speed of energy transition, especially in the energy space, and to support the global race of fighting climate change and its dire impacts on the environment.

The first case is an example from our past studies in the healthcare sector, where complex problems could not be solved only by technological innovations. A transdisciplinary approach combined with design thinking tools and methodology has been used to solve problems. Our second case is about our own energy efficiency efforts in buildings. If this successful case can be scaled up, its impact on energy transition can be meaningful. Our last case is focused on developing a new energy efficiency/transition framework targeting Türkiye's industrial sector. The reason we have chosen the industrial sector is due to two important factors: firstly, its impact will be meaningful and will improve Türkiye's competitiveness, and, secondly, it is a well-organized, relatively easy-to-reach target.

Case Study 1 is from General Electric Healthcare, and it was published by the *Harvard Business Review*. Case Study 2 is based on our efforts carried out at the Ozyegin University campus over the last few years. Our transdisciplinary efforts, which focused on energy-efficient campus buildings, yielded remarkable results, and were documented by publications. Case Study 3 is based on our current focus, which is still ongoing. The reason we have included the national energy transition as Case Study 3 in this article is that even in the nascent phase, the project immediately brought together the leading industrial NGO, academia, and the Ministry of Energy and Natural Resources (MENR). Several companies have agreed to be the test case. This last case has the potential to be our proof-of-concept study for TADTM on a much larger scale.

4.1. Case Study 1: Application to Medical Process Development by Following the TADTM

The General Electric Company used the term "Imagination at Work" as its logo at the beginning of the 21st century, signaling its increased focus on innovation and solving the world's complex problems with out-of-the-box design thinking. GE Healthcare, where the first author (CO) worked for six years, was at the point of integrating design and design thinking into marketing and product management, especially for its healthcare division. Her efforts are discussed below as they summarize an important and successful example to explain where our experience and inspiration in the TADTM approach comes from.

In a competitive environment, solving healthcare issues for clinicians while taking care of patients' needs is always a challenging issue. Clinicians' needs, patients' comfort, and the cost-benefit ratio must be met for sustainable solutions. Where technology alone cannot solve all issues, transdisciplinary brainstorming and integrating design solutions may help.

With this in mind, GE Healthcare Systems started to work with a world-class design team and led workshops with caregivers, patients, and all healthcare value chains, from C-Suite to clinicians. One such example to demonstrate the process is explained below.

The problem statement we encountered in 2010 was the difficulty of imaging children with serious illnesses. A CT scan or an MRI for young children, where complete stillness during a scan is crucial, was very problematic and often required heavy sedation or anesthesia during the procedure. This case was proving to be cumbersome, costly, and certainly not desired by parents and clinicians. The GE Global design team, GE Healthcare marketing and product management teams, together with child life specialists from leading children's hospitals, the Betty Brin Children's Museum, and award-winning design firms, developed a pediatric imaging solution, to improve patients', families', and hospital staff's scan experience. The idea the team came up with was to create a child-friendly imaging experience through children's eyes. As adults, the transdisciplinary team identified parts of the scan procedure that could cause anxiety for the child and created imaginative ways to make sense of these anxiety points. In the end, the GE Adventure Series was created as a product offering, making the child feel like part of an adventure, and the staff role-played, making use of all senses, such as visual, auditory, and olfactory. It has been a successful outcome, decreasing the need for sedation, thus improving the quality of life of the children as well as decreasing the cost to the overall healthcare system. More information can be found on the company's website [24]. Later, we used similar transdisciplinary research and design thinking workshop methodology to solve women's healthcare imaging mammography issues. Combining engineering with designers, clinicians, and patients at the same time resulted in many successful outcomes.

GE Healthcare had a well-established new product introduction process in place, focused on the predictable delivery of high-quality products in compliance with regulatory requirements. After many discussions and demonstrations, GE's leaders recognized the potential value of an additional filter of customers' clinical business needs integrated with GE's technological capabilities, which had the potential to deliver better business results and expedite market penetration. This new approach was named the "Healthymagination Value Creation Process" [25]. The process highlights are summarized in the below-listed steps:

(a) Identify the problem: This step is the most challenging. From the top decisionmaker to the engineers in product development, engagement, and a willingness to try a new methodology had to be ensured. As can be expected, there were many pushbacks and much resistance.
(b) Identify and engage all stakeholders: Engineers, product managers, marketing and sales teams, executives, clinicians, and patients were involved. Our first kick-off workshop in-house without the clinicians and patients had over 150 members of product teams. It lasted a full day and was a big investment for the company.
(c) Carry out continuous field observation trips and in-depth discussion sessions using design tools and DTM.
(d) Try out ideas with prototypes and test.
(e) Measure impact versus the previous state: Our goal was to improve access and quality of healthcare while decreasing costs for the healthcare system. The data collected have been a great way to keep teams engaged.
(f) Get continuous feedback from all stakeholders, and particularly from patients, to continually improve the product.

The Healthymagination efforts of GE were also recognized by Harvard Business School, and the ultrasound product portfolio transformation with the value creation product innovation process was published as a case study in 2011 [25]. The literature review shows a number of studies with a similar approach combining transdisciplinarity with a methodology that helps in identifying critical issues, discussing them, and solving them. One such example is by Pineo et al. [26]. In this study, which is also focused on healthcare, the challenges and benefits of a transdisciplinary approach and collective problem-solving using a new methodology are discussed. They have based their model on Stokol's framework [27]. They have identified three key challenges in transdisciplinary work that they aimed to address through their model. The first issue is participation, the second is knowledge integration, and the third is moving from knowledge to action [26].

4.2. Case Study 2: Achieving Energy Efficiency at a University Campus by Integrated Studies

Similar to Case Study 1, here we discuss the efforts carried out by the Center for Energy, Environment, and Economy (CEEE) at Ozyegin University (see [15] for details and references). The "integrated engineering and architecture" project was supported by two different EU grants we received and successfully completed, including EU-FP7-NEED4B (Project NEED4B) and EU-Horizon2020 (Project TRIBE). The TADTM formulation we present here was formally introduced by the authors of this paper based on these studies. We discuss these efforts in narrative form below, where we will list alpha (α), beta (β), gamma (γ), delta (δ), epsilon (ε), and theta (ϴ) for each identity.

Project NEED4B was funded in 2012 by the EU Framework Program 7 (EU-FP7) and involved five countries: Spain, Belgium, Sweden, Italy, and Türkiye. The Turkish demo site was the SCOLA building for social sciences on the campus of Ozyegin University. The campus was still in its initial phase and was undergoing construction. We started the project by establishing a group of researchers in the Center for Energy, Environment, and Economy (CEEE), corresponding to theta (ϴ). In our current framework of the methodology, alpha (α) represents the students and faculty members at the university who care about their comfort at the workplace. Those who are interested in climate change or the Earth's future are the student organizations, which can be considered beta (β). These two groups were important for efforts; however, they are not part of the design team and do not know the impact of the work being carried out until it is completed. In the later phase of our studies, student organizations (beta β) were influential in carrying out the concepts developed. In addition, several NGOs outside the university, which can be considered as beta (β), took an interest in our studies as they helped us to disseminate the concept to a wider audience outside the university.

The second project, TRIBE, involved engineers, architects, data scientists, and psychologists, and aimed to establish behavior change among the students to encourage energy efficiency in a campus building at Ozyegin University. Again, students and faculty members (alpha α) interacted with the researchers at CEEE (theta ϴ), with the support of the university (gamma γ) and funding from the EU (epsilon ε)

The university and the foundation behind it (FIBA Holding) had a vested interest in constructing new energy-efficient and environmentally friendly buildings and a university campus. They have committed additional funds, human capital, and land, and established a framework to help reach this goal. They were the gamma (γ) part of our methodology. In such efforts, the next step should be to scale up the concept to Istanbul, Türkiye, and Europe. This requires the involvement of other entities, namely the Istanbul municipality, the Turkish government, and the EU, which establish the rules for the construction projects and, if needed, provide incentives for the construction of high-performance buildings.

When we consider this picture, it is obvious that there is a missing link. Who would build such an energy-efficient building, and with what funds? Here, the importance of international global organizations becomes essential. In this case, the answer was the EU, through its Framework Program 7 and Horizon2020 program, which can be considered epsilon (ε). They have provided Euro funding for the research and the demonstration through the NEED4B project and for the TRIBE project (see [15] for details). The EU incentive has helped the university (theta ϴ) and allowed this cutting-edge project to be carried out to establish a high-performance, energy-efficient buildings culture in Istanbul, Türkiye, and Europe.

The next step required was to carry out cross-cutting integration work, which needs in-depth research and organization. This step was to be performed by a theta (ϴ), in this case by the Center (CEEE), which integrated all stakeholders using a research-focused knowledge base, scientific and technological expertise, and innovative approaches. The CEEE engineers and architects, working closely with the design and construction teams, were involved in every aspect of the building, starting from day one. A concept called the ''Energy-Efficiency Core" was established, and, later, preliminary studies for comfort and economic risk analysis were carried out. Following these steps, the intricacies of transdisciplinary concepts and many other details were listed in another paper for application to high-performance buildings [28]. A detailed and comparative analysis of the SCOLA building based on thermodynamic analyses was also reported. The discussion of these studies, along with several others and the citations to the original reports, can be found in [15] and on the CEEE website (https://ozuecem.net accessed on 28 February 2024).

These studies show that a cross-cutting concept of a theta (ϴ) carried out by a group of academics and strategists can combine different aspects of a complex problem and result in an effective solution for energy transition on a university campus. By establishing a focus area called the "energy core," the demonstration study conducted by the team resulted in a building that has been using less than half the energy of the second most efficient building on the university campus, and it had almost 80% lower energy density than a typical academic building that one can find in Turkish universities. With energy use of less than 50 $kWh/m^2/year$, it also met the mandates set by the EU-FP7 NEED4B project and approached near-zero goals [15].

These studies clearly show how people from different disciplines, such as engineering, architecture, design, economics, and psychology, among others, can work on complex problems to achieve an impact that individuals cannot achieve alone.

4.3. Case Study 3: TUSIAD-CEEE Joint Industrial Energy Efficiency Initiative

In this opinion paper, we have decided to focus only on the energy efficiency aspect of energy transition in Türkiye as the third case. Below, we discuss why this is a complex and important problem and how it can be tackled using the TADTM approach.

Industrial energy use corresponds to almost 60% of the total energy consumption in Türkiye [29]. There are several industrial companies working with numerous strong NGOs representing society at different levels. With their efforts in energy efficiency studies, they will have a significant impact on carbon dioxide emissions and the financial aspects of the companies and the country. Therefore, the government has a vested interest in initiatives to improve industrial energy efficiency. In addition to the benefits of energy efficiency during the climate crisis, it also has the potential to improve the competitiveness of Turkish industries that are also exporters mainly to EU countries.

The transition from traditional energy sources to renewables is crucial for the world and Türkiye [29]. The plans for different governments include the acceleration of renewable energy systems, the development of a hydrogen ecosystem, an extended nuclear energy roadmap, planning to fade out coal, and providing incentives for energy efficiency. However, the widespread industrial "energy saving and energy efficiency" initiatives, which have been on the agenda for Türkiye for almost a decade, have had limited success so far.

For industrial companies with complex operations, unambiguous and easy-to-implement industrial energy efficiency guidelines are not readily available. To develop effective guidelines, there should be clear, sector-specific benchmarks. These benchmarks should not only indicate what needs to be achieved but also should lead different sub-groups to a clear idea of how to achieve the recommended outcomes. Accordingly, these groups should be able to produce their own paths, based on their own data, to achieve specific energy efficiency measures beyond just energy savings concepts. These efforts then need to be combined with the help of experienced leaders.

Preferably, a more comprehensive initiative is needed, which would include academicians, strategists, and thinktanks outside the government, working closely with all stakeholders. The TADTM approach will be integral in facilitating such complex discussions among the cross-cutting expert group. To this end, we have recently started a new initiative, including many stakeholders, such as the Center for Energy, Environment, and

Economy (CEEE, theta θ) at Ozyegin University, the Turkish Industry and Business Association (TUSIAD, epsilon ε), the Turkish Ministry of Energy and Natural Resources (MENR, delta δ), industry associations (beta β), businesses (gamma and beta γ, β), and consumers (alpha α).

Energy awareness and energy-saving initiatives have been implemented and communicated widely by many NGOs as well as the Turkish MENR for the last two decades. Also, the center, CEEE, has held many successful energy efficiency projects, studies, and dissemination efforts (see [15]). However, CEEE, a theta (θ), cannot complete such a herculean task alone. Per our defined methodology, to be able to reach a wide range of industries and companies (gamma γ) across the Turkish industrial sector, we teamed up with Turkish Industry and Business Association (TUSIAD) as our partner (which can be considered as a beta β representing many gammas γ).

Towards this goal, TUSIAD (beta β) carries the role of an umbrella organization, along with many of its member companies (some beta β and some gamma γ), and the Turkish MENR (delta δ) and CEEE (theta θ) agreed to work together, and to discuss their mutual needs and capabilities, as well as the limitations and constraints, to develop applicable solutions and strategies together. In this case, the leadership and initiation started with CEEE (theta θ). As the problem is mutual and important, it was relatively easy to bring the key stakeholders together.

The first challenge was to agree on the data collection, data privacy, and data sharing issues. As theta (θ), we had to prove the trustworthiness of the center as a gatekeeper, and make stakeholders believe in its scientific capability. The second challenge was to secure funding for the project, which came from TUSIAD, from a company and from the university (through CEEE). At the ideation phase, i.e., framing different aspects of the problem and preparing the key questions to be asked, the issues were framed, and the data to be collected were discussed. The core group representing each stakeholder group finally agreed on the steps to be followed as well as the context. At this stage, one of the critical success factors identified is to obtain the buy-in of the company CEOs and for them to initiate the project in their respective companies. This is followed by their engineers, energy managers, and supervisors on the plant floor generating ideas and asking critical questions. CEEE is poised to provide strategic and academic support.

This new initiative is named "Türkiye's Industrial Energy Efficiency Outlook Project". After a year of planning, discussing, and researching, the core team launched the project at the beginning of September 2023 with the participation of all stakeholder representatives as well as an opening speech and inauguration by Mr. Fatih Birol, the President of the International Energy Agency.

Türkiye's Industrial Energy Efficiency Outlook project aims to contribute to the practical implementation of the industrial energy efficiency potential at the highest level by raising awareness of energy efficiency to the highest level, identifying the energy efficiency and savings potential of leading industries in comparison with international and domestic references, and providing guidance for the transition from energy savings to energy efficiency.

Our premise is, as was the case in other studies we have conducted, that an ecosystem of collective learning and ideation will lead to developing recommendations that are actionable and effective. The support of CEOs and the participation of MENR officials will provide resources and regulations that will enable execution. By doing so, we will be able to create an evolving strategy that will be continuously customized to the needs, capabilities, and conditions of each industrial body toward better energy efficiency practices.

MENR regularly prepares energy benchmarking reports to increase energy efficiency awareness and guidelines for its implementation in various industrial sectors [30]. These reports compare the energy consumption of businesses with similar production processes, guiding businesses to evaluate their own performance and take the necessary measures to save energy. MENR has already shared reports related to buildings, the cement industry, the glass industry, the sugar industry, and the textile sector [30]. Most of the reports include process charts and specific energy consumption values (SEC). In addition to MENR reports, we will also be using ENERGY STAR benchmarking and the Solomon energy intensity index (EII).

These reports are necessary for implementing the TADTM approach; however, they can be further improved. The workshops to be conducted will be the key to the success of industrial energy efficiency initiatives across the national energy space, as focused actions will follow the detailed multi-stakeholder discussions. These workshops are expected to be a valuable resource for CEOs and other sector and company officials who are interested in improving energy efficiency in their businesses. By participating in the workshops, participants will gain the knowledge and skills they need to implement effective energy efficiency measures and achieve significant savings. While designing the workshops, the aim is to reach an outcome that will be custom-designed to fit the needs, challenges, and capabilities of industrial sites. CEOs and high-level company officials are expected to play a key role in motivating their teams to participate and contribute to the study. In addition to these core activities, the workshops will also provide a forum for participants to network with each other and build relationships.

5. Concluding Remarks

In this paper, we have outlined a methodology involving different levels of stakeholders who have a vested interest in solving or strategizing complex problems. We identified the people (alpha α), small organizations and families (beta β), corporations (gamma γ), governments (delta δ), and multinational global organizations (epsilon ε). They all work on problems but do not provide a coherent strategy that makes the solutions long-lasting and sustainable. There, the importance of another layer is defined as the academics, strategists, and thinktanks (theta Θ) who can provide an extensive methodology and innovative solutions for specific complex problems. To this end, we provided a baseline case where transdisciplinary design thinking was applied to product innovation, solving problems with design beyond technology. Later, we introduced three different case studies and discussed the interaction between them and how the theta (Θ) layer is needed and is, indeed, essential for the success of such a framework.

The methodology we presented here is unique because it brings many stakeholders together from different disciplines and allows different levels of decisionmakers to work together toward a common goal for the solution of critical problems. As decision making and problem solving become more inclusive, solutions will be shaped in a way that is more ready to execute and deliver the desired impact. The challenge for leaders is to let go of the decision-making power and responsibility, actively listen to others' opinions, and bring small clusters of the right people to the discussion, representing their layer of knowledge and experience. The ideas behind the approach presented in this paper are expected to inspire corporations and governments, enabling them to address different types of complex problems, including the climate crisis, more effectively with wider participation by all parties.

In the paper, we first discussed two different problems, one in a medical company and one in a university campus, to show how the TADTM approach was used. We also discussed how we apply this to the Industrial Energy Efficiency Initiative in Türkiye, which is intended to lead to an effective energy transition initiative nationwide. Such an effort is obviously essential to combat the climate crisis. It will help people to use less energy, albeit more efficiently, per product or service that different industrial sectors are providing. The financing, implementation, and acceptance of the use of the TADTM approach are still challenging. As discussed before, energy efficiency needs to be considered following a fundamental systematic approach, which requires interactions of many disciplines depending on the focus area, whether they are industrial processes, transport issues, or buildings, regions, and cities, thus making the TADTM a relevant, necessary approach to expedite the execution of a wide range of transformations.

Author Contributions: Conceptualization, C.M.O. and M.P.M.; methodology, C.M.O.; writing-original draft preparation, C.M.O.; writing-review and editing, M.P.M.; visualization, C.M.O.; supervision, M.P.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: This study is supported by the Center for Energy, Environment, and Economy (CEEE) from Ozyegin University in Istanbul. We thank the members of the TUSIAD (Turkish Industry and Business Association) Working Group for valuable discussions and input. We also thank the anonymous reviewers who have contributed to the clarification of some of the intricate concepts discussed in the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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