Data-Driven Energy Development in the Year 2035

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1. Introduction

It is expected that global energy demand will increase dramatically over the next decade, and the majority of this growth will come from the developing world [2]. As undeveloped countries transition into developed economies, their energy demands will rapidly increase. A critical, yet arduous, task is ensuring the implementation of sustainable energy practices and products in these countries during their periods of growth and beyond. Additionally, ensuring implementation of a reliable energy infrastructure will promote the adoption of new products and contribute to quality of life improvement for the population. Engineers employed at a company producing renewable energy products in the year 2035 must understand how to design for this emerging market and understand how to most effectively use the tools at their disposal.

2. The World of 2035 and Energy Demand Development

The world of 2035 will be considerably different than the world of today. In terms of global power, gross domestic product (GDP), military spending, and technological development Asia will surpass the combined numbers of the United States and Europe. The global population is expected to grow to 8.3 billion by the year 2030, and over 60% of the world's population will live in urbanized areas. Developed nations will be home to 'aging' populations as birth rates continue to decrease, resulting in a likely decline in economic growth. An increase in migration between nations, coupled with the increase in urbanization, will drastically increase the demand for resources [2].

The world will also be more interconnected. Everyday devices will have integrated communicative technologies and a record number of people will be connected via the internet. The world will have entered the era of big data, where processing power and data storage will have become inexpensive; in turn making data collection an almost ubiquitous process. This will create markets for data security and analytics, along with the rise of fears of an Orwellian surveillance state in developed countries [2]. The engineering design community and many engineering firms will have embraced and integrated these technological advancements into the design process. This allows them to derive improved consumer-centric, data-driven design solutions and expedite portions of the design process [3], [4]. Despite the great advancements we've seen so far [5], design for the developing world is still a relatively complex process and there is still need for improvement. For example, data acquisition is difficult in some regions of the developing world and local cultures may make some technically valid solutions unimplementable [6].

Demand for food, water, and energy will dramatically increase given the growing population size and development of the global middle class [2]. Global energy demand is expected to increase by 28% between 2015 and 2040. Of the expected energy demand growth, Organization for Economic Cooperation and Development (OECD) countries are expected to increase their energy demand by 9% and non-OECD countries are expected to increase their energy demand by 41%. Note that the majority of non-OECD countries are part of the developing world, where the largest increase in energy demand will take place [1]. Expected future energy consumption, as predicted by the U.S. Energy Information Administration (EIA), is displayed in Figure 1.

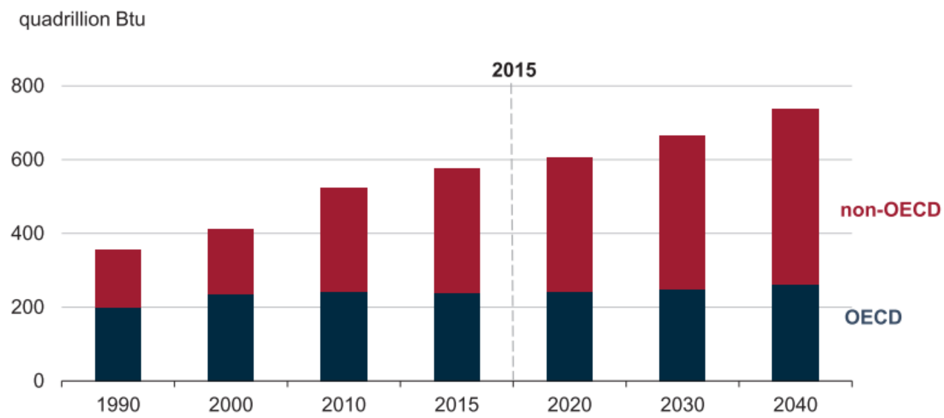

Figure 1: World Energy Consumption [1]

Economic growth is predicted to be highest among the non-OCED nations, estimated to be 3.8% per year on average, representative of the growing middle class in these nations. As the global middle class continues to develop, energy demand will rise correspondingly. The expected GDP growth of both OCED and non-OCED countries between 2015 and 2040 is displayed Figure 2.

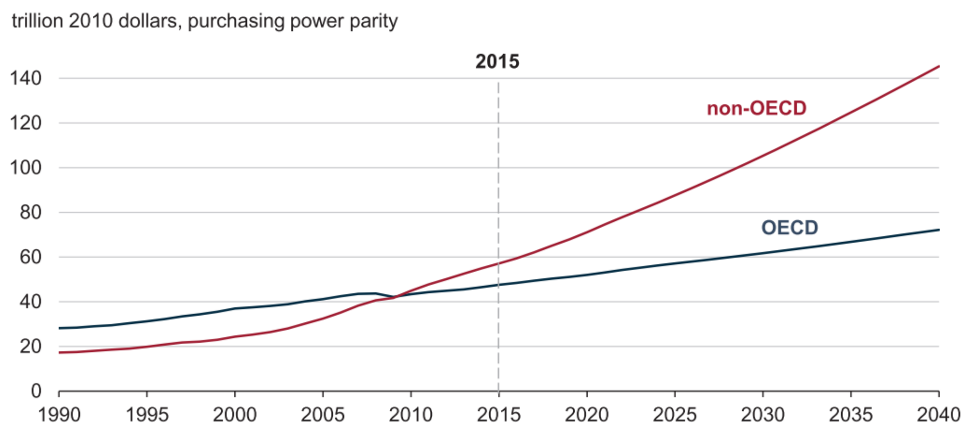

Figure 2: World Gross Domestic Product [1]

In 2011, India had the highest number of people in the world living without electricity, 404.5 million. India and Indonesia both had the highest percentage of their populations living without electricity, 65% [7]. Broken down by region, Africa has the largest population without access to electricity, 644 million. Developing countries have approximately 1.35 billion people in total without access to electricity, mostly located in rural areas [8]. While in the year 2035 a significant portion of these people will have relocated to urbanized areas, there will still be many rural inhabitants without access to a reliable source of electricity [2]. The number of people without access to electricity by region, is displayed in Figure 3.

Number of people without access to electricity by region (million).

	2009			2020
	Rural	Urban	Total	Total
Africa	466	121	587	644
Sub-Saharan Africa	465	120	585	640
Developing Asia	716	82	799	650
China	8	0	8	2
India	380	23	404	342
Other Asia	328	59	387	307
Latin America	27	4	31	16
Developing countries[a]	1229	210	1438	1350
World[b]	1232	210	1441	1352

[a] Includes Middle East countries.
[b] Includes OECD and transition economies.

Figure 3: Number of People Without Access to Electricity by Region [8]

The costs of photovoltaic and wind energy sources are expected to continue to decline, making them more feasible options for economically disadvantaged countries in the developing world by 2035. The historical and expected costs of photovoltaic and wind energy generation sources are displayed in Figure 4.

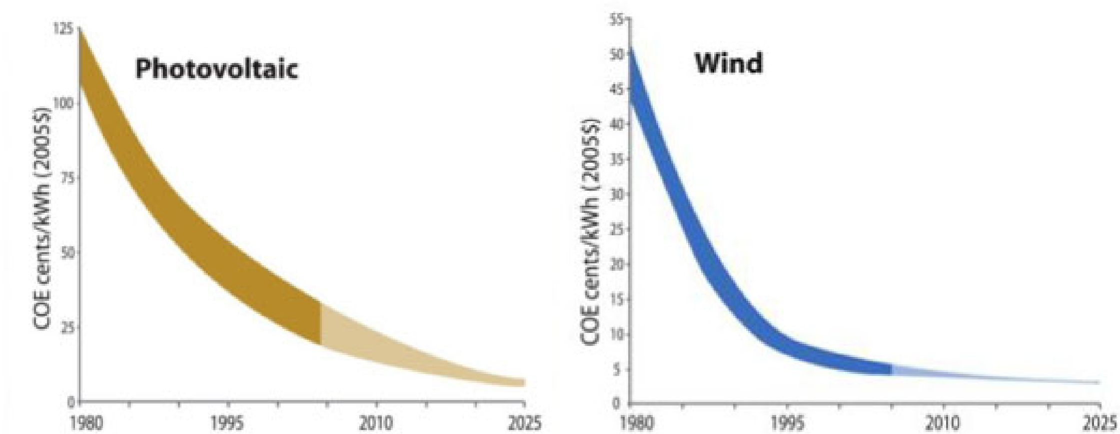

Figure 4: Cost of Energy for Photovoltaic and Wind Sources [9]

3. Design for the Developing World and the Internet of Things

There is a dramatic difference between the developing world and the developed world when it comes to culture, markets, and engineering design objectives. In 2010 the World Bank estimated that 20% of the world's population was living on less than $1.25 a day [5], though this percentage is expected to decrease dramatically by the year 2035 [2]. To help contextualize this disparity it is worth noting that operating the Dallas Cowboy's football stadium requires three times the amount of electricity the country of Liberia is able to generate [6]. Although areas in the developing world may be considered resource poor, in total they represent a largely untapped five trillion-dollar market [5] which will have grown even larger by 2035. To effectively implement solutions in these regions, engineers will need to spend time considering the impacts that resource constraints will have on their design solutions. The major challenges that need to be addressed in the developing world are a lack of clean drinking water, chronic hunger, inadequate health care, short life expectancy, inadequate housing, poor education, and lack of sanitation [5]. Note that the technology best suited to alleviate these issues, lacks the energy infrastructure to support it.

Addressing the design challenges for the developing world is a non-trivial issue, but a solution may come from a new technology currently emerging in the developed world, the Internet of Things (IoT). Devices integrated with IoT technology allow them to interconnect with a number of other physical devices, allowing for information to be passed between them. While this does not provide an obvious solution to the problem of implementing sustainable design solutions in developing nations, it will be argued that the connectivity allowed by the integration of IoT technologies will have a profound impact on the design process, that will allow designers to adapt their products for the developing world. A layout of the components that comprise the IoT space are displayed in Figure 5.

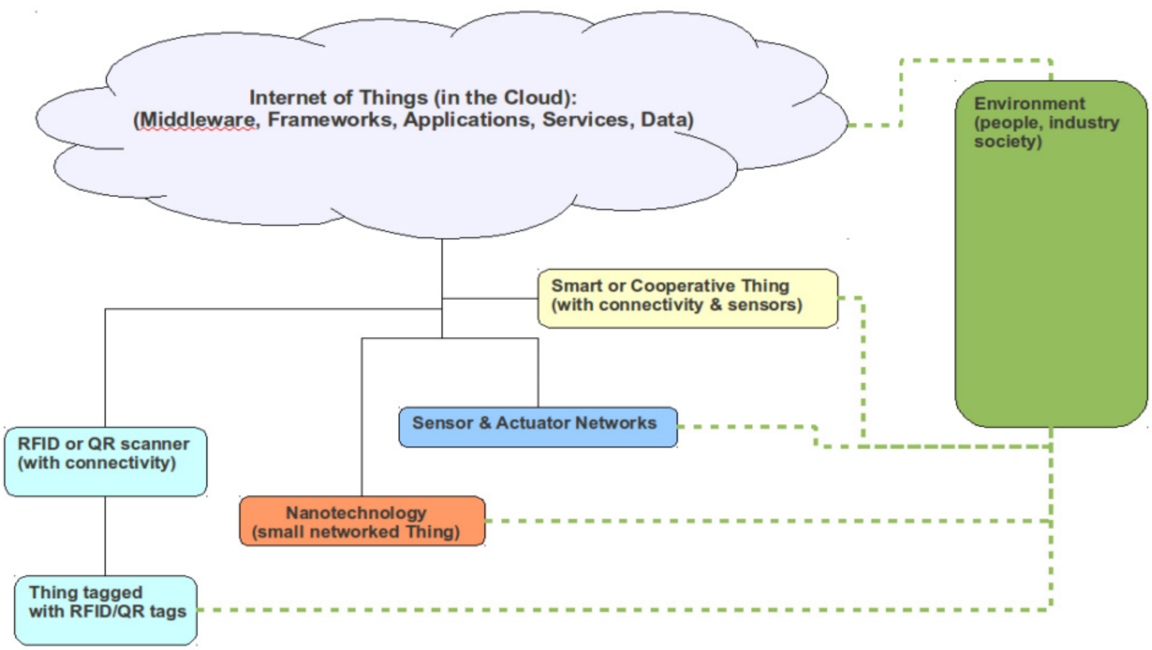

Figure 5: Internet of Things Components [10]

While it may appear difficult to enable device communication in the developing world, the International Telecommunication Union (ITU) estimates that in 2015, 95% of the world's population was living within a 2G cellular network, which allows for device communication [11]. Data gathered from an IoT enabled product could be extraordinarily valuable to the customers, the company, and other organizations. Data gathered by the device that tracks product performance in its environment could be used to optimize future system configurations and designs. This provides additional benefit to both the customer and the company; the consumers would see improved product performance and the company would likely see an increase in demand for the improved product. Note that this would be most effective if the product has a higher degree of modularity, allowing for rapid updates [12]. The data gathered by the product might also be useful to other organizations who are interested in producing other products or offering services for the environment in which the data was collected.

IoT technology in the developing world also has many other practical applications, specifically with respect to environmental monitoring, resource management, and healthcare [8]. Integrated environmental monitoring technology could be used to warn or monitor areas effected by natural disasters [10]. Many areas in the developing world are considered to be resource poor, so better monitoring and management of these resources (water, electricity, food, etc.) could drastically improve quality of life for a substantial number of people. This technology can also be used to monitor the health of the local population and transmit medical information to others, allowing for easier access to medical care in these regions [13]. With regard to implementing IoT technology in the developing world, the Red Cross stated that "emerging technologies will play a particularly important role in amplifying efforts to facilitate community-level knowledge and health, connection, organization, economic opportunities, access to infrastructure and services, and management of natural resources" [11].

4. Successful Energy Product Development in 2035

A company manufacturing small-scale renewable energy products in the year 2035, will want to seize the opportunity to enter the emerging market in the developing world. To do so successfully, the company will need to understand how it had previously designed its products and how it will need to adapt its approach to better suit customers in the developing world. Specifically, more sustainable energy solutions have traditionally been more expensive to implement and only provide power intermittently. These issues pose a major problem for developing countries, since they have less capital to invest in energy infrastructure and loss of power can have a devastating impact on their communities [9]. One solution to the inherent intermittent nature of renewable energy is diversity [14].

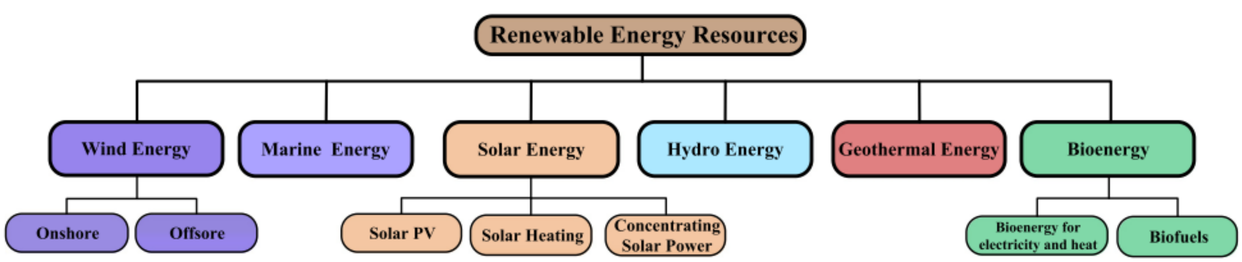

Figure 6: Overview of Renewable Energy Sources [14]

A design firm manufacturing renewable energy products in the year 2035 will not be able to obtain success by focusing its resources solely on one form of energy generation technology, especially if its target market is in the developing world. In many rural areas it is also not economically efficient to deliver power through an interconnected grid system [9]. Hybrid renewable energy systems (HRES) offer a unique solution to these problems, especially since the price of photovoltaic and wind energy generation sources is expected to continue to decline [9]. HRES use a combination of diesel, photovoltaic, wind, fuel cells, biogas, batteries, and/or flywheels, to ensure a steady supply of energy to the consumer. This approach provides a more robust and sustainable solution, as compared to implementing only one form of non-renewable or renewable energy [15].

Another challenge of deploying renewable energy products in the developing world, is the large variation in the environments in which they will be operated. Notably, variation in local weather conditions, terrain, and energy demand, will all have an impact the optimum product configuration for each location. Taking advantage of IoT technology imbedded in the device, system designers can use data recorded about weather and other exogeneous conditions to refine their designs and overall system architecture. This is of particular concern when designing HRES, however multiple tools are available to optimize these systems based on the location of operation, such as the Hybrid Optimization of Multiple Energy Resources (HOMER) software program [15]. Figure 9 displays a table of advantages and disadvantages of common renewable energy sources, which should be considered when designing energy products for specific locations in the developing world.

Energy source	Advantages	Disadvantages
Biomass energy	• Abundant and renewable • Can be used to burn waste products	• Burning biomass can result in air pollution • May not be cost effective
Geothermal energy	• Provides an unlimited supply of energy • Produces no air or water pollution	• Start-up/development costs can be expensive • Maintenance costs, due to corrosion, can be a problem
Hydropower	• Abundant, clean, and safe • Easily stored in reservoirs • Relatively inexpensive way to produce electricity • Offers recreational benefits like boating, fishing, etc.	• Can cause the flooding of surrounding communities and landscapes. • Dams have major ecological impacts on local hydrology. Can have a significant environmental impact • Can be used only where there is a water supply • Best sites for dams have already been developed
Marine energy	• Ideal for an island country • Captures energy that would otherwise not be collected	• Construction can be costly • Opposed by some environmental groups as having a negative impact on wildlife • Takes up lots of space and difficult for shipping to move around
Solar energy	• Potentially infinite energy supply • Causes no air or water pollution	• May not be cost effective • Storage and backup are necessary • Reliability depends on availability of sunlight
Wind energy	• Is a free source of energy • Produces no water or air pollution • Wind farms are relatively inexpensive to build • Land around wind farms can have other uses	• Requires constant and significant amounts of wind • Wind farms require significant amounts of land • Can have a significant visual impact on landscapes • Need better ways to store energy

Figure 7: Advantages and Disadvantages of Different Renewable Energy Resources [14]

When optimizing certain product configurations designers should not only consider the physical aspects of the location where the device will operate, but the culture and needs of the consumers in that region as well. Previously, designing products for the developing world required a team of designers to visit the sites in which their designs were to be implemented, which required a lot of time and expenditure. This has been a prominent issue in the Design for the Developing World community for a quite some time [5], however the rise of big data analytics and IoT present a unique solution to this problem. Instead of having to travel to the location where a product is intended to be implemented, designers can now exploit data gathered from previous products, to determine how effective their design solutions were. For new designs, data could be purchased from other companies operating in the area or from a third-party source. Patterns from this data can reveal latent preferences specific to certain cultures or regions, which could help to inform future designs. The advancement of big data analytics research in academia could provide a powerful tool to those looking to improve design for the developing world practices.

Success for a company manufacturing renewable energy products in the year 2035 will be defined not only by the objective quality of their solutions, but how they work with the communities in which their solutions will be implemented, as well as their data driven approach to design. Computer processing power and global communication will have dramatically reduced in cost, allowing the company to embed sensors in their products which will provide the opportunity for unprecedented amounts of data acquisition and analyzation [2]. The company will face developmental challenges in not only generating methods for analyzing this excessive amount of data, but also in quelling fears and securing the privacy of those providing it. This will be one of the largest obstacles to the company's success it will need to overcome.

5. Broader Impact and Company Policy

While the integration of IoT technology will provide an additional toolset for addressing the issues in the developing world, it alone will not suffice as a solution. The company will need to make partnerships, both with preexisting IoT technology companies, to assist with manufacturing, and non-profit organizations, which can provide information about and aid in, the developing world. The company should also engage in public-private partnerships (PPP) with public sector entities (governments, city councils, municipalities, etc.) in the areas in which they intend to deploy products. Not only will this allow the company to gain better insight to the community and culture of the area, but the IoT enabled devices can be used to benefit the local community. Previous work has demonstrated the effectiveness of PPP's in expanding renewable energy access in the developing world. Specifically, with China's renewable energy development program, Sri Lanka's Energy Services Delivery Project, the Cinta Mekar micro-hydro project in Indonesia, and Micro-Hydro Village Electrification scheme in Nepal, Rural Electrification Project in Laos, and India's Solar Lantern Project. These projects have all provided substantial benefits to the communities in which they were implemented as well as to the companies which partnered with them. These projects have helped connect power to some of the poorest households in those regions, provide microcredit loans for income-generating activities, sponsor education programs, provide access to better healthcare, and improve local infrastructure [16].

Internally, the company should develop a dedication to effective employee on the job training and improving engineering education as a whole. Engineering will become an increasingly multidisciplinary practice over the next decade and to develop globally competitive employees, the company will need to focus its employee training on areas outside of the employee's background experience. Widening the employee's area of proficiency will allow them to be more dynamic and versatile in the design process. A focus on engineering education will also benefit the company by better preparing future engineers before they reach industry, reducing the level of on the job training required. Exposing engineering students to the company before they enter the job market will also likely increase their applicant pool, allowing for a higher sustainable growth rate or a higher degree of selectivity among the applicants. This can be accomplished by partnering with universities and other post-secondary education entities.

Engineers will also need to more carefully consider the environmental impacts of their designs, as environmental legislation is expected to become increasingly more restrictive, especially in the developing world. Introducing the concepts of life cycle design and ecologically sustainable design, will not only add to the toolset with which employees can tackle problems, but it will make them more competitive in the global market. Like all other fields of engineering, energy engineering is also becoming increasingly interdisciplinary practice, where expertise solely in science and mathematics will no longer be sufficient. Successful energy engineers will have to obtain knowledge of the policies, legislation, economic incentives, and education, that drive the system inside of which energy infrastructure exists. Many new employment opportunities will have opened up for energy industry professionals who have not only have the technical knowledge required to succeed in the energy industry, but also broad knowledge of environmental, economic, and social issues, associated with energy development [17].

6. Conclusion

Middle class growth is expected to increase dramatically in the developing world, resulting in a corresponding increase in energy demand and opening up a portion of a largely untapped five trillion-dollar market [5]. This presents an excellent opportunity for a company designing and manufacturing small-scale renewable energy products in the year 2035. To take advantage of this opportunity, the company will need a highly interdisciplinary workforce and need to develop a better understanding of the environments and cultures, in which their solutions will operate. Integrating IoT technology into their products will provide a better way to understand these environments and cultures, though data acquisition and increased communication. It can also provide additional service for those in the developing world such as resource management, improved healthcare access, and environmental monitoring.

The success of a global manufacturing enterprise in the year 2035 will be defined not only by the objective quality of their solutions, but how they work with the communities in which their solutions will be implemented, as well as their data driven approach to design. Their understanding of the underlying environmental, economic, and social issues, related to the needs they aim to fulfill, is crucial to their success. The rise in global communication and large-scale data acquisition will provide new opportunities to work closer with customers and gain better insight into their preferences. These advancements will also allow for the company to derive higher quality consumer-centric, data-driven design solutions and expedite portions of the design process.

The company will face many research challenges, such as effective large-scale data management and analysis, IoT technology integration, and complex system optimization. To ensure success in the developing world, partnerships should be formed with local public entities, to aid in the design process and maximize benefit to the community. The company will also need to work closely with universities and other post-secondary education entities, to ensure that it’s employees have the multidisciplinary toolset needed to develop effective solutions for these problems.

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