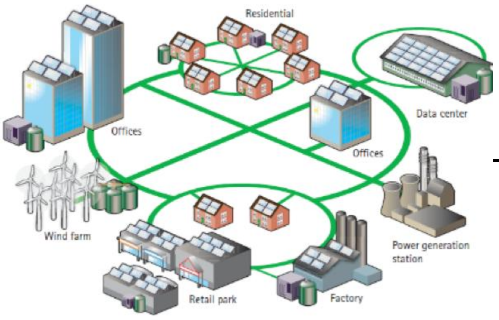
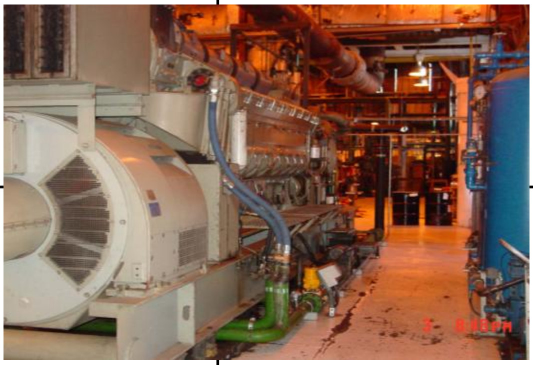
Asia-Pacific
Economic Cooperation

Microgrids for Local Energy Supply to Remote Areas and Islands in APEC Region





APEC Project No. S EWG 15 11A
Piloting Smart / Micro Grid Projects for Insular and Remote Localities in APEC Economies

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Microgrids for Local Energy Supply to Remote Areas and Islands in APEC Region

Edited by Kirill Muradov

APEC Energy Working Group

Expert Group on New and Renewable Energy Technologies

Institute of Lifelong Education, Moscow

November 2012

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Foreword and Acknowledgements

With the advent of new digital capabilities and reduced costs of renewable power, smart micro- or mini-grids have recently generated considerable interest. By and large, intelligent microgrids will serve as building blocks to integrate distributed generation and dispersed loads into a future smart grid. Hybrid microgrids combine power from both traditional and renewable sources and can be a part of the larger centralised networks or operate in the "islanded" mode. Remote microgrids never connect to the main grid and ensure the energy independence of isolated communities. In some cases, geography and economics may never permit access to the grid and connecting a remote community to the conventional power grid is expensive and can take more than a decade. Now, building hybrid microgrids is cheaper and faster than extending the grid to the areas where most of the people without electricity live.

In the Asia Pacific, there is growing understanding that microgrid is capable to bring essential energy services to off-grid communities and offset some notorious failures of the large-scale centralised generation. Some countries show significant progress in technology development, testing activities and have already established a sizable energy sub-sector driven by microgrid-based solutions. Others are gradually catching on and employing foreign expertise to run pilot projects. Even in Russia with its large, centralised power plants and abundant energy resource, high fuel cost led enthusiasts in the far eastern regions to explore renewable power. Pilot projects of local hybrid power have therefore taken off in a few remote townships.

Building on APEC efforts in creating enabling environments for smart grid and smart energy communities, the Ministry of Energy of the Russian Federation proposed an APEC project in 2011 under the title "Piloting Smart/Micro Grid Projects for Insular and Remote Localities in APEC Economies" (No. EWG 15/11A). This was an APEC New and Renewable Energy Technologies Expert Group (EGNRET) project proposal which was approved by the APEC Energy Working Group (EWG) and was co-sponsored by Canada, Japan, Korea, Singapore, Chinese Taipei, Thailand and the USA. A project team of experts and enthusiasts from Russia led the implementation of the project throughout 2012.

This volume brings together most essential contributions from the workshop on Microgrids for Local Energy Supply to Remote Areas and Islands in APEC Region that was held on October 15-17, 2012 as the core activity of the project. The objective that guided the project team in preparation for this release was to provide the reader with basic insights on microgrid technology development and, more importantly, outline a menu of options for microgrid pilot project development with references to some success stories.

The report is organised in five chapters. In the first, introductory chapter, Mark Sardella offers an overview of the evolution of the power industry — from bulk macro-generation, to smart, micro-generation — and explains the essential properties of microgrid and related self-reliance and self-organisation principles. Beom-Shik Shin further provides an insight from a political scientist, elaborating on the social significance of microgrid deployment.

Chapter 2 focuses on the opportunities for a transition to a localised hybrid power generation in case of Russia's Far East. As a starting point, Irina Ivanova and her co-authors from the Energy Systems Institute, Siberian Branch of the Russian Academy of Sciences analyse the prerequisites and priorities for local power development while Alexander Solonitsyn and Elena Pipko review the move towards "local energy systems" and the renewable potential in the Primorsky Region of Russia. Dariya Eremeeva and Anatoly Chomchoev discuss the experience and opportunities for hybrid power in the Republic of Sakha (Yakutia), the largest Russian region, including from unconventional sources like small-scale nuclear plants.

In chapter 3, authors discuss economics and technology testing of hybrid smart micro systems. Economics of hybrid renewable microgrid is briefly reviewed by Peter Lilienthal. A summary outcome of a study of hybrid microgrid development in a typical eastern Russian township may be found in the paper by Irina Volkova (coauthored with Viktor Kolesnik). Larry Adams and his co-authors from Energinet.dk review the results of the Cell Controller Pilot Project in Denmark.

Chapter 4 includes a few papers on community-driven business models for rural off-grid energy sector. Karen Ubilla summarises the research of the Energy Centre at the University of Chile on self-management foundations for successful microgrid projects. Brad Reeve shares a success story of an energy cooperative in Alaska, US that embarked on hybrid renewable power development. Further, Steven Pullins presents a “Village Renewable-Enabled Microgrid” concept, intended for implementation in India and other BRICs. Fedor Lukovtsev concludes with the observations on the social benefits of microgrid solutions for remote ethnic communities.

Finally, in the concluding chapter, Kirill Muradov recalls APEC activities related to rural, off-grid energy and puts these into a current regional and global context.

This brief introduction would not be complete without mentioning those who made this project viable and largely successful. Kirill Muradov (International Projects and Research Coordinator, International Institute for Training in Statistics, National Research University Higher School of Economics) and Pavel Korovko (Deputy Head of Laboratory, All-Russian Thermal Engineering Institute) were the core project team members, having provided a lot of ideas and also made lots of paperwork. Talyat Aliev (Deputy Director, International Cooperation Department, Ministry of Energy of the Russian Federation) provided important guidance as the project overseer with essential support from Svetlana Beznasyuk and Maria Bunina (International Cooperation Department, Ministry of Energy of the Russian Federation).

On behalf of the project team, I thank Konstantin Ilkovsky (Member of the State Duma of the Russian Federation, Chairman of the State Duma Sub-Committee for Regional Energy Policy) for effectively leading the preparation of the workshop and substantial contribution to the workshop agenda. Besides, Dmitry Timofeev (Deputy Director for Investment, Far Eastern Energy Management Company), Fedor Lukovtsev (Director, Institute of Northern Asia and the Integration Processes) provided many useful comments on the workshop agenda while Anastasia Vasilchenko (student, National Research University Higher School of Economics) also helped developing the agenda, engaging speakers and provided technical support.

The photos on the book cover showing various components of microgrid systems are used by courtesy of Brad Reeve, General Manager of Kotzebue Electric Association and Larry Adams, Senior Controls and Power Systems Engineer at Spirae, Inc.

The project team expects that the readers will benefit from this compilation. We tried to make it accessible for a non-technical reader. APEC is known as a flexible platform that brings together public and private sector interested in low-carbon, green energy supply. APEC Energy Working Group and APEC Expert Group on New and Renewable Energy Technologies address renewable and smart energy in a wider economic context, beyond just technology solutions. We do hope that the project triggers wider adoption of microgrid for efficient and clean energy supply to remote and isolated communities across APEC member economies.

Vitaly Kalmykov
Project Team Coordinator
November 2012

Self-Organisation: The Key to Optimised Microgrid Development

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Nearly half of all electricity generated in the world today comes from power plants that use steam turbines built in the days of rotary telephones and manual typewriters. These 1960's-era power stations burn coal or fuel-oil and operate at thermal efficiencies of around thirty-percent, meaning that they waste about seventy percent of the energy in the fuel they consume.

Did the electric power industry miss out on the technological revolution of the past 50-years? What can be done to bring the industry in-line with telecommunications, transportation, computing and countless other industries that have evolved so dramatically over the same time frame?

The key to promoting an evolution of the power grid begins with removing the barriers that are hindering it, followed by laying the organisational and regulatory foundation on which evolution can flourish. Power networks are complex systems, and as such they can be coaxed, using appropriate ownership models, incentives and policies, to self-organise into highly beneficial and adaptive states.

A phone built in 1968, compared to a typical phone in use today

A coal-fired power plant built in 1968, compared to a typical coal-fired power plant in use today

Figure 1. Evolution of communications vs. electric power industry

Power Grid Evolution

It is helpful to know what the evolution of the power grid might look like, and since a couple of regions around the globe have evolved grids, we have a window through which to see the future.

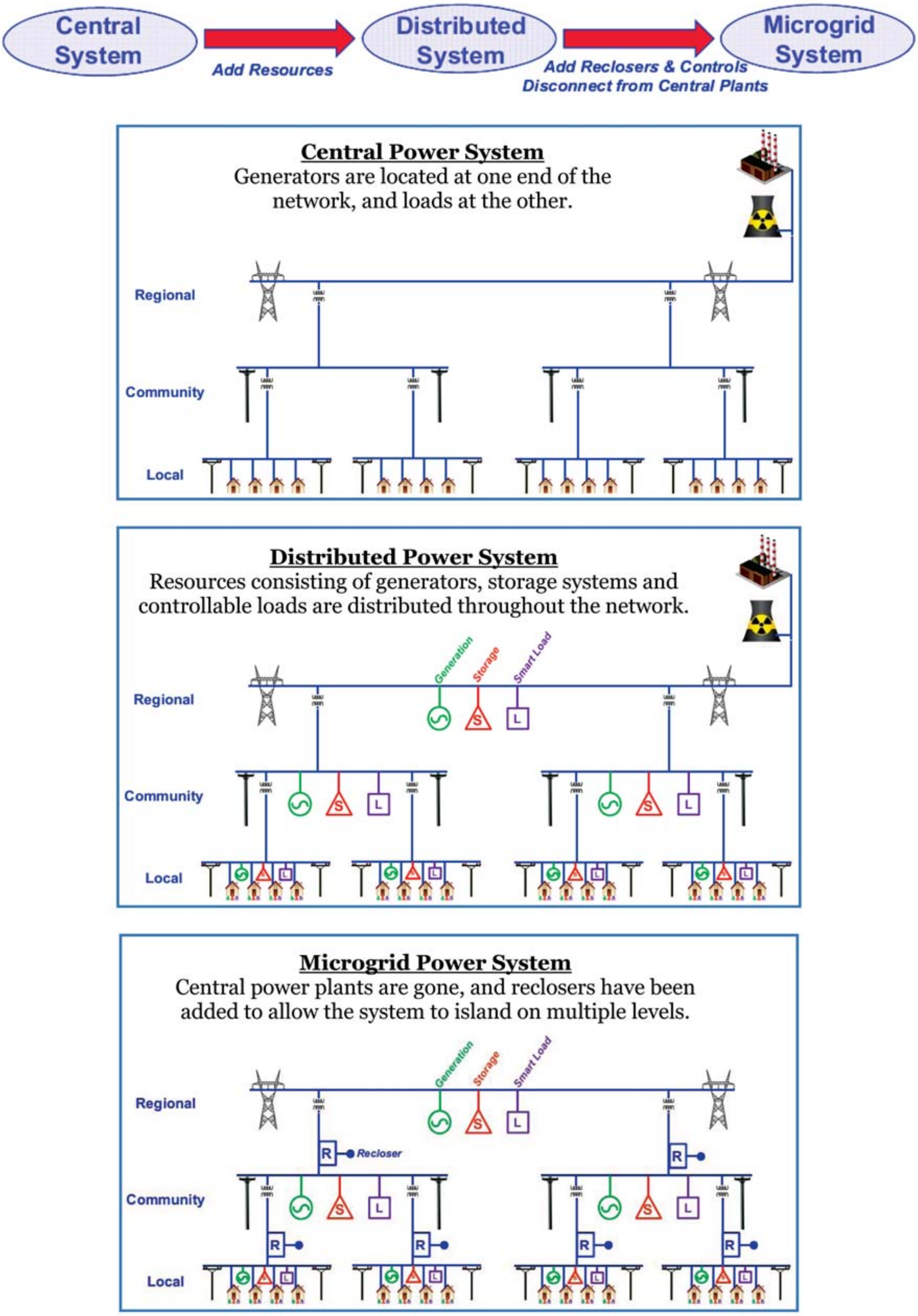


Figure 2. Decentralisation of the power system

The first thing that becomes clear when studying evolved grids is that they are decentralised. The typical way the decentralisation process begins is by connecting additional generators to the grid, including solar and wind but preferably including a wider array of technologies. The next step in decentralisation is connecting other types of resources to the grid, including controllable loads and energy storage systems, such as batteries. All three types of resources to be added — generation, storage and controllable loads — should be diverse in size and technology and should be dispersed widely throughout the network.

Decentralised power networks are considered an evolutionary step forward because they are more diverse, more complex and they bring significant advantages. Distributed power systems are less reliant on the large, central power stations that are so inefficient, and they reduce reliance on expensive, long-haul transmission lines. Diversifying the energy supply opens electricity markets to new players, and makes the grid less vulnerable to problems that arise with any single generation technology. And distributed grids are more easily expandable, because increased loads can often be served by simply adding new generators rather than upgrading power lines.

The next evolutionary step beyond distributed electric systems is microgrid systems. Microgrids are decentralised power networks that have been strategically populated with distributed resources to the point that they are able to operate without central power stations. They typically have the ability to interconnect with other power grids, but they disconnect automatically whenever it is beneficial to do so, such as when the other grid experiences an outage. When disconnected (or "islanded") from other grids, microgrids rely solely on their own resources — generators, storage systems and controllable loads — which work together to maintain stable conditions on the grid and a balance between electricity supply and demand.

Moving from distributed systems to microgrid systems is especially significant because it enables local self-reliance in electricity. Once a region is no longer reliant on an outside power supplier, an entirely different relationship forms between the region and its former electric supplier, putting the region in a much stronger negotiating position and making it far less vulnerable to outside influences.

Policy Drives Evolution

Most technological evolutions are driven by innovation and access to capital, but evolution in the electric power sector is predominantly driven by regulation. Privately owned electric utilities are powerful monopolies, especially where regulators allow a single, private company to own both the distribution system and the generation resources. Regulators attempt to reign in the power of such utilities by making rules controlling access to markets and assigning risks and rewards. Regulatory policy, depending on how it is crafted, can either promote or hinder the evolution of electric power systems.

Figure 3. Microgrids — a step in the evolution of power systems

Importance of Power Evolution

Evolved electric power systems, including microgrids, would yield a number important advantages over our current electric systems. First, microgrids lend themselves to newer, smaller generating units that are generally more efficient and less polluting. Given that the U.S. electric power sector releases more than 300 million pounds of toxic air pollution annually, and is responsible for one-third of all U.S. climate-changing emissions, this is a significant benefit.

The network architecture of microgrids gives them outstanding fault tolerance, assuming the connected resources have been selected and installed strategically. Unlike a central power system, in which the loss of a critical generator or transmission line causes a widespread outage, a well configured microgrid simply breaks itself apart into smaller units when a fault occurs, under a process called dynamic islanding. The degree to which connected resources have been selected and located strategically on the grid determines the number of islands that can form. For example, given a microgrid system with sufficient generation, storage, and load resources, individual homes could island from their neighborhood power system, the neighborhood system could island from the local power system, and the local system could island from the regional system.

Microgrids also offer significant economic advantages over central power systems. Because microgrids are decentralised, the money spent on electricity from microgrids gets dispersed more widely, creating a more vibrant and robust economy than if the money had been concentrated into a few hands. Further, microgrids lend themselves to local ownership and control, so more energy dollars stay in the local community, where they are re-spent to create additional, local economic value.

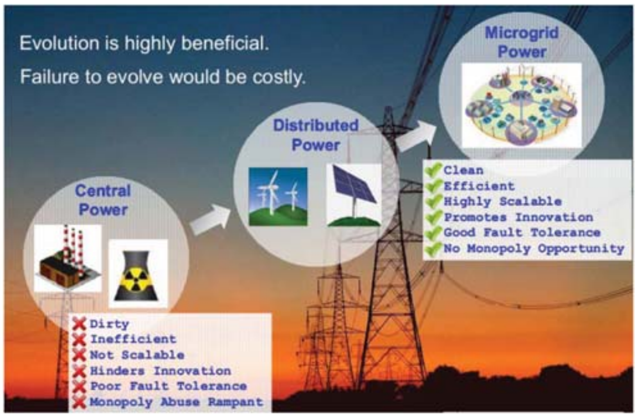
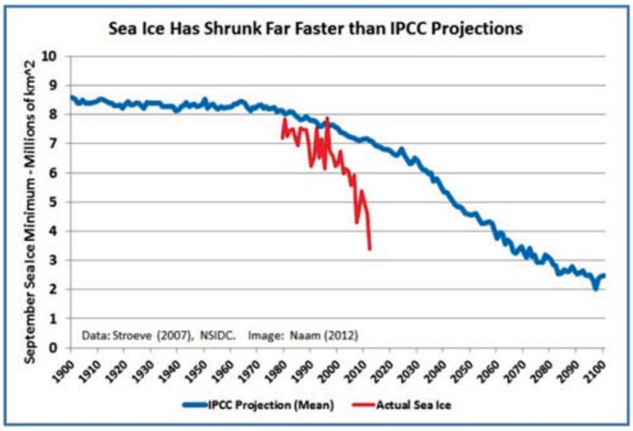


Figure 3. Benefits of the evolution of power systems

Microgrid systems are not natural monopolies like central power systems, and therefore, so long as ownership and market rules are crafted properly, microgrids should also be less prone to the type of corruption that has plagued central power systems.

Since microgrids are self-reliant energy systems, they are highly desirable for applications in developing regions not currently served with electric power. Implementation of microgrids to promote economic development in remote and insular regions is a focus of the Asia-Pacific Economic Cooperation (APEC). But microgrid development need not be limited to remote regions — they are just as applicable and advantageous, and potentially more easily implemented, in regions served by central-power systems. And, just as the emergence of grid-connected solar systems accelerated the development of photovoltaics technology, the promotion of grid-connected microgrids will greatly hasten the development of technologies and infrastructure to support microgrid development anywhere.



Data: Stroeve (2007), NSIDC. Image: Naam (2012)

Figure 4. Sea Ice: IPCC projections and the actual size

Finally, the best reason to modernise our power systems is that failure to do so could be catastrophic. No other single industry contributes more climate-changing emissions than electric power, and the hour is getting late for addressing carbon emissions. New data from the Arctic shows that the sea ice is melting far faster than predicted by climate models, and extrapolation of the data shows that the Arctic could be ice-free in summer by the year 2019. Ice reflects sunlight far better than ocean water, so as more ice melts, the planet absorbs more of the incident sunlight. It is estimated that the loss of summer ice in the Arctic will result in an additional climate forcing as large as the current anthropogenic forcing. Bluntly stated, the rate at which the planet is warming could double in the next seven years unless we move swiftly to cut our emissions.

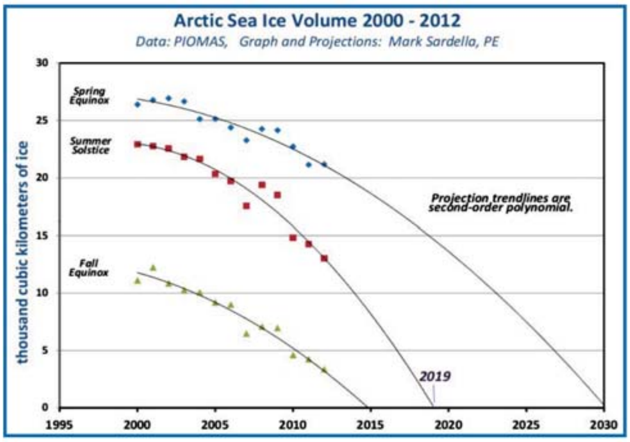


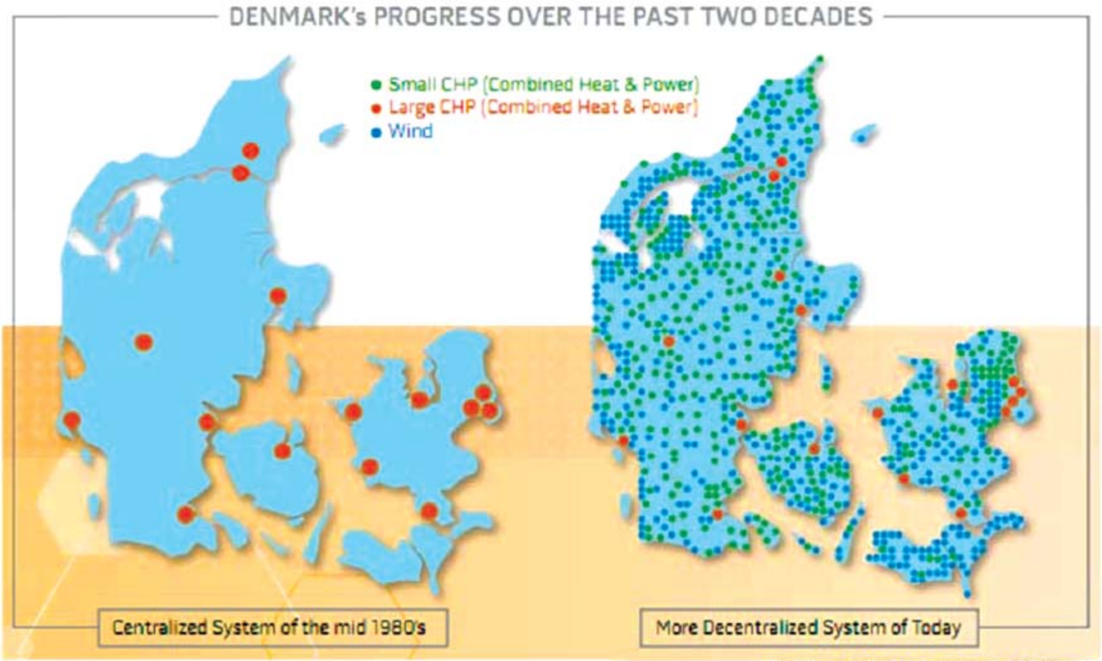
Figure 5. Arctic sea ice volume, 2000–2012

Regions with Evolved Energy Systems

Denmark is a model for decentralisation and self-reliance in energy. In 1973, more than 90 percent of Denmark's energy supply came from imported oil, yet as a result of sweeping reforms, they became energy self-reliant in 1997 and have stayed that way ever since. Today, nearly two-thirds of the homes in Denmark are heated with highly efficient district-heating systems, and about 20 percent of all energy consumed comes from renewable sources. The country is on target to reach their goal of a 30 percent renewable energy supply by 2020.

In the electric sector, Denmark not only converted it's privately owned transmission network to a public asset, they gave it a new, twofold purpose: ensure that it operates at peak efficiency, and provide all Danish citizens with a right-of-access to generate power in parallel with the grid. Those policies should be the model for the world, especially given their success.

A lesser known success story with energy decentralisation is the town of Gussing, Austria. Gussing was nearly bankrupt In 1988 when Peter Vadasz and two of his friends conducted a study to find out how fast money was leaving town to pay for imported energy and fuels. Four years later, Vadasz was elected mayor on a platform to create jobs by stopping the leakage of energy dollars. By 1996, he had completed the first phase of Gussing's biomass-fired district energy system, fueled by wood waste from a local forestry cooperative. Next, they built the world's most advanced biomass gasifier, and fed the gas to a cogeneration system to generate the town's electricity. Over the next ten years, energy localisation was credited with creating more than a thousand jobs, as businesses moved to Gussing to take advantage of the stable, affordable energy costs. The tiny town has cut its carbon footprint by 90 percent, become a major center for renewable energy research, and they now host 30,000 eco-tourists per year.



Source: U.S. Department of Energy

Figure 6. Progress in the decentralisation of the electricity sector in Denmark

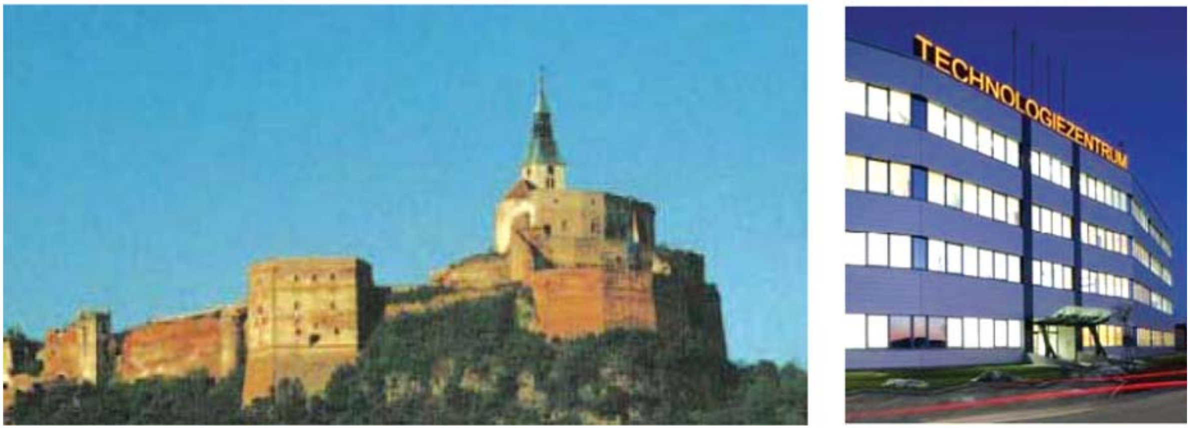


Figure 7. Gussing, Austria

Policies for Evolving

Based on policies used in regions that have done the best job at decentralising their energy systems, the following policies are recommended for supporting the evolution of power grids:

- **Operate the network of wires “for benefit” rather than “for profit”.**

Power lines are highways on which electricity travels, and it makes far more sense to travel on publicly owned highways. The network of wires should be treated as essential infrastructure, much like bridges, roads and sewer lines. Don’t expect a financial return on the power lines — the benefits come from having a good system in place, not from operating it at a profit.

- **Reward resource providers according to the value they create.**

The most common way to attract independent generators to connect their systems to the power grid is with multi-tier feed-in tariffs (FIT’s). Feed-in tariffs are guaranteed-price, long-term contracts for delivery of kilowatt-hours. They are the single most successful renewable energy policy instrument in use today. But even at that, most FIT’s don’t do all they could to foster value-creation on the power network. Tariff rates should be carefully adjusted to incentivise the resources the network needs most, and to express the values held by the region being served. Clean technologies, or ones that use plentiful, local resources might receive greater rewards, for example. If the system needs firm capacity at a certain time or at a particular location on the network, the FIT should be crafted to attract those resources to those locations. And the reward system need not be limited to generation — capacity and ancillary service providers should also be rewarded according to the locational or time-based value created by the services they provide.

- **Treat users as valued system resources.**

In the same way that resource-providers are rewarded according to the value they create, users should be charged according to the value of what they consume. Again, the opportunity to express the values held by residents of the region is significant. The rate structure can be highly progressive, such that each user receives a basic amount of energy at little or no cost but pays an increasing price-per-unit as consumption rises. And the use of real-time pricing, which alters the price of energy based on the network load, provides value by enticing users to shift loads to times when electricity is less expensive, thereby reducing the peak load on the system.

Policies That Hinder Evolution

Based on policies in use in the United States that have prevented evolution in the electric power sector, the following must be avoided:

- **Allow combined generation/ distribution entities that are private and for-profit.**

When the same, private for-profit business is allowed to own both wires and generation, the resulting monopoly has proven too powerful, and regulators have been unable to prevent it from wielding its monopoly power to the detriment of the consumers. All transmission and distribution wires must be publicly owned and operated on a "for-benefit" basis, and the right of all users to interconnect resources to the network must be guaranteed by law.

- **Allow private, for-profit market participants to control access to the market.**

Under no condition can access to electricity markets be controlled by a private market participant. This seemingly obvious rule has not been followed in the United States, where for-profit utility companies owning both wires and generation have provisions in law allowing them to disconnect any resource at any time, for any reason, with no recourse by the owner of the resource. This has not entirely stopped installations of distributed resources, but it has limited them to those allowed by private utilities, and utilities retain the right to disconnect any or all connected resources at any time, for any reason.

- **Periodically withdraw public funding assistance for a certain technology.**

If public assistance is provided to accelerate a particular technology (and it is questionable whether this is a good idea, since feed-in tariffs may be more strategic), the support must be committed for a known duration, and that duration must be sufficient to carry projects from conception to commercialisation.

- **Provide guaranteed returns on capital investments.**

Under a policy of guaranteed investment returns, utilities maximised their rewards by building expensive systems, rather than efficient systems. Had returns been based on high fuel-efficiency or low emissions, we would have very different power systems today. Incentives must reward exactly what you want to see.

- **Allow private utilities to negotiate special rates to retain customers.**

Back in the 1970's, businesses in the United States that needed heat to carry out a manufacturing process discovered that they could install on-site cogeneration systems, which generate both power and heat, to get their energy at a lower cost than the utility could provide. To stop them from doing it, utilities illegally offered monetary incentives to these customers in exchange for agreements to forego installation of on-site generation. Lawsuits followed, until utilities successfully convinced lawmakers to intervene. The laws that followed, called "load-retention rates," gave utilities the right to negotiate special rates, in secret, as needed to retain their best customers. The rationale for the laws was that all customers benefit when utilities don't lose their best customers. These load-retention laws, still in effect in some parts of the United States, dealt a tremendous blow to the decentralisation of electric power.

- **Decouple utility revenues from their sales volume.**

After years of building and operating electric power systems with incredibly low production-side efficiency, electric utilities in the United States were put in charge of consumption-side efficiency. Arguing that the consumer-efficiency measures they were advocating were reducing their revenues, utilities successfully lobbied for a policy known as "revenue decoupling." Revenue decoupling ensures that utility revenues remain unchanged as their sales decline. There are many flaws in the logic of arguments supporting revenue decoupling laws, but the main problem with them is that by guaranteeing the revenue streams of incumbent energy providers, the process by which businesses get pushed out of markets as they become obsolete no longer functions. If we had guaranteed the revenues of typewriter-makers, for instance, we would still be paying them today, despite having no use for their products.

Utilising Self-Organisation

Self-organisation is the process by which simple rules give rise to order in complex systems. Most systems exhibit some degree of self-organising behavior, but depending on the rules governing the system, higher levels of order can emerge. One example is complex adaptive behavior, which enables the elements of a system to respond collectively to changes in circumstances. All successful ecosystems are complex adaptive systems. The next higher level of order is swarm intelligence, enabling elements of a system to collectively solve problems in ways that individual elements of the system cannot. Honey bees select their new hive location using swarm intelligence.

Can complex-systems theory be applied to the development of electric power systems, as we try to usher them toward more complex, adaptive and intelligent states?

There is reason to believe it can, especially to help solve the problem of optimally populating networks with distributed resources. The electric power network itself is a complex system, but the system we want to optimise includes not only the grid and the resources connected to it — it also includes the businesses and individuals involved in developing new resources for the network.

Experience shows that an important ingredient for rapid technological evolution is providing a platform on which to evolve. The network of wires, so long as access is guaranteed, is that platform. It is also known from both theory and experiment that the rules governing interactions between elements of a system determine the degree of order that will arise. The policies effecting resource developers, and the regulations governing markets and grid operations, are those rules.

The difficulty lies in knowing how to craft rules such that the system becomes populated optimally and ends up with the ordered, intelligent characteristics we are seeking. The power network is complex enough, and the rulemaking options vast enough, that it is surely easier to find an optimal result experimentally than analytically — a characteristic known as being "algorithmically incompressible."

Fortunately, there are examples of good policymaking leading to evolution. Countries with more evolved power grids have better rules for grid access and, consequently, more entities developing grid resources. Ones that pay a premium for electricity generated by a particular technology excel in development of that technology. But these examples evidence success in reaching goals that are somewhat limited compared to the task at hand. To reach the goal of adding distributed resources in sufficient number and diversity to enable a self-reliant power system to emerge requires a more carefully crafted set of policies.

If policies are to induce power systems to evolve to the point of enabling local self-reliance, as microgrids ultimately do, the policies may need to embody the values held by self-reliant societies. Each country seeking energy self-reliance must identify those values on its own, but examples common to all of them may include achieving the highest possible efficiency, and providing opportunities for all interested parties to participate in the development of a wide range of locally available, renewable and clean resources. Cooperation among participants may also be a characteristic common to self-reliant societies.

Summary and Conclusions

Microgrids represent an evolved state of electric power systems, and so the key to advancing microgrids is to foster the evolution of electric power systems. Because microgrids are self-reliant power systems, they are attractive for remote regions not yet served by electricity, but microgrid development may progress more quickly with a focus that begins with upgrading existing, centralised power systems.

The evolution of power systems begins with populating existing grids with high levels of distributed resources. When this is done strategically, the resulting system will take on beneficial characteristics, such as being diverse, clean, reliable and fault tolerant, and yielding local economic benefits and opportunities. Fully optimised, power systems can be operated as islands, providing the most desirable characteristic of all — local self-reliance in electricity.

Complex systems theory suggests that achieving an optimal result from decentralisation requires a platform on which the grid can evolve, and a well crafted set of policies and practices. It furthermore lends insight into the direct role that policies and practices play in the degree of order obtained in the result, including how strongly the values embodied in the rules may be expressed in the power system created under those rules. Determining what policies will be needed to help power systems evolve to a state so ordered that they provide local self-reliance begins with identification of the values of self-reliant societies, followed by ensuring that those values are expressed throughout the policies.

Because values are so strongly expressed in electric power-systems, energy policymaking carries enormous responsibility. Energy policy provides one of very few opportunities to make an enormous difference in the quality of people's lives, the health of their environment, and the vibrancy of their economy. Enabling energy self-reliance, including by advancing the evolution of central power systems to distributed power systems and then to microgrids, is a tremendous way to honor that responsibility.

Why Smart Micro-grids?
In Quest of Humanistic, Developmental, Regionalist Approaches

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Introduction

This brief report discusses the establishment of, the usage of, and also the future of microgrid off the grids from a social and political scientist's perspective.

Microgrid system can be defined as a network that links multiple distributed power generation sources into a small network serving some or all of the energy needs of participating users. Microgrid can provide various benefits, including reduced energy costs, increased overall energy efficiency, improved environmental performance and local electric system reliability. The growth of distributed generation combined with emerging technologies, particularly energy storage and power electronic interfaces and controls, are making the concept of a microgrid a technological reality. Benefits and potential of microgrid system are highly realistic and fair.

While it certainly is true that, the future of this project is heavily dependent on the technology development, it does not solely depend on technology itself. Rather, one may put more weight on the social and humanistic discussions on the topic at stake. Most of the recent researches discuss microgrid from just technological and business perspectives, such as generation, storage, distribution and further technical development etc. Meanwhile, this paper will elaborate on the humanistic and developmental aspects of microgrids to enhance the technological and business side of microgrids.

A Humanistic Approach to Microgrids

Energy problems define the 21st century and it will for a long time. Our predecessors' unbearable reliance on fossil fuels after the industrial revolution certainly built the foundation for modern developments, but the consequences of that have not been so favorable to us today. With global warming so apparent in our daily lives, the future looks gloomier than ever. On one hand, this problem has led each nation to focus more on acquiring energy resources, and on the other hand, they're betting the fate of their nations on developing a sustainable energy system that can be truly eco-friendly.

In dissecting the ways in which the energy issues are discussed recently, one may find interesting that experts are so used to treat energy issues as part of the greater economic and security issues. This sometimes leads them to put their economist or security supremacist masks on. One would therefore hear the terms "supply and demand" and "international tensions" more so often than the actual human-related energy issue itself.

Ultimately, corporations put priority in energy development for profit reasons and pay less attention to human beings. For example, a common agenda in talks about the Russian Far East and the East Siberian development projects is energy-related. However, the people in these regions are worried that these development projects only fill the pockets of the central or local governments and the corporations without raising the living standards for the local people. Such kinds of "exploitive resource developments" are only natural to bear the burden of big worries of local people.

Energy development and usage should not be approached solely from the economic and security aspects, but from the human-centered aspect. Many researches shows that microgrids, as an alternative, can serve that purpose very well. Unfortunately, energy market regulations and policies lag behind the progress of microgrid technology, creating uncertainty and inhibiting investment in microgrids and the benefits they might provide. Moreover, in the middle of these discussions, the importance of human factor is not seriously taken into consideration most of the times.

There are two points about the importance of the human factor. First is the need for proportional representation of consumers in establishing the microgrid systems. We ought to ask questions such as “why, where and how people should be involved in microgrid system” first. The answer to this question is clearer than ever: people should be involved from the early stages of designs to overall development plans of the region or area. Microgrid development especially needs to consider the local conditions and the local inhabitants.

In the 1960s and 1970s, many countries around the world spent a lot of time and energy in rural development. In the case of the Republic of Korea, the “New Village Movement” and other forms of rural development fostered the growth of farms and fisheries and were very successful. But not all countries shared the same outcomes as the Republic of Korea, and important lessons were learnt from these experiences. Poor funding for these great projects from the Western countries contributed to such negative turnouts. A more important lesson is that one of the main reasons why a lot of developmental projects had negative outcomes had to do with the failure to incorporate local participation in the process, and also the fact that these projects neglected a realistic needs of the rural areas.

The fact that the microgrid system has been eyeing on small units of local community is very encouraging. Besides, the fact that the APEC Energy Group developed a project with a focus on microgrids for “remote and isolated local areas” is very exciting. Nevertheless, local contribution to the establishment of microgrids is a must. It will be hard for any locale to develop if there is no local contribution and participation from the beginning.

The second point is the absolute need for public education on what microgrids are. This point has been made by many past experiences of “smart and microgrid” tests from all around the world, including the US, the EU, and even Kenya.

It is especially important to help the local communities to come to a sufficient understanding of what microgrids are. This may seem so redundant and simple for the experts, but it may not be the case for the locals. This task may be hard because some locals might not bother learning about the benefits of microgrids. Winning the minds of the locals with enough time and effort in persuading them, providing enough information and advertisement will be the biggest asset of the project developers without a doubt.

In addition, in creating a regulatory regime for microgrids, people’s participation is also necessary. Unique local conditions should be considered as they may be different by regions. For instance, there are enough studies done on the role of local awareness and support in determining the cost and sustaining the microgrid system. Concerning the cost sharing, subsidies, etc., people should be informed of all possible burdens and benefits from early on.

As far as a local community is concerned, it is also important to establish an education system to pull labor sources from the locals themselves not only for sustainability reasons but also for the local welfare. Local development plan and project should accurately reflect the unique features of the local condition and the needs of the local people. A system that engages local people will leave truly sustainable infrastructural legacies in the regions.

Microgrids in the Context of Local Development Planning

First, there must be an "extensive and comprehensive development plan" that is networking many factors through microgrids as links. Making the lives of people better does not just equate to enough and efficient energy. Rather, the focus is on what they will do with the provided energy.

It is important that the rural conditions improve to meet the needs of its inhabitants and transform into a place where people can enjoy living. Achieving such goal requires not only microgrids, but also other infrastructures such as roads, bridges, schools, health and other facilities, etc. Struggling to find where and how the energy will be used is an important step that should not be ignored in the future endeavors.

For example, recent research shows that the access to electricity, in conjunction with complementary infrastructure such as markets, roads, and communications, can contribute to the increased productivity in two key economic domains of rural livelihoods: small and micro-enterprises (SMEs) and agriculture.

Hence, the way energy will be used will also determine the success or failure of the microgrid project. This, in turn, stresses a basic approach that puts priority on local characteristics. Microgrid projects must be open to all possibilities, especially to reflect the unique characteristics of the local region. The technology development should also follow the path of prioritising local characteristics instead of being solely driven by a set of standard project assumptions. Moving forward with discussions as to how this can be done may be the first step.

Second, there needs to be a gradual but progressive development plans about microgrid establishments.

The 21st century development is far different from the development of the industrial ages, which tended to focus primarily on the economy of scale. A primary property of microgrid — “small but efficient” — helps it to be constructed on a philosophical basis, apart from an economy-centered basis of the industrialisation period. As mentioned in the beginning, global warming and the growing worries over the environment makes us think like we did never before and develop a greener development model of post-industrial society, other than those before.

At the Durban Climate Change Conference which took place in South Africa in 2011, many nations agreed to start work on a new climate deal that would have legal force and, crucially, require both developed and developing countries to cut their carbon emissions. The term now need to be agreed by 2015 and come into effect from 2020. This shows an international awareness of the need for change from an industrial-civilisation that focuses on fossil fuels to a greener-energy-supported-civilisation.

In this regard, "small but efficient" is the key. The development of internet communication technology and spread of networking principles in political, economic and social spheres make microgrid systems more smart and realistic. These may indeed emerge as a new post-industrial platform of development that can replace the old and wholly fossil-resource dependent system. The core issue at stake is how microgrids will develop a community with an eco-friendly and sustainable approach. We need to understand and plan microgrid projects as a basis of new active units of the future post-industrial way of life.

Microgrids for the Greater Asia-Pacific Region

Modern industrial-society development model struck its match in Europe but lit really in the US. In Asia-Pacific, where modern and postmodern development is active, the meaning of micro-grids needs to be discovered not only in a paradigm of modern development, but in a realm of futurological vision.

Ways in which micro-grids link Asia-Pacific is limitless: developments in low-inhabitant areas such as the Russian Far East and Siberia, energy equality in remote islands such as in Malaysia, Indonesia, the Philippines etc., and infrastructural developments in less-developed countries like the Democratic People’s Republic of Korea, Myanmar. And this kind of regional development efforts will form the foundation of macro-, meso-, sub-, micro-region formation.

Of course, these problems confront each individual nation. However, regional cooperation in solving this kind of problems is far more efficient and especially it will greatly contribute to regional stability and co-prosperity. This said, discussions of smart microgrids can be more detailed and be applied to seek the potential of becoming a key solution to complicated regional problems.

Concluding Remark

Deployment of microgrid systems should no longer remain a topic of discussions on technology or economic profit. With the importance of those concerns fully respected, microgrids must adopt a more humanistic and developmental approach in its establishment and be discussed in a comprehensive environment where its potential can be truly discovered in a futurological way in the 21st century.

Local Energy Development in the East of Russia: Preconditions and Priorities

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Preconditions for Development

In the East of Russia, the border of centralised electricity supply virtually coincides with the border of the Extreme North regions. In Eastern Siberia and the Far East there are large extensive electric power systems that include 90 power plants with the total capacity 45.8 thousand MW, generating about 180 billion kWh of electricity annually (Table 1).

In the north-eastern regions centralised electricity supply covers only a minor part of the territory. In total, 10 local power subsystems as part of 6 isolated power systems are in operation in these regions. They are Norilsk subsystem in Krasnoyarsk Territory, Western and Central subsystems in Sakha Republic (Yakutia), Central subsystem in Magadan Region, Chaun-Bilibino, Anadyr and Egvekinot subsystems in Chukot Autonomous Area, Central subsystem in Kamchatka Territory, Central and Okhta subsystems in Sakhalin Region (Figure 1). The South-Yakut power subsystem is connected to the interconnected power system of the East by the 220 kV overhead transmission line. These power subsystems include 40 power plants with the total capacity 7.4 thousand MW, generating 20-25 billion kWh of electricity annually.

The rest of the territory is supplied with electricity from autonomous power plants. Almost 25 per cent of autonomous and standby power sources of low capacity (up to 30 MW) in Russia are located here. Their number is about 4 thousand, the total capacity is 1.7 thousand MW. Despite of their rather great number the share of low-capacity power sources in the total capacity of power plants in Russia's East slightly exceeds 3 per cent.

Table 1. Characteristic of electric power industry in the eastern regions of Russia (as of 2010)

Power systems and sources	Number of power plants	Capacity of power plants, thousand MW	Electricity production, billion kWh
Interconnected power systems of East and Siberia	90	45.8	180
Local power subsystems	40	7.4	24
including RES	4	0.1	0.5
Autonomous and standby power sources	3,960	1.7	2.1
including RES	12	0.02	0.01
Total	4,090	54.9	206

Compiled on the basis of the Federal State Statistics Service forms "Power balance" and "Information about thermal power plant operation" for 2010.

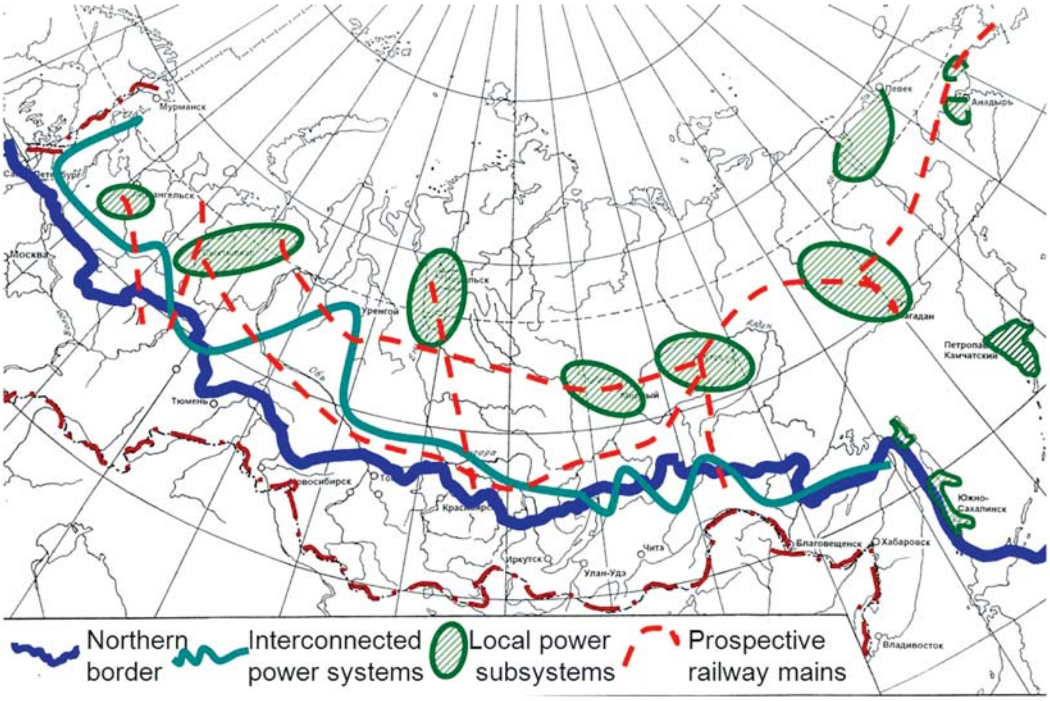

Figure 1. Zoning of Russia's territory by the degree of electricity supply centralisation

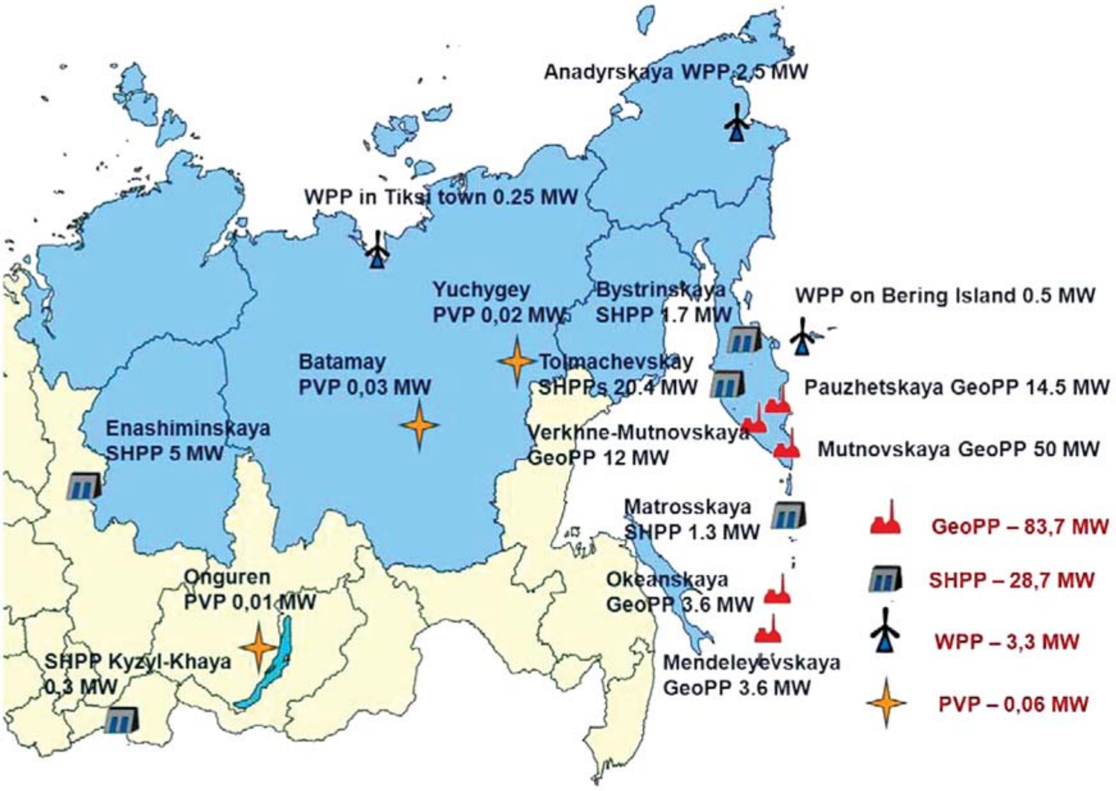

Figure 2. Allocation of renewable energy sources in the eastern regions

The local energy sector in the East is represented mainly by diesel and gas-turbine power plants on delivered fuel. Dispersion over the territory, weak development of transport infrastructure, complex fuel supply chains all considerably increase fuel cost. As a result they lead to high indices of production cost of electricity (up to US$ 0.80/kWh) and heat (up to US$ 1.70/Gcal). Therefore, different mechanisms of cross subsidisation are used to decrease the price burden on consumers. The annual budget subventions to level energy tariffs are estimated at US$ 1.7 billion.

Renewable energy sources (RES) are not virtually used in the eastern regions. Their total capacity makes up only 116 MW, of which 84 MW is the capacity of five geothermal power plants located in Kamchatka and the Kuril Islands. Only five small hydro power plants, three wind power plants and three photovoltaic power plants are in operation there (Figure 2).

Priorities of Development

A rational scale of local energy development in the East of Russia was determined based on the studies that estimated the economic efficiency of connection to centralised electricity supply, construction of cogeneration plants with local fuels and low-capacity nuclear power plants as well as construction of power plants with renewable energy resources. The studies used the methodological approach and simulation models[1] the authors had at their disposal.

Validity of centralised electricity supply is under the influence of distance from electricity supply centers and consumer load, as well as electricity tariffs in the system. The studies performed made it possible to determine economically expedient territorial borders for centralised electricity supply based on the price terms in the eastern regions.

Depending on the connected load, the maximum remoteness of consumers that is expedient for connection amounts to 30-90 km in the power systems of the East and 25-75 km in the north-eastern power subsystems (Figure 3)[2].

Construction of mini-cogeneration plants on local fuels (coal and natural gas from local fields) allows the electricity production cost to be decreased almost twice as compared to diesel power plants. At the same time, the admissible payback period of such projects is possible only at the tariffs of US$ 0.30-0.40/kWh depending on the mini-cogeneration plant capacity (Figure 4). Hence, this option of electricity supply is rational only for consumers located close to the fields[3].

Conversion of power plants on diesel fuel to natural gas with involvement of cogeneration facilities is rational in the buffer zone of gas pipeline routes. The results of feasibility studies on natural gas usage at diesel power plants demonstrate sufficiently high efficiency of this option[4]. At the current level of diesel fuel price in the areas to be switched to gas, the gas price economically expedient for conversion should not exceed US$ 200-500/1000 m³ depending on the diesel power plant capacity (Figure 5).

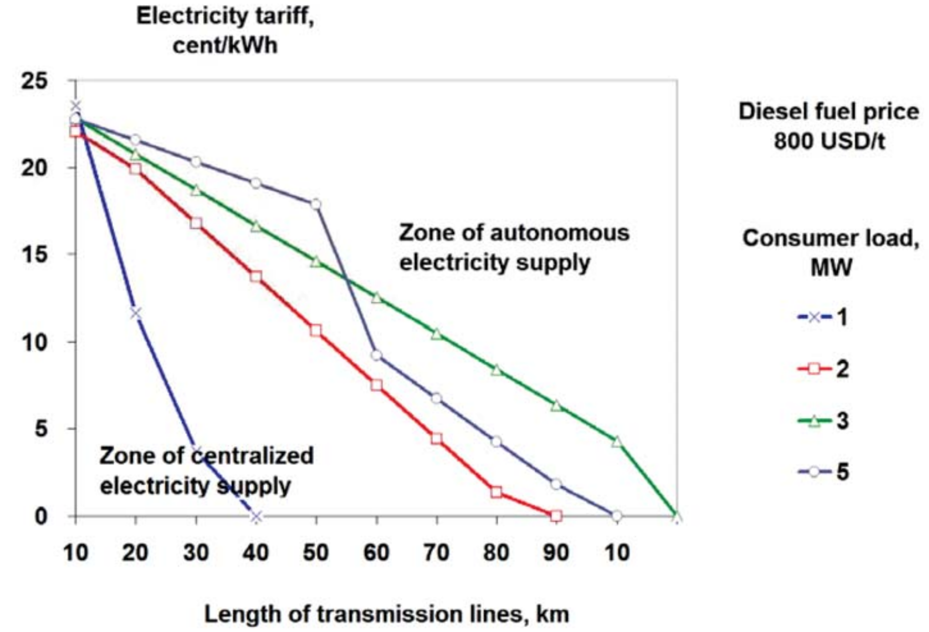

Figure 3. Zones of expedient use of centralised and autonomous electricity supply

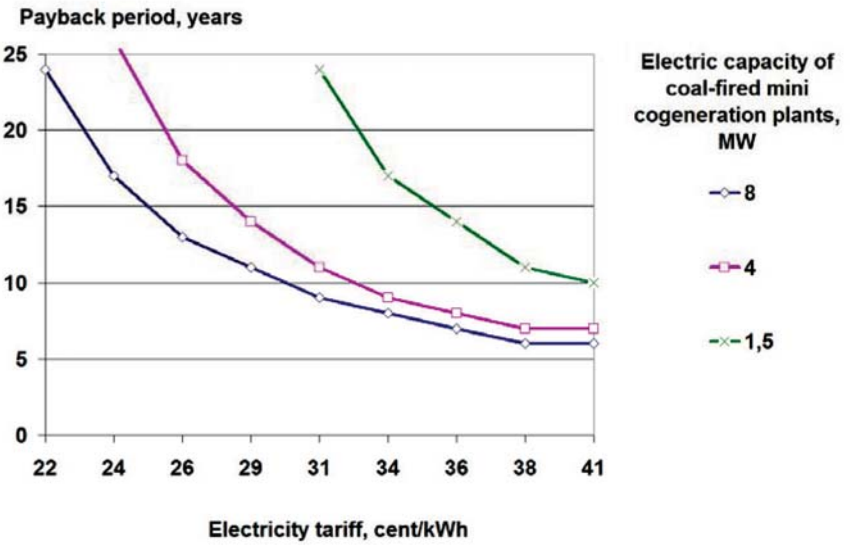

Figure 4. Payback period for projects of construction of mini-cogeneration plants on local coal versus electricity tariff

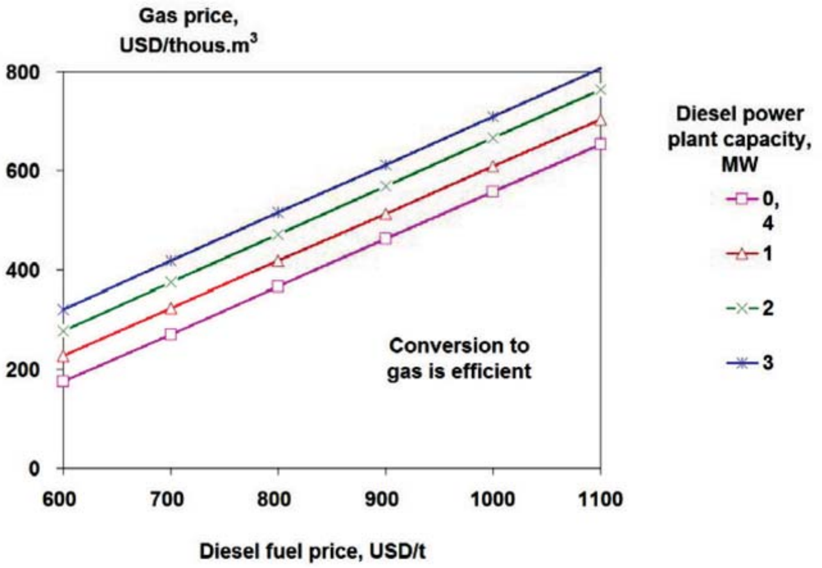

Figure 5. Conditions for effectiveness of diesel power plant conversion to natural gas

The studies that estimated the cost-efficiency of the construction of low-capacity nuclear power plants (LC NPP) made it possible to determine the conditions for their competitiveness as compared to the conventional scheme of diesel power plant + boiler plant. With the maximum fuel prices in the eastern regions (US$ 1,000 /t of diesel fuel and US$ 125 /t of coal), the capital investment in low-capacity nuclear power plants should not exceed US$ 9 thousand /kW (Figure 6).

It is rational to place low-capacity nuclear power plants in the hard-to-access settlements with a complex fuel delivery scheme and with a considerable expected increase in electric loads related to the development of mineral resources. There appear to be dozens of potential sites for the construction of LC NPP with 6-12 MW reactorswhile the number of sites for floating nuclear power plants with reactors KLT-40 is limited[5].

The top priority sites for the allocation of low-capacity nuclear power plants intended for power supply to the new industrial facilities in hard-to-access areas and electric capacities required to develop ore deposits are presented in Table 2.

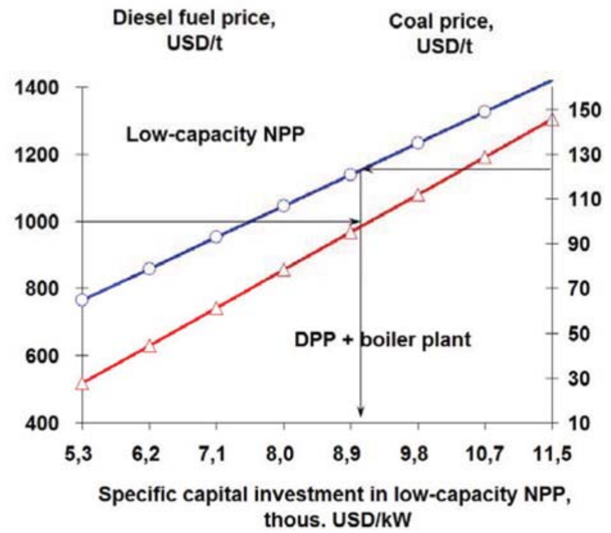

Figure 6. Cost-effectiveness zones for low-capacity nuclear power plants

In the last years, documents of varied significance have highlighted the plans to use renewable energy sources. The target of Russia’s Energy Strategy until 2030[6] is an increase in the share of the renewable energy sources in the total electricity production from 0.5 per cent to 4.5 per cent. The total capacity of the renewable energy sources to be commissioned is estimated at 25 thousand MW.

The General Scheme for the Allocation of Electric Power Facilities of Russia until 2030[7] sets the total capacity of the renewable energy sources to be commissioned at a lower value, up to 6-14 thousand MW. Under the basic scenario, the major increase is expected in the biomass capacities,and under the maximum scenario, nearly 50 per cent of all capacities to be commissioned are wind parks.

According to the Energy Forecasting Agency that has been considering various scenarios of the development of electric power industry for the period until 2030[8], the total capacity of the renewable energy sources to be commissioned until 2030 is even lower and estimated at 5 thousand MW of which one fifth is in the eastern Russian regions. This is explained first of all by the insufficient measures of state support to the renewable energy in the legislative acts of the Government of the Russian Federation.

The major barriers that hinder the development of renewable energy sources in Russia are:

Institutional:

- insufficient legislative basis in the sphere of RES;
- ineffective system of measures intended to meet environmental constraints;
- unwillingness of authorities to participate in funding of the investment projects;

Financial:

- absence of federal financing mechanisms;
- insufficient domestic and foreign investment capital;
- high cost of special equipment;
- lack of long-term loans on acceptable terms.

Informational:

- insufficient information about technologies and possibilities of their application;
- lack of reliable data on the indices of renewable energy resources;
- negative experience in RES operation.

Therefore, the authors’ forecast related to the penetration of renewable energy sources is even less optimistic. A rational amount of renewable energy capacity to be commissioned in the eastern regions until 2030 is estimated at 340-360 MW (Figure 7). Thus, the total capacity of renew-

Table 2. Primary sites for allocation of low-capacity nuclear power plants

Allocation	Consumer	Electric capacity, MW
Yuryung-Khaya settlement	Tomtor rare-earth metal (niobium) deposit	36
Tiksi settlement	Restoration of Northern sea route	12
Ust-Kuiga settlement	Kyuchus gold deposit	30
Peschanoe settlement	Copper ore deposit	30

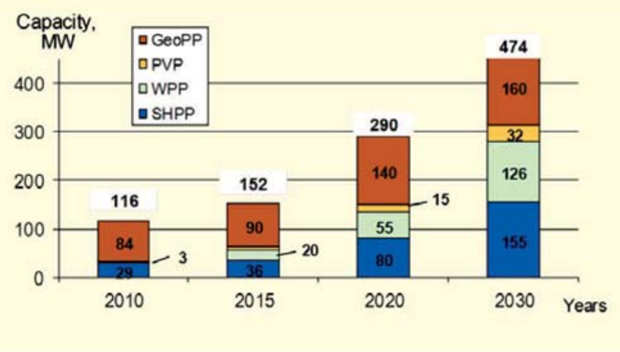

Figure 7. Rational commissioning of renewable energy sources in the eastern regions

able energy sources in these regions will reach 470 MW.

The key factors that affect the efficiency of RES allocation include the indices of the potential of renewable energy sources and distance between the settlements and fuel facilities. Therefore, the priority sites for the allocation of renewable energy sources are the zones characterised by the best potential and high fuel cost for consumers. By virtue of their capital intensity the projects for the construction of renewable energy facilities are not commercially attractive. Payback of the projects is provided by the reduction in fossil fuel consumption and decrease in budget subsidies. With the current level of RES cost, there is need for US$ 17-23 /kWh[9] of state support on average for the eastern regions to decrease the electricity tariff.

Conclusion

The research allowed to identify the sites for priority allocation of local energy facilities of different types which are presented in Figure 8.

The authors estimate the total capacities to be commissioned in the period until 2030 at 520-540 MW, including 70 MW of mini-cogeneration plants on local types of fuel, 108 MW of LC NPP, and 357 MW of renewable energy sources (Table 3)[10].

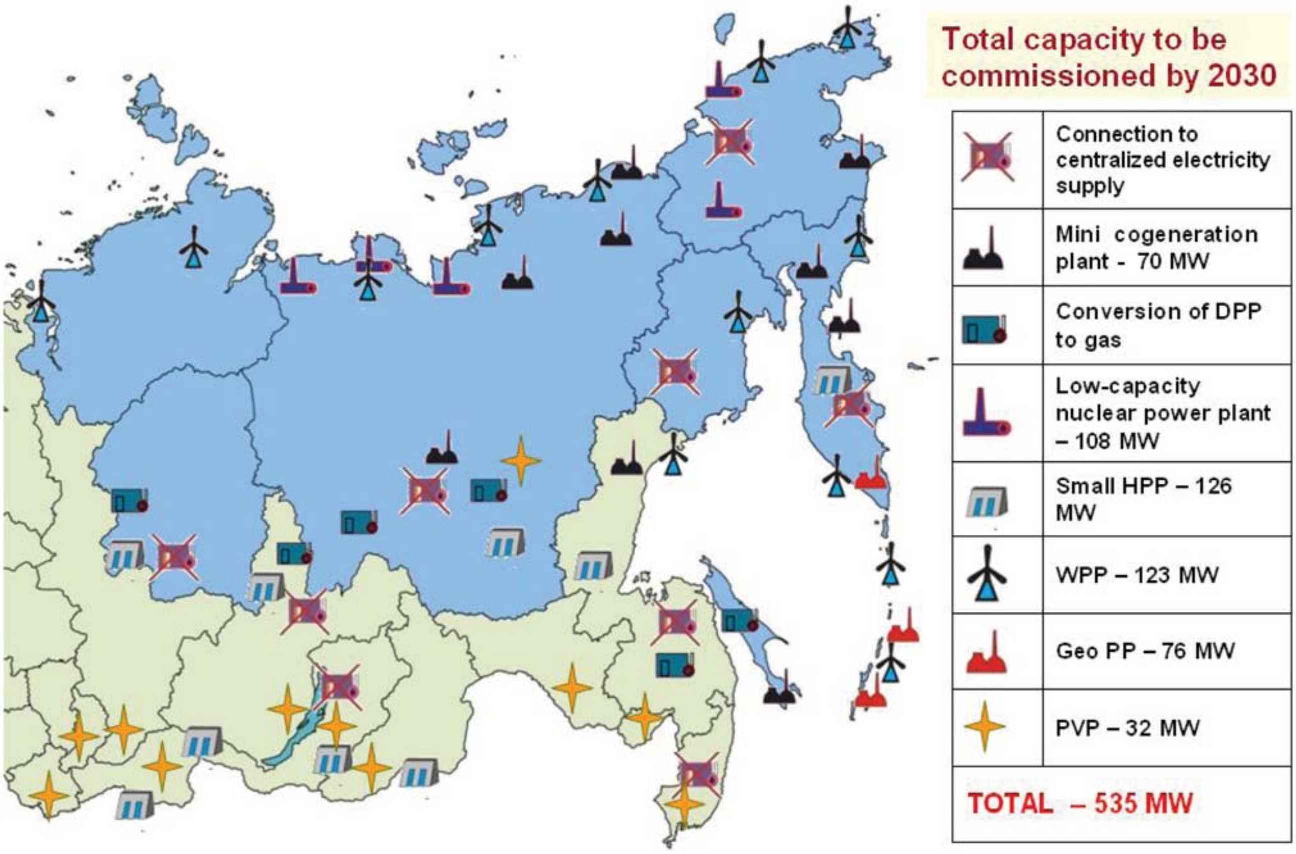

Figure 8. Sites for priority allocation of local energy facilities

Table 3. Rational commissioning of local energy facilities in the eastern regions of Russia until 2030

Type of energy source	Commissioning of capacities, MW
Mini cogeneration plant	70
Low-capacity nuclear power plant	108
Small hydro power plant	126
Wind power plant	123
Geo power plant	76
Photovoltaic plant	32
TOTAL	535

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Prospects of Local Power Development with the Maximised Use of Renewables in Russia's Far East

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Introduction

In 2001-2003, the School of Engineering of the Far Eastern Federal University (SE-FEFU) in Russia introduced the notion of LoES which stands for Local Power (Energy) Systems, before the concepts of Smart Grid and Microgrid became widely known and accepted. SE-FEFU also proposed using such terms as "energy island", "energy aerology". It adopted an end-user perspective and began developing a holistic approach to the power systems that would ensure high quality and reliability of energy supply to remote settlements, mining companies etc. This was an interdisciplinary approach: a variety of specialists were employed to address a wide scope of issues, including diesel gensets, WTGs, mini-hydros, solar etc., and in fact, to combine all sources in one system.

Developing and Implementing a Concept of Local Energy Systems

The basic Concept of Local Energy Systems for Remote Areas of Russia was subsequently developed in 2002-2008. The authors defined a key operational unit: LoES, or Local Energy System with Maximised Use of Non-Fossil Sources of Energy. The conceptual delimitation between renewables and non-renewables was therefore rejected as it was of no importance for the end user.

What does this abbreviation really mean? Strategically, SE-FEFU objective is to encourage the emergence of a "Local Energy of Russia" sub-industry that would co-exist and complement the "big" grid power. The rationale for creating it is the notorious irregularity of operation of the existing Russian power system. Range of applications for this new local energy sub-sector will

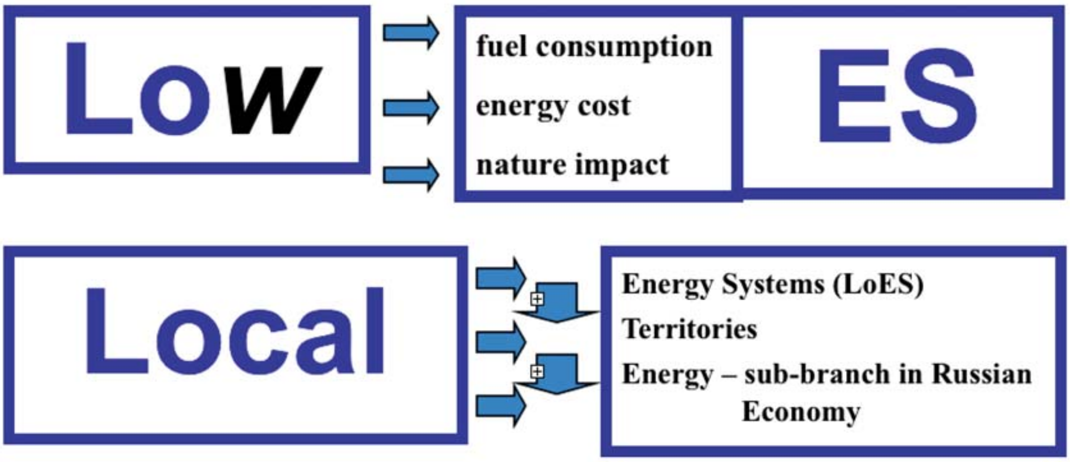

Figure 1. Local Energy Systems = LoES

include: power supply to the "energy islands" and the end points of weak grids that do require reconstruction and backup. In fact, this concept may apply to about two thirds of Russia's territory (especially in the North and the East), 20 million people, 40 thousand settlements, 10 per cent of Russia's generation today and up to 20 per cent (50,000 MW of installed capacity) in the future.

The Concept suggests developing an integrated full cycle of LoES-related services, from research to construction where SE-FEFU is responsible for research but implementation (production, procurement, installation) is handled by the Hydrotex Co. and other allied companies, to observe specialisation. About 30 scientific and practical publications have been released so far.

The Concept provided a guiding framework for a number of investigations and reports. In 2007, the Local Power team of the SE-FEFU produced a research report on "Renewables of the Sakhalin Region: Assessment and Potential Use for Energy Generation Purposes up to 2020". It was discovered that the technical wind potential exceeded current regional energy consumption by the factor of 1,400. The report identified tentative sites for wind-diesel and hydro-diesel LoES, grid wind farms and included regional wind maps and cadastral diagrams of rivers.

The feasibility study of a wind farm 36 MW project on the Russky Island in the Far East of Russia was the next important deliverable of the Local Power team at the SE-FEFU in 2009 and was used to assess the energy supply for the APEC 2012 Leaders' Week. The study was commissioned by the JSC RusHydro (Russia) and Mitsui & Co (Japan). The capital expenditure, infrastructure excluded, were estimated at ~ €2000/kW of installed capacity while the estimated energy costs, with a 20 years depreciation pattern of RUB 3.5/kWh. This project helped the team to acquire experience in construction and maintenance of three 60-meter high wind measurement masts, produced by NRG Systems (USA) and commissioned by Mitsui & Co. Despite of some additional expenses, SE-FEFU decided not to remove the equipment completely and has been keeping one of the masts in operation for education purposes and meteorological services.

The wind-diesel LoES Golovnino project arrived in 2010. The project site is on the Kunashire Island, one of the Kuril Island of the Sakhalin Region, Russia. It was commissioned within the framework of the Kuril Islands State Develop-

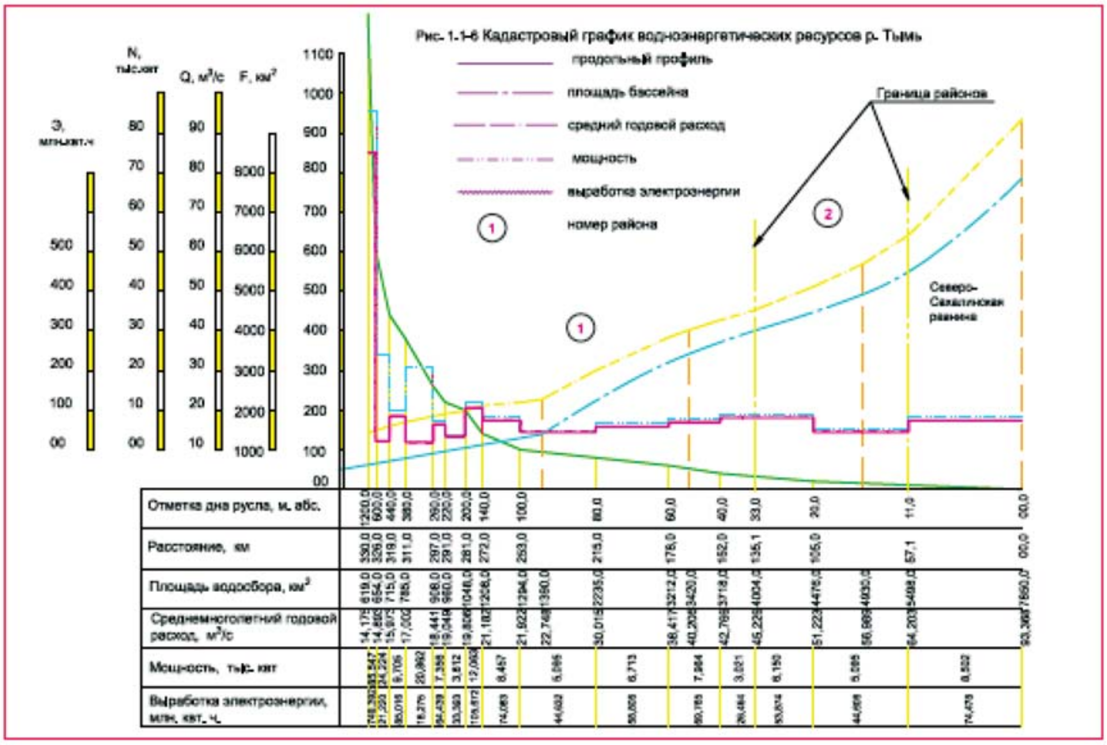

Figure 2. Cadastral Diagram of Thym river, Sakhalin

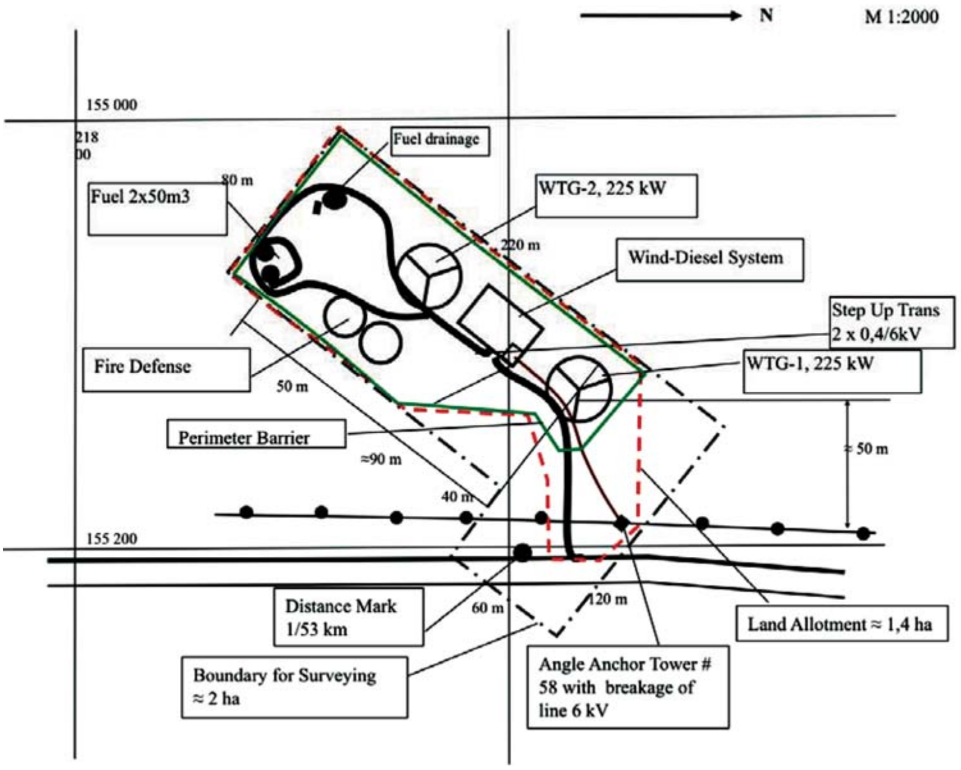

Figure 3. Golovnino Project. The sketch of General Layout

ment Programme and the basic wind-diesel technologies were provided by Danvest Energy A/S (Denmark). It is expected that the wind power penetration will reach 74 per cent annually.

Development of the wind-diesel LoES Maximovka project in Primorsky Territory is in progress. The regional energy company Primteploenergo commissioned this project with installed capacity (planned) at 640 kW, a hot genset reserve of 120 kW, remote control, average consumption at 60 kW.

A follow-up undertaking — the Local Power Development Programme for Primteploenergo Company — is also in progress. The scope of the

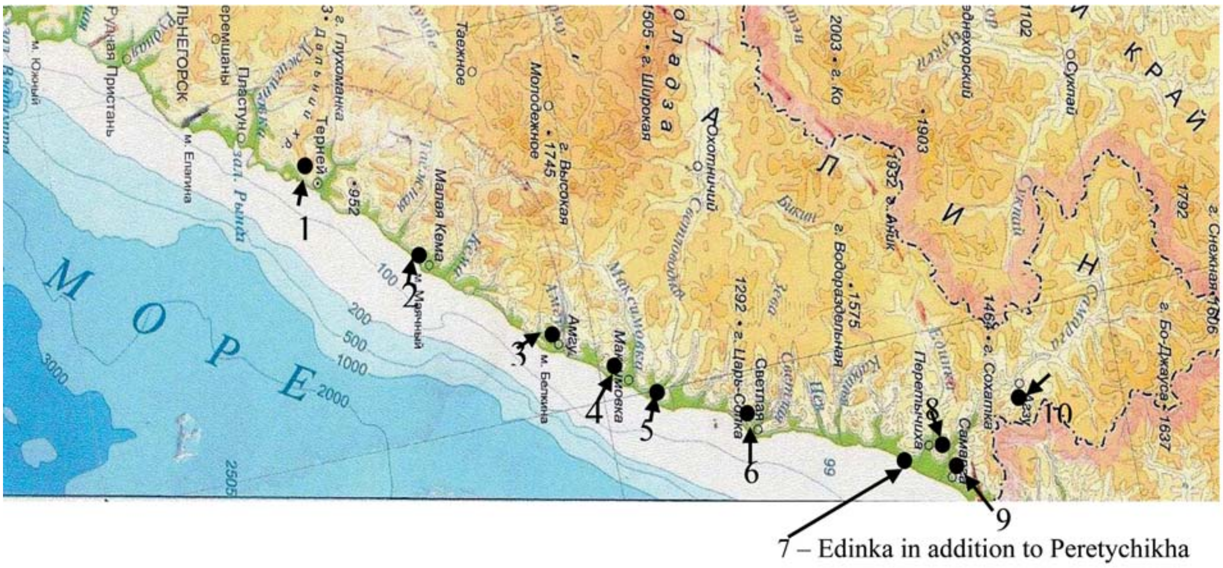

Figure 4. Arrangement map for wind-diesel and hydro-diesel LoES in Ternei municipal region, Sakhalin, Russia

Programme includes the development and installation of ten wind-diesel and hydro-diesel LoES in Ternei Municipal Region, Sakhalin Region, Russia. Installed power now totals 6.5 MW and is projected to reach 14.08 MW.

The technical specification of the Local Power Development Programme for the Sakhalin Region was developed in accordance with a request from the regional Ministry of Energy. The area includes 22 villages on the Sakhalin Island, Kuril Islands and the Programme relies heavily on mini-hydros and wind turbines.

Challenges and Lessons Learnt

The challenge is not in technical solutions that are widely available now but in the specific circumstances of the Russian power industry. For example, the cost of energy in Agzu settlement (North of the Primorsky Territory) is US$ 2.0 per 1 kWh (2012). The Local Power team at SE-FEFU applied its in-house LoES-Balance software to find out that a hybrid LoES (wind-hydro-diesel) may reduce the cost down to US$ 0.7 per 1 kWh (DCF depreciation for 20 years). Now, the expenditure on fuel supply contributes 50 per cent of the basic energy cost. However, the customers may not be willing to pay even US$ 0.7/kWh and the "new" energy cost may also need subsidising from the Government. (Agzu is an aboriginal settlement of Udege people). Furthermore, the capital expenditure is very high to build this new system from the owner perspective. It is not about simply reconstructing the old power station built in 1970s: the equipment has been fully depreciated, so the new required facilities include very expensive fuel supply and fire defense systems. These result in capital expenditure of more than US$ 3,500 per 1 kW of installed capacity. These long term investments may only be provided by the Federal Government.

Another underlying challenge is that a complex federal system of subsidies discourages the owner from reducing the cost of energy and replacing diesel power supply with renewables. As a result, there have been only a few pioneer companies in Russia that risked and tried exploring renewables for their internal, corporate use not for sales.

In Russia, the absence of a leading government agency which may be responsible for the development of local power is a particular issue. First, the former "Soviet" system prioritised huge energy projects that included very expensive HV grids with the length of thousands km. Second, the Ministry of Energy of the Russian Federation is not ready to work with the "energy fleas". Third, the Ministry of Energy focuses on fossil fuel energy. There are subsidies for diesel fuel for households, but no real subsidies for renewable energy.

Given that the Ministry of Regional Development of the Russian Federation is responsible for equalising the economic opportunities among different Russian regions, SE-FEFU proposed that this ministry be empowered to also address the regional energy issues and thus to complement or even compete with the Ministry of Energy. This proved irrelevant because the whole power industry and related issues fall under purview of the Ministry of Energy. Some countries go as far as creating new dedicated agencies, e.g. the Ministry of New and Renewable Energy in India. In case of Russia, another more feasible option is to develop clear federal regulations stipulating the payback of investments instead of appointing ministries. However, given that the life time of such projects is 20-25 years, investors may probably start up here right now.

The Way Forward

Opportunities exist to utilise the huge potential of renewables in the Far East of Russia in distributed and isolated power systems to provide electricity to the end points of weak grids and remote "energy islands": settlements, mines, oil & gas companies etc.

What is needed to further the development of Russia's Far East? To name a few pre-requisites, these include rising fertility in remote areas, new all-season roads, new secondary schools and kindergartens, upgraded municipal hospitals, lower environmental impacts and preserved nature. Advanced technology in the power industry may help addressing these challenges, for example, the use of derivation & floating type mini-hydros can save salmon spawning rivers. Besides, people in remote settlements have the right to live in conditions that do not differ from the urban ones. Eventually, it is unlikely that these multiple problems could be solved without a reliable and affordable local power.

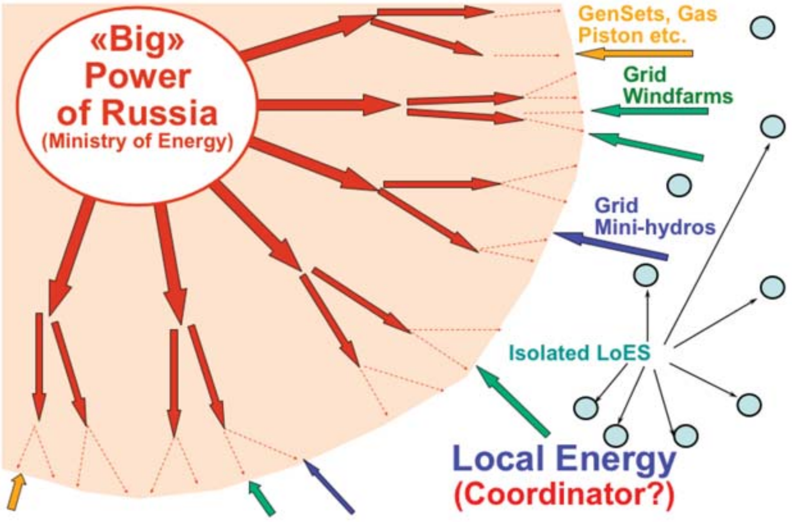

Figure 5. Local Energy branch structure

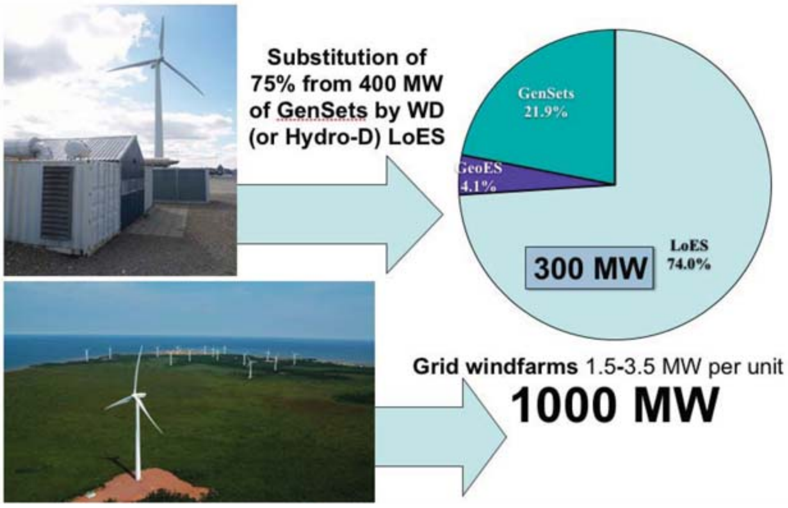

Figure 6. Prospects for LoES development in Far East up to 2030

There could be various opportunities worth exploring in collaboration with APEC member economies and APEC Energy Working Group in the field of local power:

(1) In the area of university courses and polytechnic education — developing a specialised Master or Graduate course on Local Power Systems in FEFU; joining efforts in polytechnic education (hydrology & HPS facilities, wind turbines, energy aerology, electrotechnics, automation, remote control, etc.). Such graduates will have developed a good understanding of a combination of various technical and economic disciplines, as the end user requires a complete and reliable power system not only a component, such as WTG. It may not be feasible to bring in so many different specialists.

(2) In the area of fundamental research — drafting regional and federal concepts and programmes for the development of Local Power. This will include developing a core approach, drafting federal regulations, identifying the basic technology choice.

(3) In the area of applied research — in new types of derivation and floating mini-hydros.

(4) Setting up a Local Power research and development centre and a federal test bed in FEFU to coordinate the process in its entirety, from scientific ground to "full turnkey".

(5) Implementing state-of-the-art technologies in real pilot LoES projects in Russia.

(6) Development and engineering of LoES.

(7) Facilitating foreign investments in the construction of LoES facilities in Russia's Far East to fulfill a projected capacity as indicated in Figure 6.

Wind and Hydro Potential at the Russian Pacific Coast for the Needs of Local Energy Development

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The resource of commercially available renewable energy in the Russian Federation is not less than 24 billion tons of oil equivalent. The share of electricity produced in Russia from renewable sources amounted to about 1 per cent in 2008, excluding hydro power stations above 25 MW, and more than 17 per cent with the latter. The share of thermal energy produced by renewable energy sources (RES) was about 3 per cent (according to the Ministry of Energy of the Russian Federation).

Until recently, for a number of reasons, primarily because of the huge reserves of traditional energy sources, development of renewable energy in Russia has been given relatively little attention. The situation began to change significantly in recent years. The need to secure a better environment, new opportunities to improve the quality of life, participation in international development of advanced technologies — these and other considerations have enhanced efforts to increase the number of renewable energy sources and move to a low carbon economy.

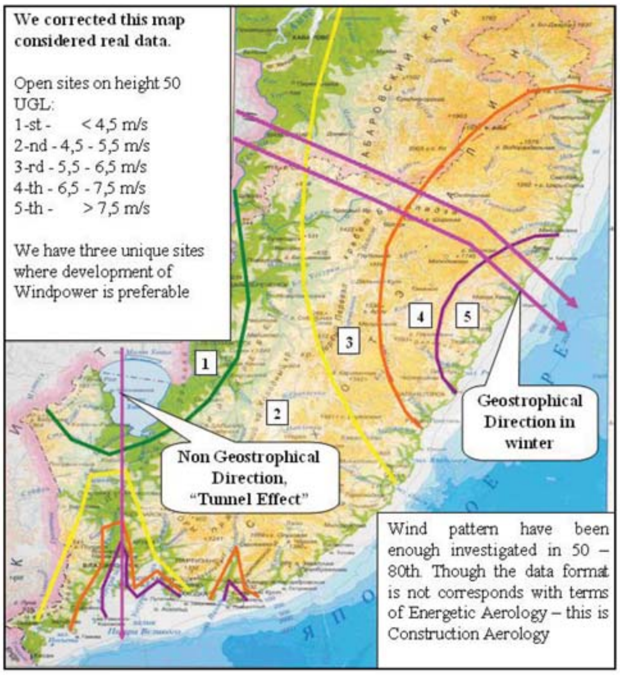


Figure 1. Measurement of wind potential in Primorsky Territory, Russia's Far East

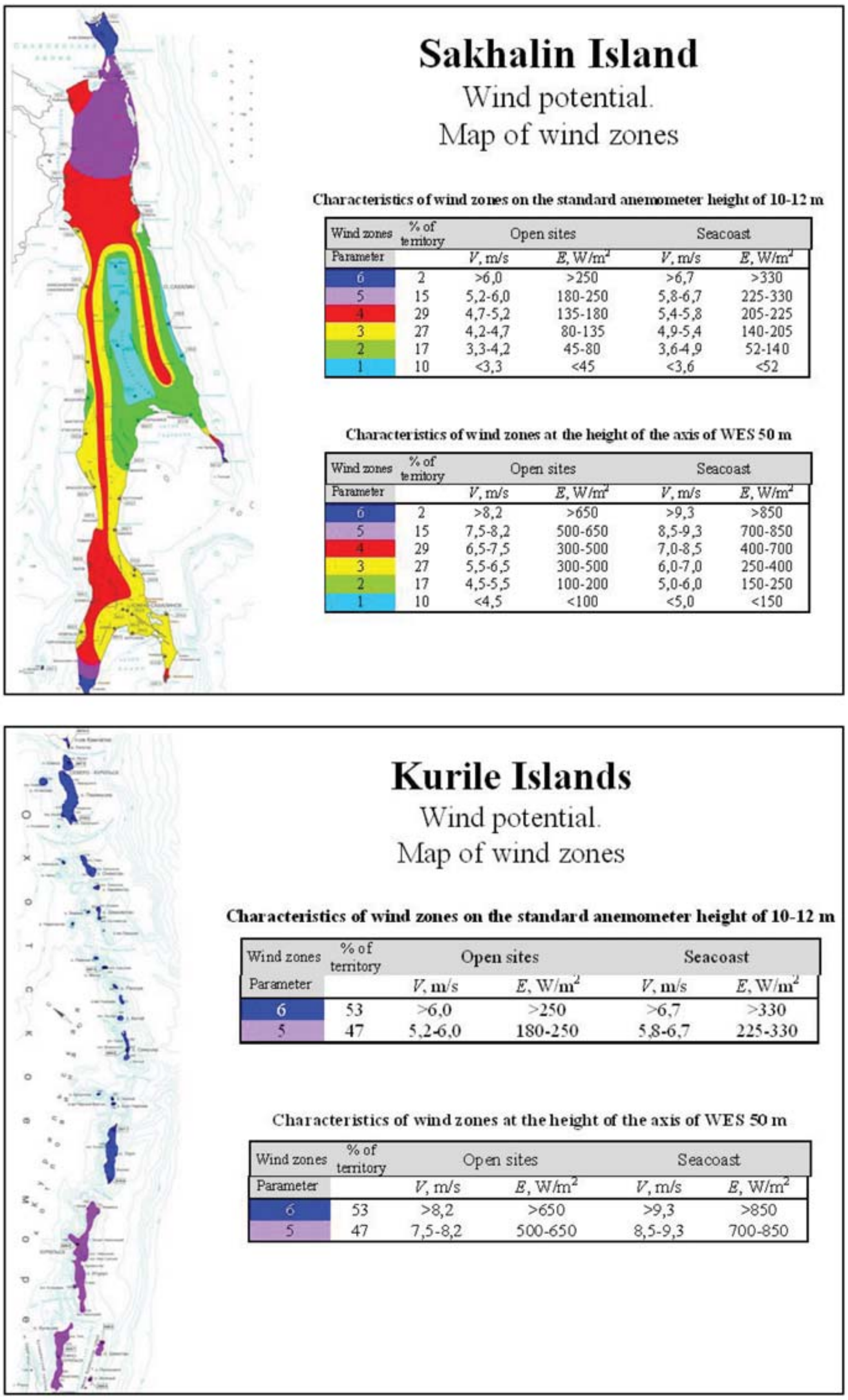
Introduction of renewable energy sources in remote villages has a number of advantages:

- an increase of useful electricity per capita;
- an improvement in the reliability of electricity supply;
- a significant reduction in the cost of electricity by maximising the use of renewable energy and saving liquid fuels;
- a significant increase in green energy compared to diesel power stations;
- a full accounting for the balance LoES cumulative costs, including the costs of a full recovery.

The choice of a site for the construction of renewable energy facilities involves in the first place an assessment of the selected area for energy efficiency. For the purpose of measurement of wind potential, a common zoning scheme was adopted with five grades where the higher grade corresponds to an increased wind speed. Figure 1 shows a map of wind zones of Primorsky Territory which is a result of a global research conducted by the Risø Danish National Laboratory for Sustainable Energy at the Technical University of Denmark, with updates by district. Such studies as well as other works determine the zoning in general, but are not appropriate to develop proposals for the use of wind potential.

Energy efficiency assessment is essential to identify the location of renewable energy facilities. In the mentioned study, the structure of the wind zones complied with the the international aerology requirements for a number of compulsory details: orography and shading. This allowed the authors to tentatively identify the locations for the installation of wind power facilities. However, in each case at the pre-design stage, the preliminary indicators should have been verified by setting the anemometer at least on a one-year period to account for the annual wind variation.

The study identified a number of locations in Sakhalin, and in particular on the Kuril Islands, where the wind speeds far exceeded the gradation zone five, so the authors added the sixth grade "very strong winds." The grade zones are there-



Sakhalin Island

Wind potential.
Map of wind zones

Characteristics of wind zones on the standard anemometer height of 10-12 m

Wind zones	% of territory	Open sites		Seacoast	
Parameter		V, m/s	E, W/m^2	V, m/s	E, W/m^2
6	2	>6,0	>250	>6,7	>330
5	15	5,2-6,0	180-250	5,8-6,7	225-330
4	29	4,7-5,2	135-180	5,4-5,8	205-225
3	27	4,2-4,7	80-135	4,9-5,4	140-205
2	17	3,3-4,2	45-80	3,6-4,9	52-140
1	10	<3,3	<45	<3,6	<52

Characteristics of wind zones at the height of the axis of WES 50 m

Wind zones	% of territory	Open sites		Seacoast	
Parameter		V, m/s	E, W/m^2	V, m/s	E, W/m^2
6	2	>8,2	>650	>9,3	>850
5	15	7,5-8,2	500-650	8,5-9,3	700-850
4	29	6,5-7,5	300-500	7,0-8,5	400-700
3	27	5,5-6,5	300-500	6,0-7,0	250-400
2	17	4,5-5,5	100-200	5,0-6,0	150-250
1	10	<4,5	<100	<5,0	<150

Kurile Islands

Wind potential.
Map of wind zones

Characteristics of wind zones on the standard anemometer height of 10-12 m

Wind zones	% of territory	Open sites		Seacoast	
Parameter		V, m/s	E, W/m^2	V, m/s	E, W/m^2
6	53	>6,0	>250	>6,7	>330
5	47	5,2-6,0	180-250	5,8-6,7	225-330

Characteristics of wind zones at the height of the axis of WES 50 m

Wind zones	% of territory	Open sites		Seacoast	
Parameter		V, m/s	E, W/m^2	V, m/s	E, W/m^2
6	53	>8,2	>650	>9,3	>850
5	47	7,5-8,2	500-650	8,5-9,3	700-850

Figure 2. Wind potential of the Sakhalin Island and Kuril Islands

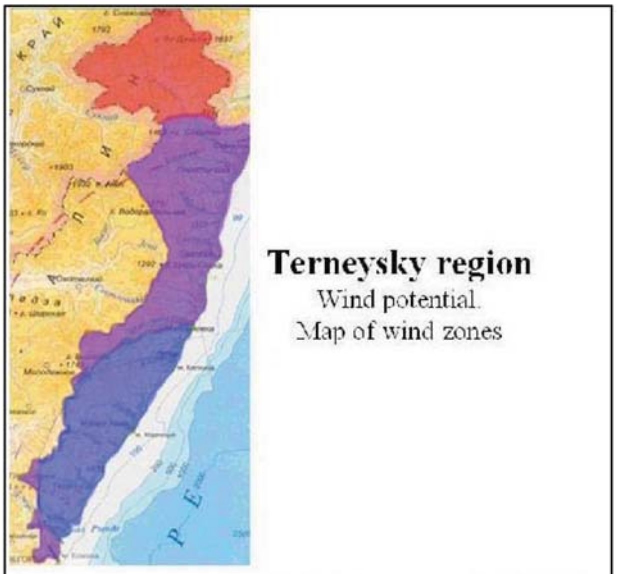
fore presented in two tables, with both standard anemometer height and the height of the wind power station of 50 m.

In terms of coverage, zones 4 and 5 (strong winds) in Sakhalin and Kuril Islands represent a higher percentage of the surveyed area than, for example, in the Primorsky Territory (continental Russia). It should be noted that the above assessment did not impose any assumptions on the use of wind potential. Indeed, the energy resources are often not in demand due to the vast uninhabited regions, but these data are of long-term value.

A more detailed map of the Terneisky region shows that there is a high wind potential and low population density in the areas with local electricity supply.

As regards Primorsky Territory, despite a sharp decrease of energy deficiency after the start-up of the Bureya Hydro Power Station irregularities persist in the regional energy system. Reasonable solutions to these problems may be as follows.

1. Wind farms in the South of Primorsky Territory with a combined capacity of 100 MW (upgradeable to 300 MW in the future) to decrease loads and losses in long grid lines and to reduce the cost of electricity.



Characteristics of wind zones on the standard anemometer height of 10-12 m

Wind zones	% of territory	Open sites		Seacoast	
Parameter		V, m/s	E, W/m^2	V, m/s	E, W/m^2
6	32	>6,0	>250	>6,7	>330
5	40	5,2-6,0	180-250	5,8-6,7	225-330
4	28	4,7-5,2	135-180	5,4-5,8	205-225

Figure 3. Wind potential of Terneysky region, Sakhalin, Russia's Far East

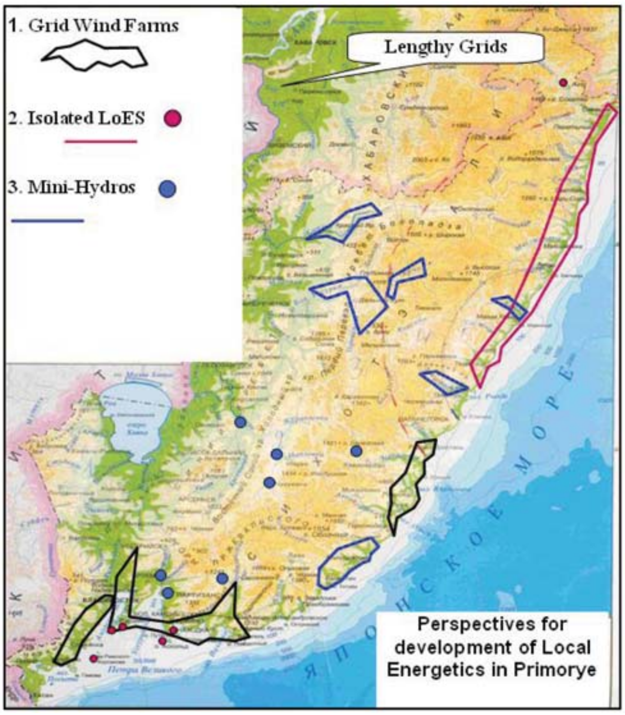


Figure 4. Prospects for local power development in Primorsky Territory, Russia's Far East

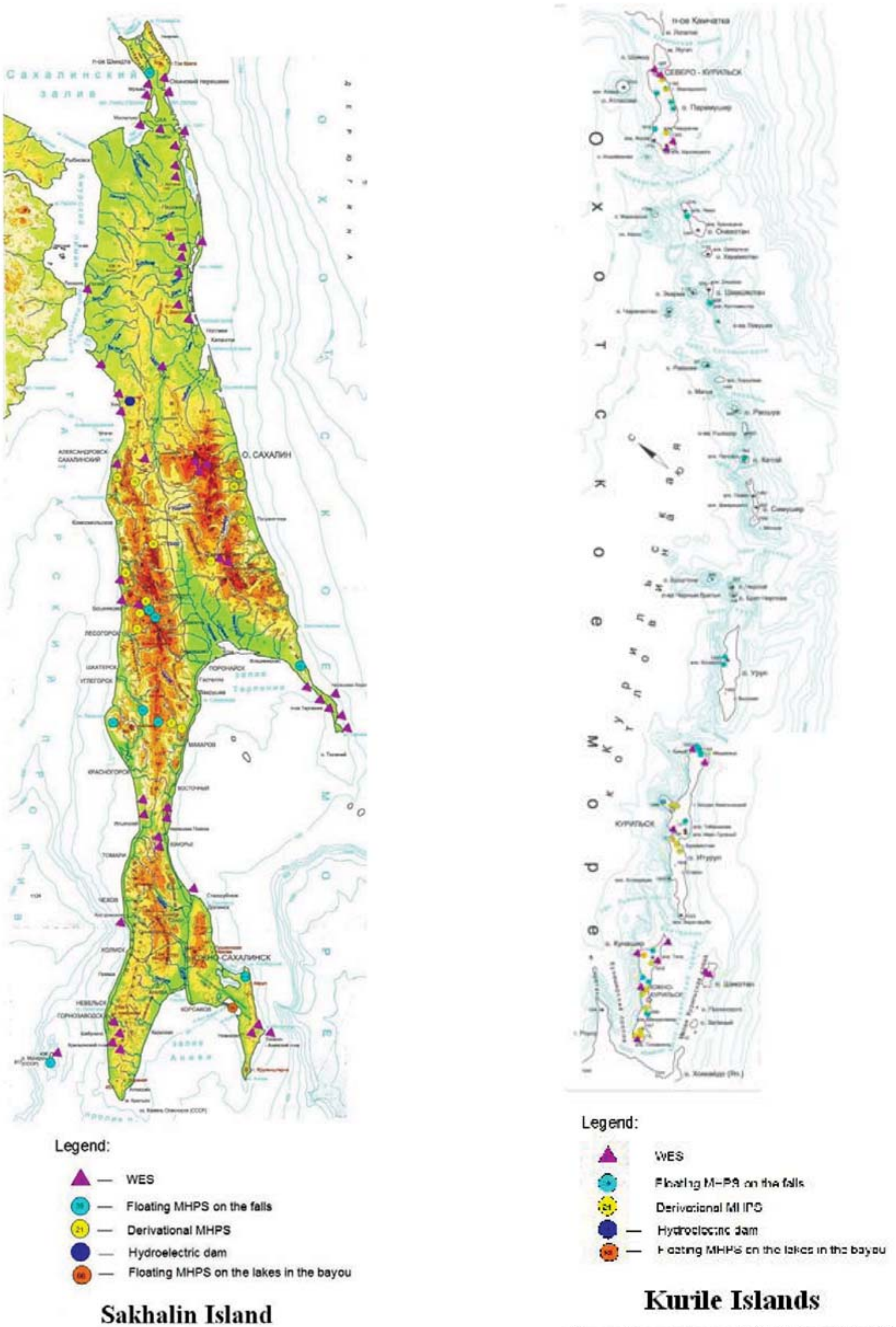
2. Mini-hydros interconnected with stable grids.

3. Installation of 25-30 autonomous LoES with the capacity of 0.4-3 MW each in remote off-grid sites. Diesel gensets would remain for emergencies after mini-grids are developed at these sites.

Sakhalin region possesses sufficient renewable energy resources, too. At some points, the average wind speed is 8 m/s or more at the standard height of the anemometer of 10-11 m above the ground level, so the average annual wind power at the height of the axis of a megawatt-class wind farm may reach 2,500 W/m2. The gross electricity generation is theoretically possible with the capacity of some real wind farm models of about 3,800 billion kWh, exceeding the annual consumption of the area which is 2,721 million kWh i.e. by a factor of 1,400.

Available water resources enable the construction of mini-hydros. The gross hydro power potential of the Sakhalin region is measured in terms of the total gross theoretical hydropower: runoff (15,500 million kWh), reservoirs (4 million kWh), lakes (50 million kWh), tidal energy (4,400 million kWh), full gross hydro power potential — 20,000 million kWh.

The total theoretical capacity exceeds the annual electricity consumption by a factor of 7.



Sakhalin Island
Promising setup of WES and HPS

Kurile Islands
Promising setup of WES and HPS

Figure 5. Prospects for the installation of local power facilities in Sakhalin and Kuril Islands

Average diesel consumption of 0.35 kg/kWh implies that the gross potential of RES will save about 1,350 million tones diesel a year. In addition, wind and mini-hydro may effectively complement each other because of weaker river flow and higher wind speed in the winter compared to summer.

Development of Local Energy Supply with the Use of Renewable Energy Sources

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The Republic of Sakha (Yakutia) is the largest region of the Russian Federation, about one fifth of the total area. Nowadays, Yakutia is still one of the most isolated and remote regions of Russia where year-round transport is not available for 90 per cent of the territory.

Sakha Energo JSC serves seventeen subregions of this Republic (as is highlighted on the map) with the total area of 2.2 million km2. One hundred and twenty five diesel power stations are operated here to provide almost one hundred thousand people with electricity (Figure 1).

The electricity tariff is US$ 0.79/kWh (as of 2012). The fuel that contributes 47 percent to the tariff is of course the main challenge. One of the reasons for such a high cost of diesel fuel is a complex multi-modal transportation with numerous transfers along the routes which are mostly of seasonal type.

Sakha Energo has to use a credit of more than RUB 2 billion annually to secure the delivery of diesel fuel. Adding to the logistic complexity, wear of the equipment and transmission lines coupled with high specific fuel consumption result in significant financial losses.

A comprehensive technical modernisation is not affordable due to the limited financial resources that originate from the customers.

Diesel fuel that is responsible for the largest component in the electricity tariff accounts for

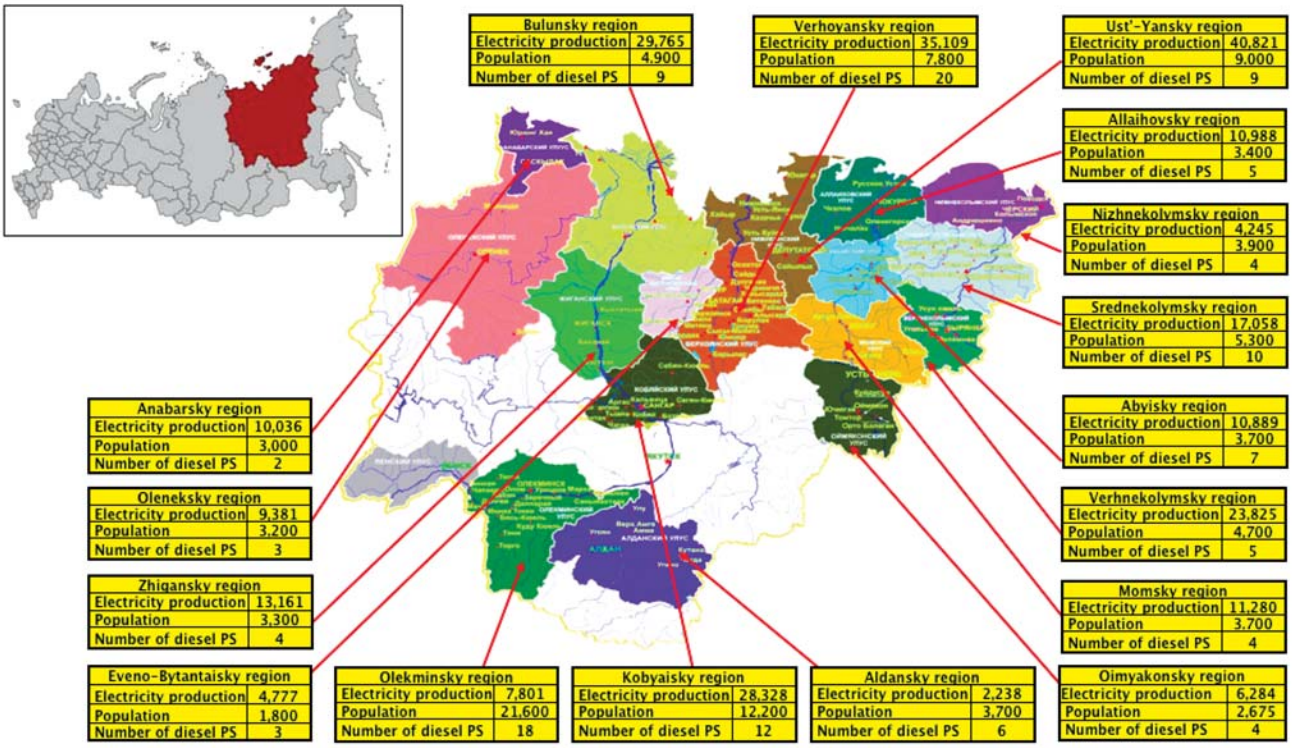

Figure 1. Local power supply systems in the Republic of Sakha (Yakutia), the largest region of the Russian Federation

90 per cent of all primary fuel consumption by Sakha Energo for electricity production.

The curve in Figure 2 shows what may be expected until 2016: the fuel price is increasing while its consumption is significantly decreasing. This is because the company intends to address the fuel issue and one of the ways is to promote the use of alternative renewable energy of the sun and the wind.

The Northern coastal zone of the Republic has significant wind potential while the central and southern parts receive high level of solar radiation.

The first wind turbine in Yakutia — Tacke TW250 with the capacity of 250 kW — was mounted in the settlement of Tiksi in the coastal zone in 2007. Sakha Energo has been operating this turbine for five years and it produced 328 thousand kWh of "green" electricity that saved the company 84 tons of diesel fuel.

However, the results of the five-year operation are somewhat mixed for various reasons. First, at the time of purchase the turbine was not new, it was fifteen years old already. Failures occurred often due to wear. This equipment was also of non-arctic version, its lowest working temperature is minus 20 C while the winter temperature in Yakutia falls to minus 40 C and even lower.

Besides, the turbine didn't have the remote control and the company staff had to visit the installation site every time the data from turbine was needed or in case of improper operation.

The lessons learnt from the operation of this wind turbine led to a list of recommendations and technical specifications for the wind power equipment that would perfectly fit Russia's northern territories:

- new, arctic version equipment;
- without hydraulic braking system;
- direct-drive model;
- with pitch control;
- ability to work off-grid;
- installation without the use of a crane (method of downward arrow) because of the complex logistics arrangements;
- maximum unit power — 100kW-150kW because of uneven wind speed spread;
- remote management and monitoring of wind farm by operations staff of diesel power station;
- installation site with due regard of the nature of wind speed and direction;
- staff training on the repair and maintenance of wind turbines.

Sakha Energo built its first solar power plant with the capacity of 10 kW in the settlement of Batamai in 2011 to produce electricity in parallel with diesel generators. For one year of operation, it produced about 10 thousand kWh that saved the company 3.4 tons of diesel fuel. That is a good indicator.

The generation is uneven due to the difference in solar radiation in winter and summer. In 2012, the company added 20 kW to the existing 10 kW and changed the supporting construction. The

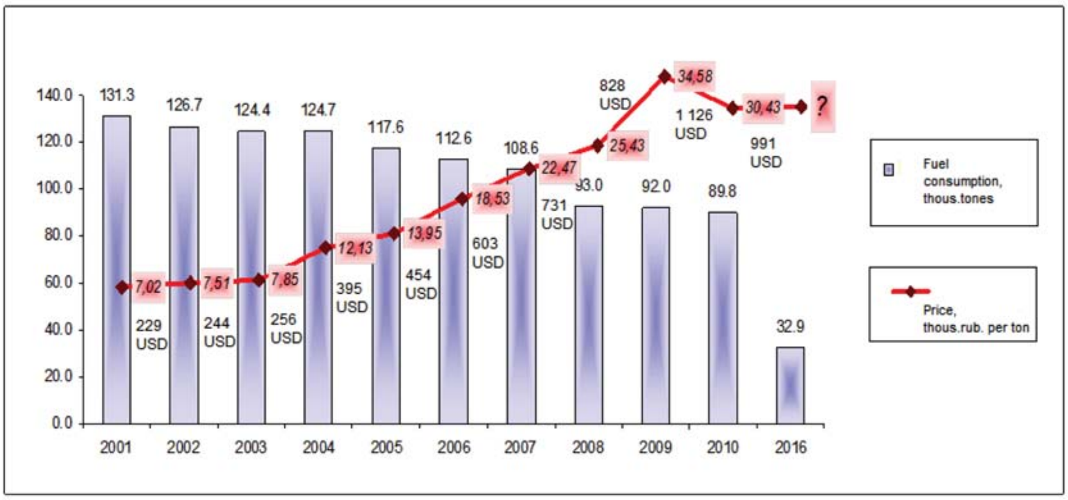

Figure 2. Dynamics of fuel consumption and price for electricity generation in the Republic of Sakha (Yakutia), 2001-2016

new design allowed the operator to change the angle of solar modules relative to the horizon. There are now two options: winter (the maximum angle) and summer (the minimum angle). It is not automated yet, so the staff has to do it manually.

An express analysis of the economic effect of the new solar power plant was conducted under current assumptions and showed that the payback period may take 8.6 years.

In 2012, Sakha Energo has also built a solar power plant with the capacity of 20 kW in the settlement of Yuchugei that is close to the Pole of cold of the Northern Hemisphere (that is Oimyakon where the temperature was registered at -71 C circa 1924). This solar power plant is also operated in the parallel mode with diesel generators.

The company notes that the solar power plant has the following advantages:

- compactness of the equipment;
- simplicity and ease of installation and use;
- long lifetime period;
- absence of rotating and moving parts, which reduces wear;
- minimum cost of operation and low cost of energy, i.e. no fuel consumption, continuous maintenance, low depreciation etc.
- modularity, i.e. possibility to increase or decrease the power of PV plant by changing the number of panels and inverters;
- adaptability, autonomy and the ability to be on-grid;
- wide operating temperature range that is important in Yakutia's severe climate conditions;
- remote monitoring and control;
- no harmful emissions.

Meanwhile, there are also disadvantages:

- high cost of equipment;
- relatively low efficiency (12-18 per cent for solar cells based on mono-crystalline silicon);
- unstable solar radiation (night, clouds, smoke, fog etc.);
- seasonality of PV plant: from early November to mid-January exposure to the sun is greatly reduced;
- need for tracking the sun.

Ultimately, Sakha Energo has developed a programme for renewable energy sources in the Republic of Sakha (Yakutia) in 2012 that was approved by the President of the Republic. The plans include building five wind farms, 51 solar power plants and three small hydropower plants of seasonal type.

Breakthrough in Small-Scale Power Generation at the Beginning of the XXI Century

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Test Ground of the Cold LLC has been developing a venture capital business for five years, selling solar power units for household generation in the Republic of Sakha (Yakutia). The company uses five acres of land where it tests wind and solar power generating household stations, construction materials, electric heating in challenging climate conditions of Northern Russia.

The research focused on the use of the wind and solar facilities in the climate conditions of Yakutia and indicated the following:

1. There is no wind at nights in Yakutia, especially in winter when it is extremely cold. Usually wind speed is 4-6 m/s, except high winds (over 25 m/s), which makes the wind power generation inapplicable. Besides, Yakutia has no constant wind flow.

2. Vibration and noise produced by wind power turbines cause additional disturbance for the inhabitants of the North.

3. Another problem of the wind power in Yakutia is that the extreme temperature drop freezes wind generator, causing icing of the fans installed.

4. In the North, the sun orbit is not high: in summer it is 320°, so solar modules need trackers. This increases the cost of the industrial use of the solar power. Yakutia is situated in the Polar Circle, thus it has polar nights in winter and solar modules do not work here.

Given the peculiar climate condition, the company embarked on exploring other non-conventional sources of small-scale, distributed energy and integrating those into remote microgrids. The Test Ground of the Cold conducts fundamental research in extracting hydrogen fuel from ice and generating electricity from the difference between constant temperature of the permafrost and the outside surface temperature. It furthers collaboration with partners such as the Institute of Physical and Technical Problems of the North, Permafrost Institute, Federal University of the North East. These institutions are represented by renowned scientists in such fields as small distributed energy, studies in materials at low temperatures, temperature extremes and others.

Building on the experience acquired, test Ground of the Cold developed specifications for a self-regulating source of small-scale distributed power, in furtherance of an accelerated deployment of microgrids. Here are some of the desirable characteristics: it should be maintenance-free, reliable, safe, small in size and weight, capable to operate uninterruptedly for at least seven years at the outdoor temperature from + 70 °C to — 55 °C, of a capacity of 7-200 kW, costing not more than US$ 800/kW.

This issue is critical for Russia that is the world's largest country in terms of surface area. There are vast areas with the chernozem soil in Russia suitable for meat, milk, vegetables, grains output and with water basins for fishing. The population of 143 million people is dispersed across the country's territory, but due to the lack of electric energy is mostly concentrated in the cities with central heating now. Meanwhile, Russia is facing the challenge to explore its natural resources in new areas of the North, and this will require low energy sources, especially at the early stages. A well known problem is the delivery of petroleum products for the operation of power stations that is very expensive in the North.

At the beginning of XXI century, the Russian science is at the forefront of addressing this challenge and has launched groundwork for the industrial production of Autonomous Sources of Electric Power (ASEP) to meet the above technical requirements. At this stage, the Test Ground of the Cold works in Yakutia to finalise the specifications and conduct field tests.

Industrially mature and commercially available ASEPs that meet the above specifications are in great demand in the North of Russia. Today, about 900 horse-breeding bases, 300 summer farms, 120 deer and 70 fishing teams in Yakutia await microgrid solutions that will incorporate ASEPs. These smart power plants will replace diesel power stations, will reduce the imports of petroleum products and will reduce electricity loss during transportation. The ASEPs may also be in demand in many of the remote areas and islands of APEC member economies.

There are ongoing experiments to develop commercial ASEP prototypes in North America and Europe. In 2009, John Deal of Hyperion Power Generation, USA announced that self-regulating energy sources would produce up to 25 MW from natural uranium in 2011. In 2008, the Danish Technical University received an allocation of €7 million for the development of small distributed power source using solid oxide fuel element based on zirconium. These projects have not yet been completed and the single prototypes that have been developed are highly expensive and are not competitive to modern diesel power stations. However, the direction of research and development is absolutely correct.

ASEPs will be fifteen times cheaper than floating atomic power stations and safe in all respects. Development of ASEPs using natural uranium and solid oxide fuel elements based on zirconium dioxide is a core of the breakthrough in small scale power generation at the beginning of XXI century for heat supply of small settlements, lighthouses and providers of the navigation waypoints. Today, the research and development outputs of the former Soviet Union have been declassified and the relevant scientific articles and books have been published. But unfortunately, the government does not show interest in the development and production of new small scale energy sources for the local energy supply to remote areas and islands.

Another issue with accelerating the development of a new self-regulating power source on natural uranium and solid oxide fuel element in Russia is that the research and development is scattered among various research institutes of the Russian Academy of Sciences, the Federal Space Agency, Rosatom State Nuclear Energy Corporation, the Ministry of Defense and others, while engineering teams almost do not exist. Many highly qualified or world-class engineers either have retired or are busy with routine assignments to secure their regular incomes.

Indeed, today we do not have a reliable, long-lasting source of small scale power. The world today is not far away from the electrochemical element invented in the early XIX century. Modern battery (100 amp/hour) used for solar module has the weight of 36kg, which a woman, reindeer herder, has to carry in order to watch TV. But this battery cannot help to heat water as the power is not enough.

That is why the Test Ground of Cold LLC has been promoting roadmaps for the production of ASEPs of the XXI century. The company has identified potential Russian partners and strives to be a leader in the emerging ASEP industry. The ambition is to spearhead the development of technical specifications, implementation of field tests in Yakutia, and to launch the commercial production in the shortest possible time. Government support and cooperation with interested private stakeholders will provide substantial impetus to these activities.

The Economics of Hybrid Renewable Microgrids

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Definition

There are many possible definitions of a microgrid. For our purposes we consider any power system that is capable of standing on its own to be a microgrid. This includes both remote systems, such as island utilities, and grid-connected systems that are capable of "islanding". That means they can continue to supply power after becoming disconnected to a central grid. It does not include renewable and distributed power projects that do not have islanding capability.

This definition includes thousands of island power systems and millions of systems if you include relatively small systems. Historically, almost all of them have been simple diesel power systems, but that is changing quickly.

Economics of Microgrids

All of those simple diesel power systems are cost-effective candidates for becoming hybrid renewable microgrids. Until recently, wind power was the only cost-effective renewable technology and that was only true in locations with a good wind resource. The difficulty of verifying local wind resources remains a significant obstacle to small wind projects because the resource can vary dramatically over relatively short distances, especially in complex terrain. The power output and therefore the financial feasibility of wind power is very sensitive to the resource.

In the last couple of years the economics of microgrids has changed dramatically due to substantial increases in the price of oil and decreases in the cost of photovoltaics. Figure 1 shows just the fuel cost of diesel versus the fully amortised cost of PV. Ten years ago PV power was four times the cost of diesel power. As recently as 2009 it was still almost twice the cost, but as of 2011 PV is now less costly than diesel power.

Microgrid Applications

Microgrids have many applications. Off-grid microgrids are mostly applicable in developing

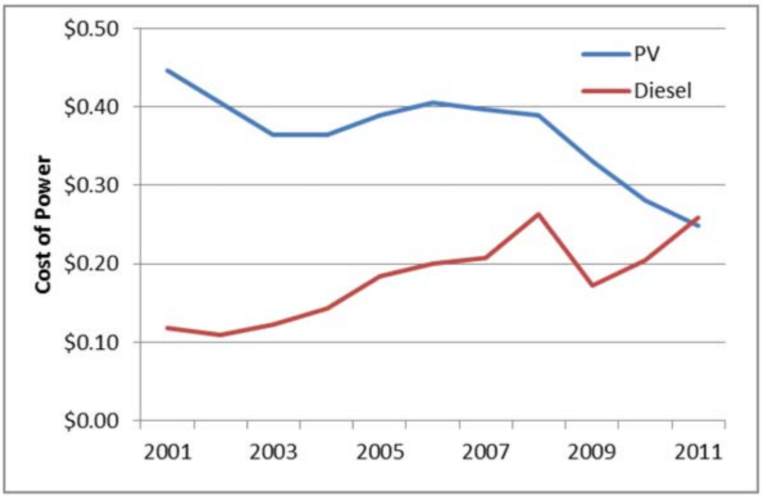

Figure 1. Cost parity for PV on diesel grids

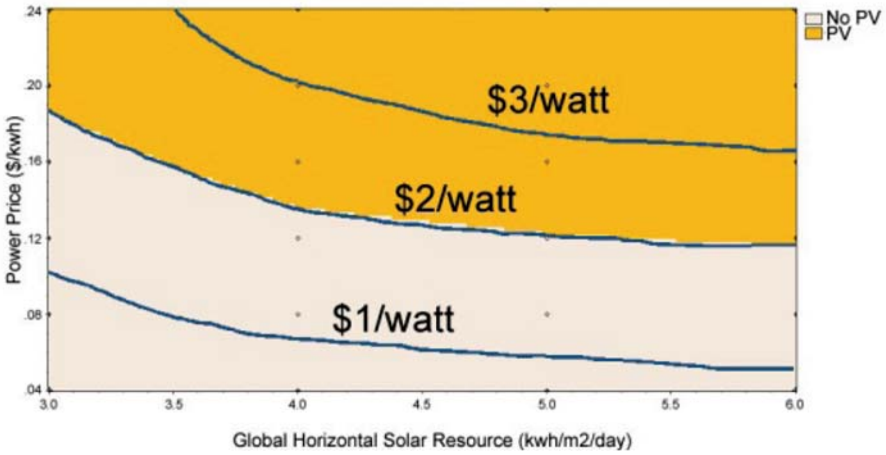

Figure 2. What makes PV cost-effective?

countries, with some exceptions like Alaska and the Australian outback. Within this category, island power systems and mining operations tend to be the larger applications. The military is very interested in making the forward operating bases more efficient and less dependent on vulnerable supply logisitics. Ecotourism is a small, but interesting niche. Village power is a potentially huge market for supplying 1.5 billion people who currently have no access to power. That market will require a sustained programme of institutional support.

The central grid in most developing countries does not provide the same level of reliability that we are used to in developed countries. As a result most commercial enterprises and many middle and upper income households have their own backup power systems. The noise and maintenance requirements of diesel generators is a major burden for these users in addition to the fuel cost.

Within developed countries the main markets currently are emergency service applications that require extremely high reliability, such as hospitals, data centers, police stations and military bases. University campuses are a special case because of their low cost of capital, long planning horizons, and the fact that they have multiple buildings under the same ownership. In the long run, microgrids have an enormous potential to enable central grids to manage the variability and other challenges of high penetrations of renewable power sources and electric vehicles.

Each of the microgrid applications is driven by a different combination of the three distinct value propositions for microgrids, as Figure 3 shows.

Hybrid Systems

Microgrids are the key to the development of smart grid technology. Large, interconnected utilities have daunting security and regulatory obstacles to implementing smart grid technologies, but the cost of diesel fuel is making high penetration renewables an economic necessity for smaller grids. Those high renewable penetrations require distributed controls and load management within a smart microgrid. Nor do isolated utilities have to worry about cyber security threats and regional power flows. This isn't conventional wisdom but smart grid technologies will be proven out on microgrids first (see Figure 4).

Microgrids can use a variety of new modular technologies that give designers substantial flexibility. Because solar and wind power systems produce variable power they do not stand on their own and must be part of a hybrid microgrid. Hybrid systems not only allow a diesel to operate at its peak performance level, but they also give system designers new design flexibility. We developed the HOMER® software to optimise system design and identify cost-effective applications of microgrids.

Design and Simulation

HOMER allows system designers to distinguish between critical, high priority loads and other loads that can be controllable. Cogeneration or combined heat and power systems are more easily deployed in microgrids. The HOMER

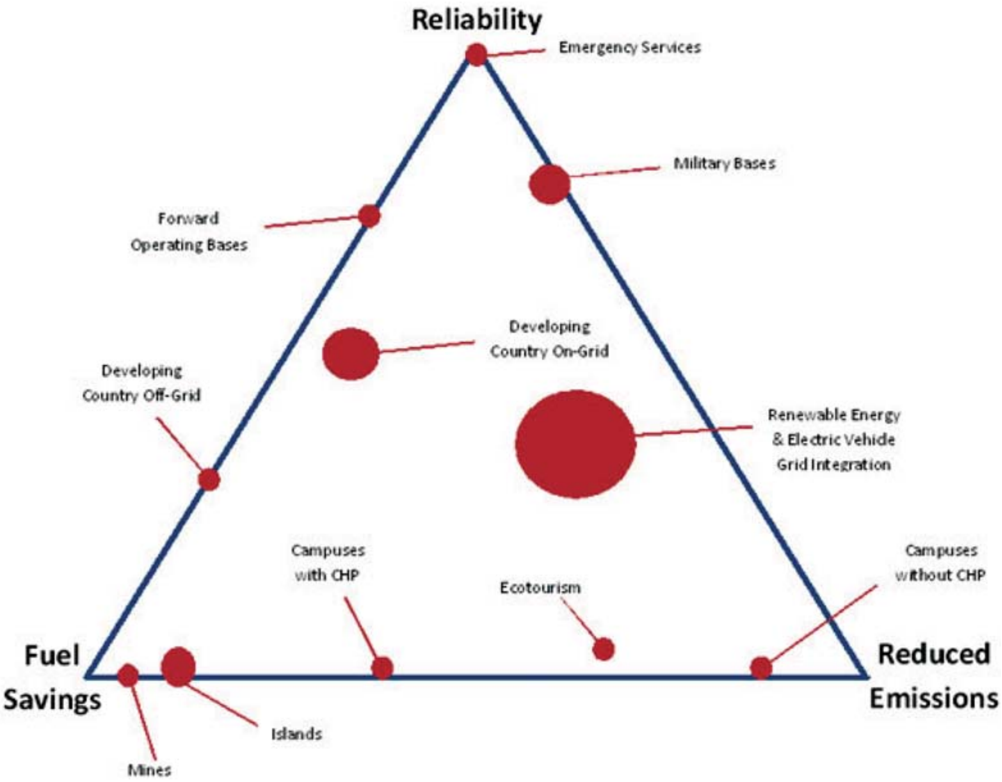

Figure 3. Multiple market segments with different value propositions

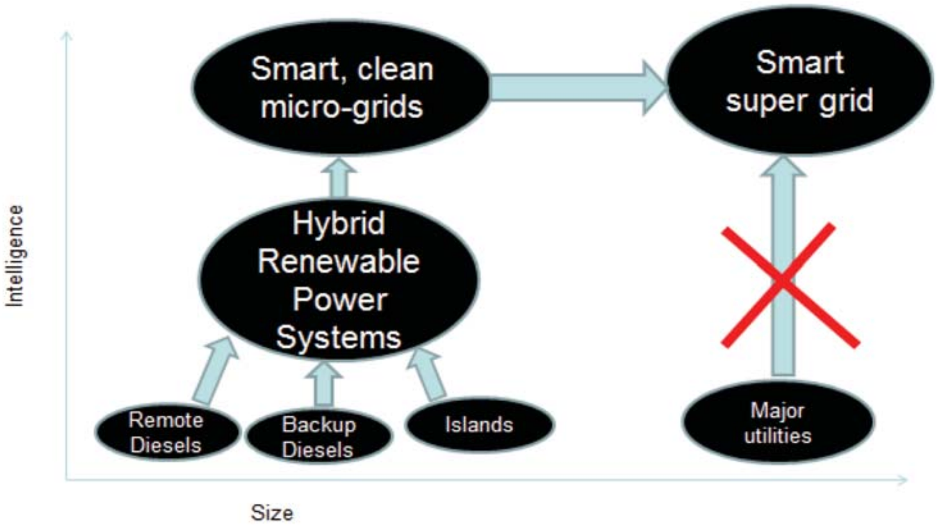

Figure 4. Clean power evolution

software handles all of these technologies, in addition to storage and conventional and renewable resources.

In order to identify optimal microgrid system designs, HOMER must answer questions, such as how much fuel will a system require, how long can the storage last. HOMER also identifies the many trade-offs between design variables. For example, a larger battery bank will reduce fuel use, but so will additional renewable capacity. A well-designed load management system can serve a similar function to additional storage capacity.

Local power systems are hard to design because there are so many alternatives and there

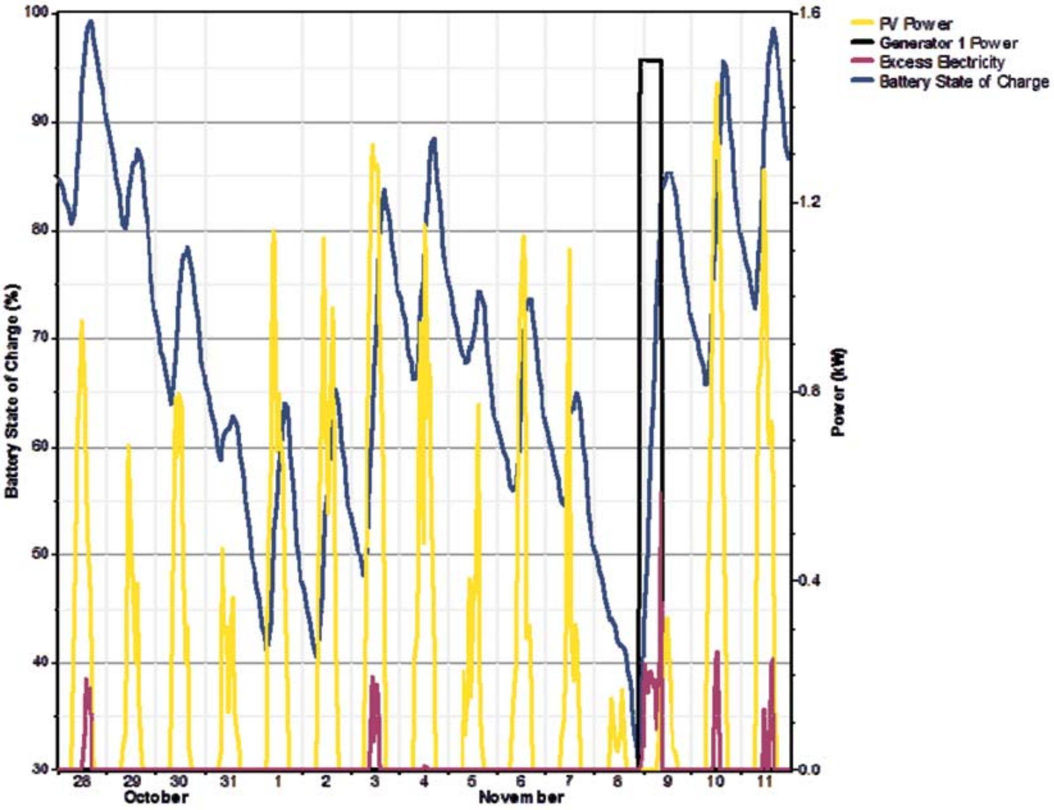

Figure 5. Hourly simulation results (sample)

is no cookie-cutter, one-size-fits-all, Model T solution. Many of them are new and different and the best solution is often a combination of technologies. Because a confused mind says “No” we developed HOMER as an easy to use software package to show which set of technologies is best under what conditions.

The renewable resources as well as the loads vary throughout each day and over a whole year. The charge and discharge cycles of a storage systems must be explicitly modeled. This makes it essential to perform chronological simulation over a whole year. HOMER’s chronological simulation engine will estimate the fuel and O&M requirements for a particular system. Its optimisation algorithm performs these simulations for hundreds of thousands of different system configurations and ranks them by a variety of cost metrics to identify the optimal system. That identifies the least cost system for a particular scenario. HOMER’s built-in automated sensitivity analyses can then show how those results vary when conditions, such as fuel prices, loads, component costs and performance change. his is particularly important when new technologies are evolving rapidly and for smaller systems where some of the input data may be quite uncertain.

Because HOMER performs hourly simulations you can look at exactly how each component operated and the energy flows in every hour of the year (as is shown in Figure 5).

Conclusion

We are very optimistic about the potential of microgrids. We strongly believe that the remote microgrids will be the trailblazers for a variety of load management, demand response, energy storage, and smart grid technologies that will allow renewable power to be deployed at much higher levels. These technologies can be deployed much more easily in microgrids because that avoids the security and regulatory complications that are major concerns for larger interconnected utilities. At HOMER Energy we are committed to helping microgrids achieve their potential by making a sophisticated analytical tool widely available and providing support to our users.

Feasibility Study on a Microgrid System with Wind Power Generation for Remote Isolated Grid Areas in the Russian Federation

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Summary

This is a report of a feasibility study on microgrid system with wind power generation in Russia. The study was performed by a team of Komaihaltec Inc, Mitsui and Co., Ltd., Toyo Engineering, and Okinawa Enetech, in the second half of 2011, funded by the Ministry of Economy, Trade and Industry of Japan. The village of Novikovo, Sakhalin was selected as a case study and the energy balance was simulated when integrating 300kW wind turbine to the microgrid system of the village.

Introduction

For thousands of remote and isolated communities in Russia, energy security has been always an issue, as bad weather or transportation troubles could easily interrupt the fuel supply to their small community power stations. As these small power stations, often powered by diesel generators, produce expensive and high carbon emitting electricity, the situation is getting harder these days with the ever rising oil price as well as the rising awareness in the international community of the need to reduce carbon emission.

Our study team, including a manufacturer of 300kW wind generating system and microgrid management experts, investigated the possibilities of wind–diesel hybrid generation system in isolated grid areas in Russia with a hope that the Japanese technology could lead to enhancing the quality of life in those communities as well as contribute to actions against global warming.

This paper describes especially the case study of Novikovo village of Sakhalin, and its simulation results when introducing wind turbine.

Case Study: Novikovo Village, Sakhalin

Outline of the village

Novikovo is a village of 550 inhabitants located in southern Sakhalin. It is about 110 km from Yuzhno-Sakhalinsk, and the distance from the neighboring community Ozerski is about 40 km. It has an independent power system not connected to the power system of the Sakhalin regional grid.

The only industry in the village is fish processing that only runs in the summer. When it is in operation from August to October, the electric consumption in the village is the highest with the daily maximum load around 500 kW (Figure 2).

Novikovo power station is equipped with seven generators, which were used in the past for the coal mining industry, but electricity is supplied by only one generator at a time. There is no synchronization board, and the power plant is not able to operate two generators at the same time.

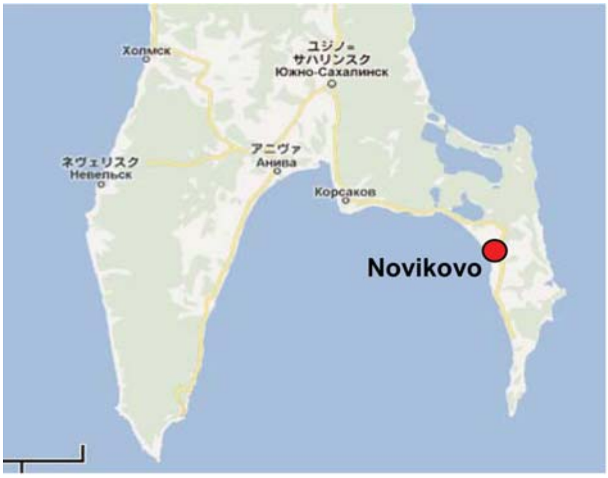


Figure 1. Location of Novikovo village, south of the Sakhalin Island

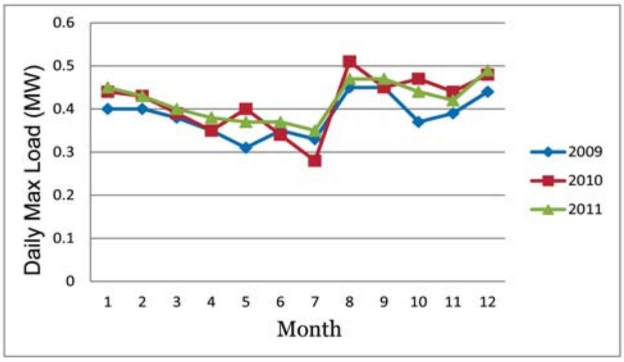


Figure 2. Daily maximum load, Novikovo village

Wind resource analysis in Novikovo

Wind resource assessment is essential to judge the feasibility of a wind energy project. In this study, two sets of data were analyzed: wind data of the Novikovo weather station and the data of 34 m high meteorological mast, installed during the study period.

The wind resource simulation was made with data from the weather station and the topographical data of Novikovo, using WAsP software, wind simulator widely used in the wind energy market. As a result, it was predicted that, rather than along the coast (6.14 m/s), the better wind (7.24 m/s) is expected around the hill side, several hundreds meter away from the power station. This wind speed is used for the energy mix simulation described in the later section of this paper.

Cold weather consideration

Standard wind turbines are designed to survive in the air temperature as low as minus 15C or 20C. Although Novikvo is located in southern Sakhalin where the climate is relatively moderate compared to other regions in Russia, the temperature tendency is investigated during winter season.

Figure 3 illustrates the change in temperature every three hours during the winter of 2010 observed at Novikovo. The daily temperature fluctuates widely and may fall below minus 15C or minus 20C, but the minimum below 20C is only observed for a few hours a day. Therefore, it does not seem to be a major problem even with the introduction of the standard model.

On the other hand, there are areas which are both rich in wind resource and very cold with the lowest temperature below 40C. Yamal peninsula and the neighboring regions are well known examples.

The cold weather model exists for some wind turbines, and one of the team members Komaihaltec is developing one for their 300 kW wind turbine. Most of the cold weather model wind turbines operate until minus 30C and survives until minus 40C.

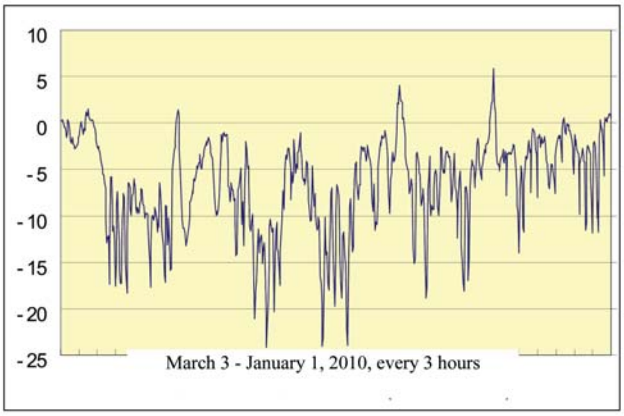


Figure 3. Air temperature at every three hours interval, Novikovo weather station

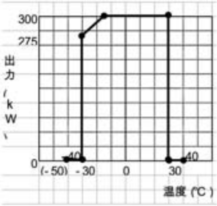
This study analyzed the correlation between the wind speed and the air temperature, taking an example of Salekhard airport in western Siberia. It was found that the wind speed is below 5 m/s when the air temperature is below minus 30C. This means that the wind turbine stop due to the low temperature could be minimal and there is a good possibility for cold weather model wind turbines to be introduced to the areas studied.

The features of Komaihaltec's cold climate model are listed below (Table 1). We intend to verify the specification under real circumstances.

Wind–diesel Hybrid Microgrid System Simulations

In this study, four cases of wind–diesel hybrid systems in Novikovo are simulated. The components are 508 kW diesel generator, 300 kW wind turbine with output limitation if necessary, hot water heating system to absorb the surplus power by dump load, and 100 kW and 250 kW batteries. Case 1 is the model with only the diesel generator and wind turbine, case 2 is the model with the heater, case 3 is the model with the 250 kW battery and case 4 is the model with the heater and 100 kW battery. Hot water heating system is considered to be added on the existing heat gener-

Table 1. Specification of Komaihaltec's cold climate model

Temperature specifications	Operating temperature	-30C ~ +30 C
	Standby temperature (standard)	-40C ~ +40 C
	Standby temperature (high specification type)	-50C ~ +40 C
Output control		At the wind speed range near to the rated wind speed and at a low temperature of nearly minus 30C, the output is controlled as shown in the diagram on the left, corresponding to an increase in the air density.
Sensor	Anemometer, wind direction	Cold area specification
	Freeze sensor	Yes
	Video monitor	Optional equipment
Heating	Blade	Anti-icing tape
	Nasser	Yes heating
	Tower base	Yes heating
	Each unit	Yes heating
Ventilation	The nacelle	Closure

ating plant to preheat the water. The average wind speed is set as 7.24 m/s based on the simulation of weather station data, and the real daily load curves at Novikovo power station are used.

The result shows that the case 1 model can not use the 29 per cent of the amount of electricity generated by the wind turbine, which means the importance of putting the surplus power to practical use. When surplus using device such as battery or heater is combined, the wind generated power will be efficiently utilised in the order of case 2, 3, and 4. The system configuration needs to be decided according to the project economy of combining different optional devices (Figure 4).

The simulation is made to investigate the impact of integrating a 300 kW wind turbine to communities with different grid capacity, namely, 130 kW, 430 kW, 500 kW, 1,000 kW, 2,000 kW and 3,000 kW. Assuming a power system of any scale of 500 kW system capacity where the maximum load rate is 100 per cent, average load rate is 61 per cent, and the minimum load rate is 30 per cent, simulation analysis was performed for the long cycle fluctuation control measure when only wind turbine was introduced without the output stabilisation device. Given that the lower limit of the wind turbine output is 90 kW which is equivalent to 30 per cent of the rated output, if the DG system capacity is less than 130 kW which is equivalent to a 90 kW difference between the maximum load and minimum load, the introduction of the KWT-300 is impossible in order to protect the equipment. If the system capacity is less than 430 kW, which is equivalent to a 300 kW difference between maximum load and minimum load, KWT-300 always needs to perform output limit.

On the other hand, if the system capacity is expanded to 1,000 kW, 2,000 kW or 3,000 kW, surplus power can be minimised and over 3,000 kW of system capacity, it is not necessary to perform output limit most of the time.

Wind Turbine Output Control in Microgrid

In the wind turbine integrated microgrid system, it is necessary to match the system capacity and demand, and control the output of

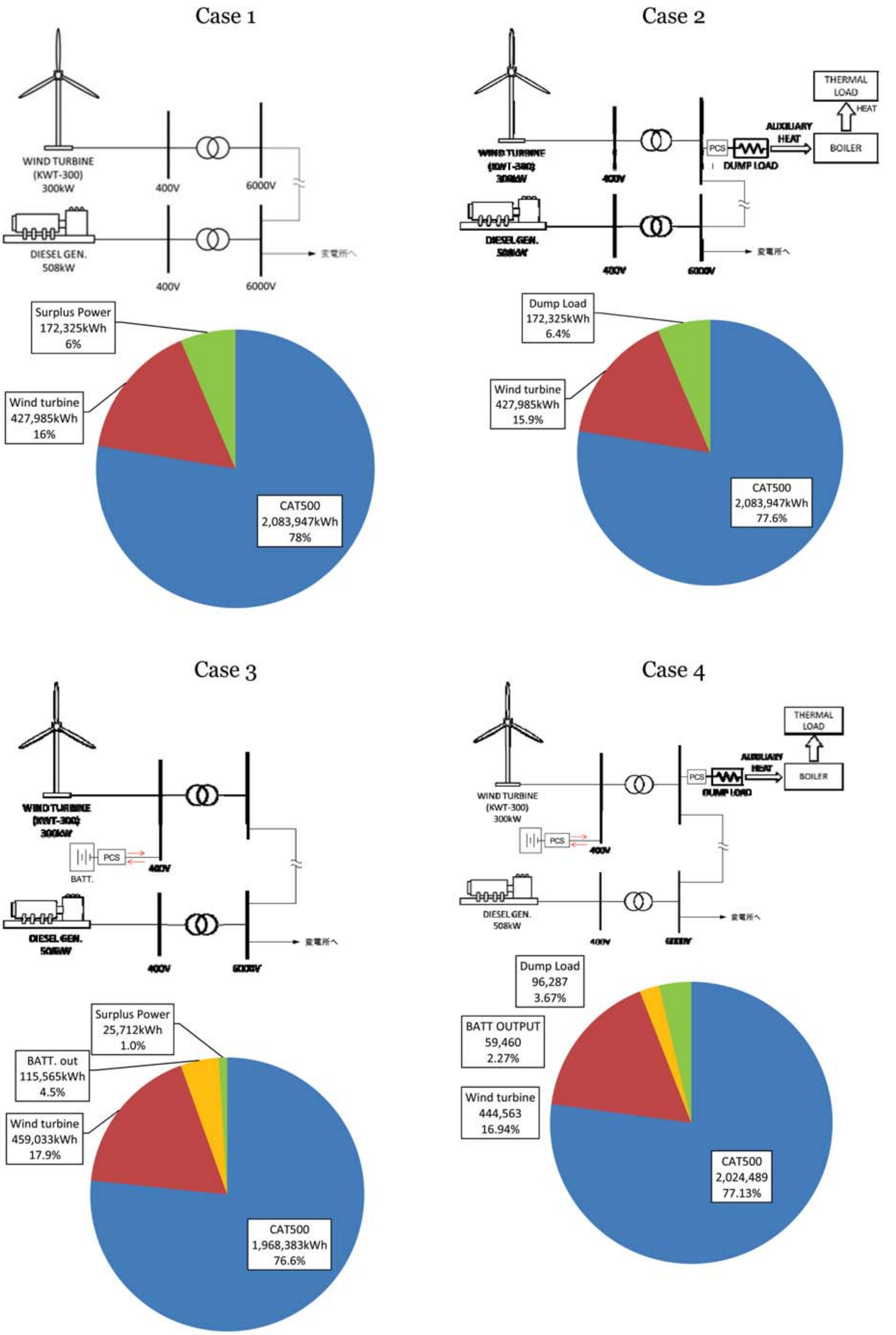


Figure 4. Simulation results for four cases of wind–diesel hybrid systems in Novikovo village

Table 2. Simulation results: output control

Case	Power change measures	Scale measures
[A] Wind power output control only	• For long cycle output fluctuation control, the wind turbine operation has to stop to handle output limit • The control for a short cycle output fluctuation might be unable to operate the wind turbine due to turbine control difficulty	None (only wind turbine output control)
[B] Wind power output control and dump load	• For a long cycle output fluctuations, rerouting surplus power to the heating system of a boiler as a dump load can be used, output limit (wind turbine operation has to stop) is also available • As a short cycle output control measure, there is the possibility that some frequency deviations appear	Dump Load (250 kW)
[C] Wind power output control and storage battery	• For long cycle output fluctuation, control of surplus power can be directed to a storage battery, or wind turbine output compensation, and output limit are available • As a short cycle output fluctuation measure, output stabilisation (output control or frequency control) by storage battery is possible	Storage Battery (250 kW — 6000 Ah)
[D] Wind power output control, storage battery and dump load (minimum storage battery)	• For long cycle fluctuations, surplus power control by storage battery, wind turbine output compensation and supply heat of surplus power by dump load are available • As a short cycle output fluctuation measure, output stabilisation (output control or frequency control) by storage battery is possible	Storage Battery (100 kW — 1500 Ah) Dump Load (250 kW)

the wind turbine. As part of this study, we have also investigated the output control of the wind turbine.

There is a need to control the wind turbine power generator according to the state of the power system. System requirements may vary depending on the size of the system. For a large system, time changing rates on reactive power and active power have to be set to the required value of the system, and there are some cases that the installation of reactive power compensation device is required. For a small system, the control of reactive power and active power is required in order to respond to the situation of electricity demand every moment according to the size of the system such as remote islands.

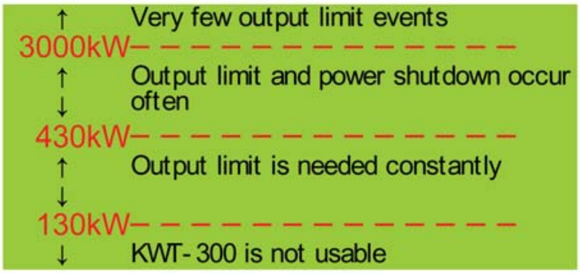


Figure 5. Output limit requirements

The 300 kW model analyzed in this research can control reactive power and active power by external signal input to handle such requirements.

The contents that can be controlled are summarised in the table below.

Table 3. Output control in microgrid: summary

		Active power control	Reactive power control
Control range		10~100% of the rated power	Power factor Cosφ=-0.86~0.86
Content of control	Constant	Input (max. value)	Input (fixed value)
		–	Initial measurement value
	valuable	External signal (4~20mA)	External signal (4~20mA)
		Time schedule	
Etc.		Soft cut-in Soft cut-out	

Concluding Remarks

This study investigated the feasibility of introducing wind–diesel hybrid microgrid in remote communities in Russia. Simulation of four system models and calculations of the balance of supply and demand over time produced results that seem to be appropriate. In future, we would like to consider the proposal of a more concrete and practical system, including the measure to keep the power quality.

Developing Microgrid in Local Energy Systems in Russia: Barriers and Opportunities

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A Structural-innovative Model for the Development of Energy Sector in Russia

The last decade saw notable changes in the external conditions for the development of the energy sector in all countries, including Russia. The most significant of these, requiring an adjustment of the industry, included:

- decrease in the reliability of electric supply;
- changes in the electricity and power market conditions;
- the necessity to enhance the environmental safety and energy efficiency of electric power industry;
- increase of consumer demand for higher reliability and quality of electric supply;
- continuous increase of electricity prices all over the world.

Worldwide experience in power industry development and research show that the only solution is to change the paradigm of the industry, and to further a transition from the extensive development characterised by the construction of major new energy facilities to the intensive development where a sharp increase of the role and functions of management through intelligent energy technologies will ensure greater efficiency of all basic energy processes. This will significantly reduce the investment in large-scale generation and will create an optimal balance through the development of local and distributed integrated power in a single system based on microgrid technologies.

Given the specificity of Russia, it can be said that the development potential for microgrids is very high, but the level of their use will depend on the model for energy sector development. Now, there are two emerging models:

- innovative model — adopted under the “General Scheme of the Location of Energy Facilities in Russia” and the “Russian Energy Strategy until 2030” (approved by the federal government);
- structural-innovative model — proposed by the Agency for Energy Forecasting project “Development of a Concept of Energy and Electric Heat Infrastructure of Russia on the Basis of Cogeneration and Distributed Generation”.

Since the second model proposes to significantly increase the share of distributed and local power generating capacity, the implementation of this model will substantially increase the potential for microgrid development in Russia (Figure 1).

However, the implementation of both models faces significant barriers at the moment. The basic barriers are as follows.

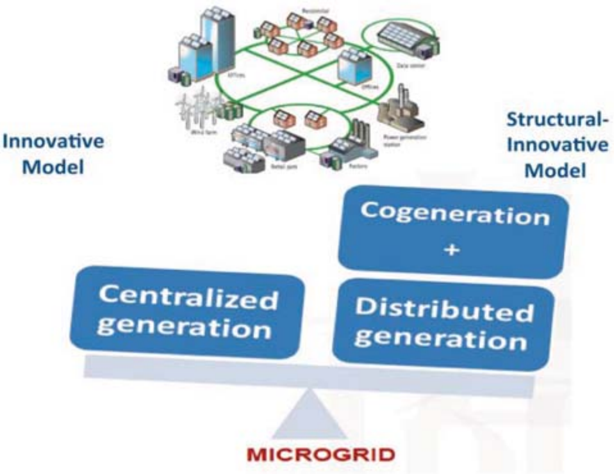


Figure 1. Microgrid development potential in Russia using various models of industry development

1. *Market barriers: will microgrid lead to a reorganisation of the energy sector?* (Figure 2)

- no policy for distributed generation (DG) development in Russia — a chaotic and unregulated development of DG;
- DG only exists at a regional level;
- the Federal Grid Company / JSC Interregional Distribution Grid Companies Holding / System Operator are not interested in DG development;
- there is no schedule or information on DG.

2. *Microgrid investment and regulatory framework: barriers*

- deficiency of the regulatory framework — tariff regulation should motivate innovation;
- understanding benefits is a barrier — consumer is not engaged in the discussion;
- Duma (Russian parliament) vision shows the need to increase waste-to-energy and energy storage;
- lack of typical technology and investment solutions for microgrids.

3. *Education in microgrid: barriers*

- inadequate skills and personnel for a new energy sector model;
- insufficient, not optimal government educational policies;
- no link between educational programmes, the standards for professional and technology innovation in the largest power companies;
- lack of sufficient skills in universities for a new energy sector model
- inadequacy of educational standards in the key areas of training required for the implementation and deployment of smart grid.

In both models of energy sector development, the priority development of microgrids is necessary for isolated and island territories, first and foremost in the Far East of Russia. At present, the territory of decentralised power of the Far Eastern Federal District (FEFD) is home to about 1,160 thousand people out of total 6,400 thousand population in FEFD.

Huge moral and physical wear and tear, high unregulated prices for diesel fuel in the logistically complex northern regions, and high staff pay differentials in power plants and boilers all contribute to the high cost of energy in the decentralised sector — up to RUB 39/KWh and RUB 10,427/Gcal., (2009: RUB 28.02/kWh and RUB 4995/Gcal). High cost of equipment depreciation and repair imply additional burden on the energy tariff rate. In addition, in the absence of a single managing company, management of individual

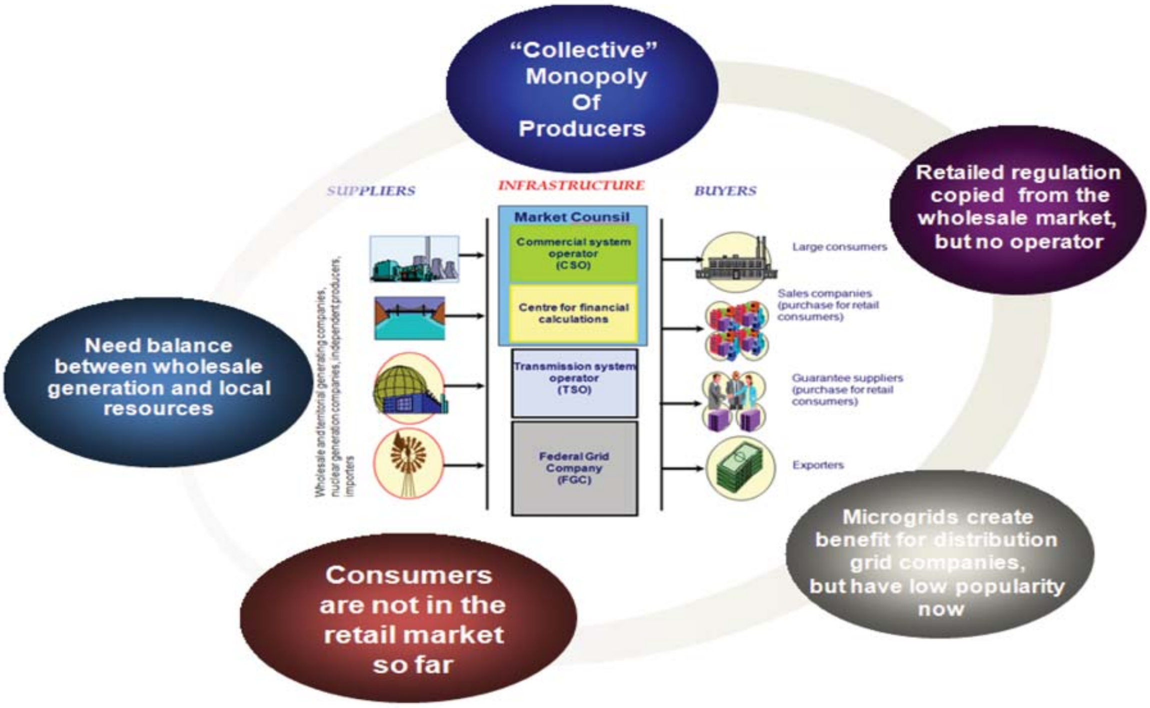


Figure 2. Market: will microgrid lead to a reorganisation of the energy sector?

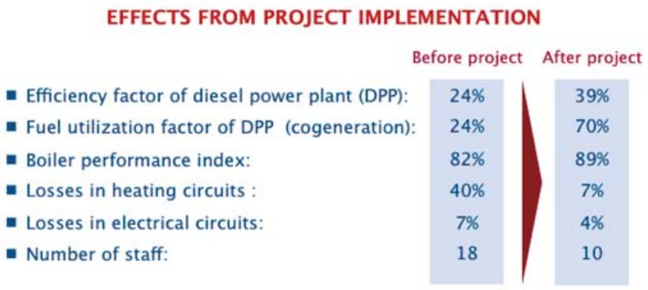
companies in the decentralised energy supply sector increases the managerial overhead.

In 2011, the subsidies from the regional budget to compensate for the difference in rates for people receiving energy from local generation (the total number of inhabitants of the Far East region make up less than 5 per cent of Russia's population) were RUB 1.931 billion, including thermal energy RUB 1.363 billion.

Including the cost of the modernisation and development into the local energy tariffs for electricity and heat is not feasible which makes it almost impossible to attract private investment into the modernisation and development of decentralised energy supply sector of this region. In fact, there is no money not only for the development of energy systems, but also for the necessary maintenance. All of this leads to frequent failures in the energy infrastructure and interruptions in the fuel, heat, and electricity delivery to the customers, and even the threat of bankruptcy of the supplier.

A Simulated Microgrid Project for a Typical Township in Russia's Far East

Overall, an analysis of the current situation in the decentralised energy sector of the Khabarovsk Territory leads to a recognition that the economic efficiency of the regional energy sector is currently at an extremely low level. A realistic and productive approach to the energy development in the region should be based on microgrids and distributed generation, which in the authors' estimates can be quite beneficial, and therefore attractive for investors. Further, the report provides an assessment of the effectiveness of a typical microgrid project for a township in FEFD. The basic scenario is assumed as follows.



EFFECTS FROM PROJECT IMPLEMENTATION

	Before project	After project
■ Efficiency factor of diesel power plant (DPP):	24%	39%
■ Fuel utilization factor of DPP (cogeneration):	24%	70%
■ Boiler performance index:	82%	89%
■ Losses in heating circuits :	40%	7%
■ Losses in electrical circuits:	7%	4%
■ Number of staff:	18	10

Figure 3. Typical microgrid project for a Far Eastern Federal District (FEFD) township: results

Table 1.

STRUCTURE OF CAPITAL INVESTMENTS

Description	Cost, million rubles
Equipment	
DPP	33
Wind turbine	46
Boiler	7
Other equipment	6
Automated process control system	13
Total Equipment	**105**
Facilities, construction and design works	
Construction and design works	67
Electric lines	1
Heat lines	6
Total construction works and facilities	**74**
Total capital investments	**179**

- Annual consumption of electric energy is 1,000 thousand KWh, electric heat — 4,000 GCal.
- Average temperature of the heating season is -20C, duration of heating season — 7-9 months. Considerable part of populated areas is characterised by an adequate wind potential (average speed — over 6 meters per second).
- The length of heating lines is 1,600 m, electrical lines — 9 км.
- Electrical energy tariffs for the operating organisation are approximately RUB 21/kWh, for heat energy — RUB 5,000/GCal.
- Electric energy tariffs for the households are approximately RUB 2/kWh, for heat — RUB 1,500/GCal; the difference between the tariffs is subsidised from the regional budget or from cross-subsidising (the case of the Republic of Sakha — Yakutia).
- Financial breakdown: 50 per cent budget funding, 50 per cent credit (10 years, 11 per cent interest).
- Tariff growth rate in case of project implementation in 2012-2014 does not exceed the forecast of Russia's Ministry of Economic Development.
- Reduction of tariffs on electric energy and heat energy by 30 per cent after the credit repayment.
- Key question for the banks: guarantee of economically justified tariffs for the duration of the credit term.

Evaluation results are shown in Figure 3 and Table 1.

Financial results appear in Table 2 below.

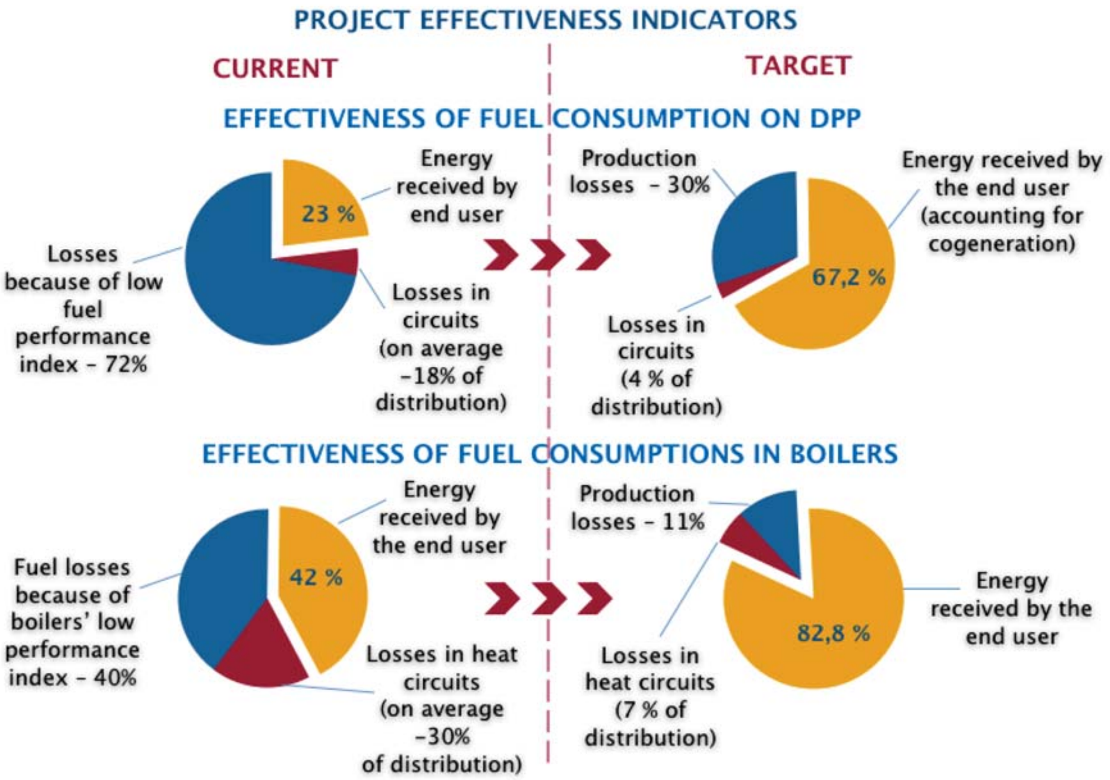


Figure 4. Typical project Microgrids for Far Eastern Federal District (FEFD): project effectiveness indicators

The project is of considerable interest for investors, credit institutions, and FEFD subregions. For the implementation of the projects under consideration, various technical and policy issues should be effectively addressed:

- *Technical:* existence of system of double accounting, coordinated work of local and central generators, appropriate protection systems for all types of local and central generators, maintaining the stability of voltage and frequency in the general networks;
- *Technological:* there must be available equipment for local energy generation (solar panels, wind turbines, co-generation equipment);

Table 2.

FINANCIAL RESULTS

Indicator	Result
Project financing, RUB million including:	217
Financing of the project on account of borrowed funds, mln RUB	111
Financing of the project from the budget funds, mln RUB	106
Payback period (simple), years	9.6
Payback period (discounted), years	12.6
Net present value for the period (NPV) 2011-2025 years, mln RUB	14
Internal cost of capital, per cent	5
Borrowed cost of capital, per cent	11
Internal rate of return for the period (IRR) 2011-2025, per cent	71

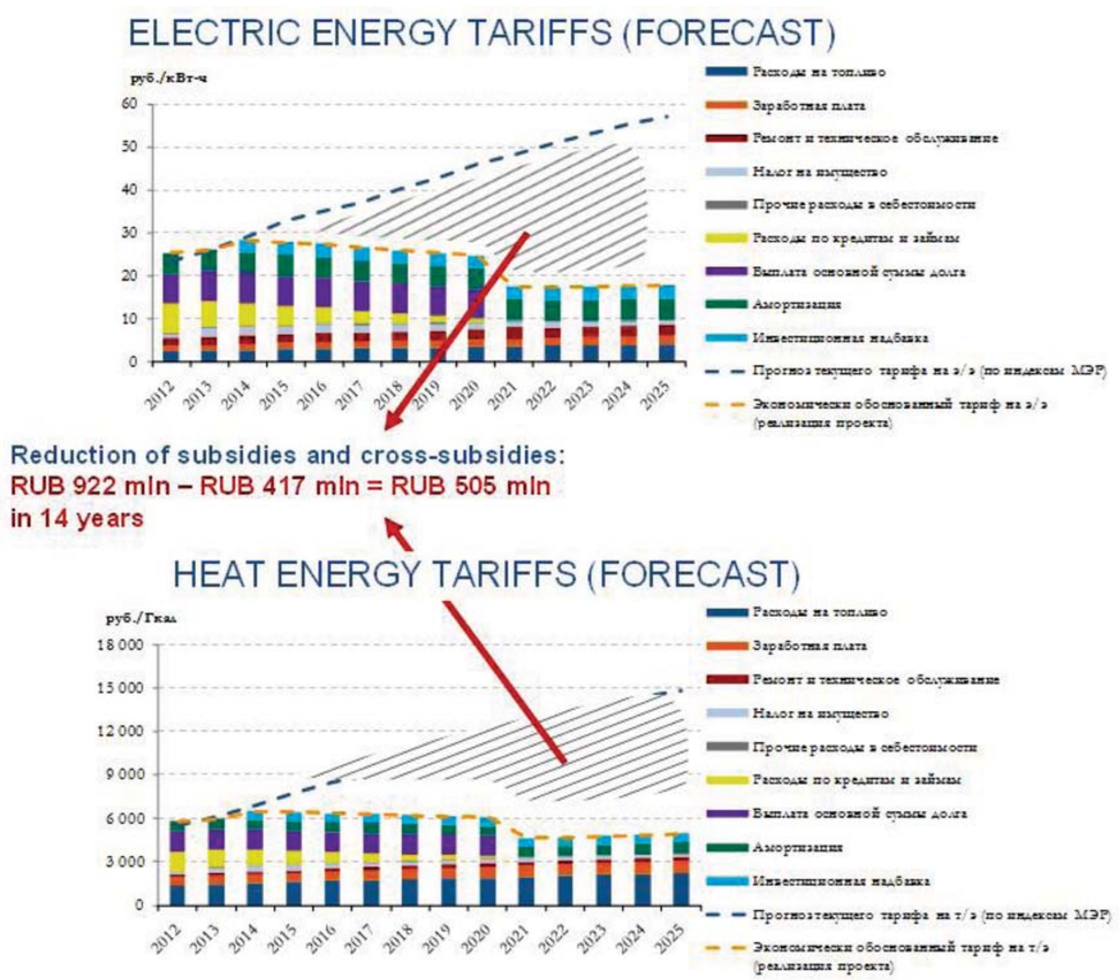


Figure 4. Typical project Microgrids for Far Eastern Federal District (FEFD): tariff forecast

- *Organisational:* there must be coordination between all participants in order to avoid overloads of generating capacities or building extra capacity, which would be underutilised;
- *Legal and economic:* a legal possibility of selling the excesses of self-generated energy to the end user; there must be a developed market for energy or an economically attractive environment for all participants in terms of tariffs for energy usage and transit.

Specific conditions for introduction of microgrids and DG in remote localities and island communities, i.e. state support of projects, aimed at modernising and developing of isolated regions, must include:

- providing long-term tariff rates for the introduced energy facilities for the entire payback period;
- providing budget support on a payback or payback-free basis (subsidies, favorable budget financing, other mechanisms);
- subsidies from the budget of the difference between the economically justified tariff rates and the actual rates;
- elimination of cross-subsidising and transition to direct budget subsidies;
- co-financing from the federal budget funds, including Federal Target Programmes, based on the public-private partnership;
- mechanism of financial injections from the investment funds and other sources.

The Cell Controller Pilot Project[1]

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Introduction

Over the past twenty years, there has been a remarkable transformation in the generation, transmission, and distribution of electric power in Denmark. Prior to 1990, most Danish electric power was produced at large, centralised generation plants from which it was transmitted and distributed to commercial, industrial, and residential consumers. Since then, thousands of generating assets have been installed throughout Denmark, including dispersed combined heat and power plants and wind turbines. The Cell Controller Pilot Project (CCPP) was initiated to develop and demonstrate the capability to use distributed generation and other energy resources connected to distribution networks for grid reliability and power-flow related applications. Moreover, it was recognised that the coordinated control of local assets such as combined heat and power plants, wind turbines, and load control could mimic the operation of a single large power plant, and therefore provide ancillary services such as power balancing, import/export of active and reactive power, and voltage control at select locations within the distribution system. Lastly, in the event of a transmission system emergency, local distribution networks (60 kV and below) could be rapidly isolated from the transmission network (150 kV and above) and operated autonomously using local resources, thereby reducing the impact on consumers and contributing to more rapid recovery from the emergency.

Initiation of the Cell Controller Pilot Project

Due to a constant political wish for environmentally friendly power generation, Denmark has experienced a vast growth in distributed generation (DG). This includes a significant increase in wind power as well as dispersed combined heat and power plants (DCHP).

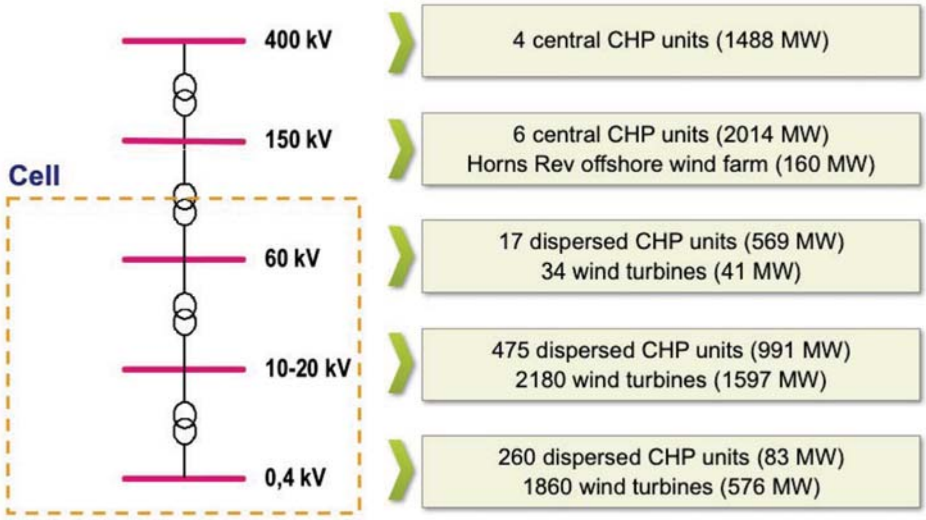

Figure 1. Production capacity per voltage level in the western part of Denmark in 2004

Already early in this millennium, the amount of installed decentralised generation systems had reached very high relative numbers especially in the western Danish power system as depicted in Figure 1. In 2004 the total installed capacity in this area could be summarised to 3,502 MW central power plants, 1,643 MW DCHP units, and 2,374 MW wind turbines (WTs), totalling 7,519 MW. In comparison, the minimum load of the area was approx. 1,150 MW and the maximum load was approx. 3,800 MW.

All of the DCHP units were primarily built for the purpose of providing local district heating. It follows that the electrical power production from these units were tied to the heat demand and not to the power demand. Hence the area of western Denmark experienced power overflows on a regular basis with close correlation to both wind conditions and outdoor temperature.

One of the consequences of this massive build-up of DG was that several 60 kV distribution networks, especially those situated along the coast line to the North Sea with prevailing wind regimes, in fact became net power producers transmitting their excess power up on the 150 kV transmission grid.

The 60 kV distribution systems in Western Denmark (the peninsula of Jutland) has been built as a meshed network with at least two supply possibilities to each 60 kV station and with interconnections between neighbouring distribution companies. The 400 and 150 kV transmission system in Jutland serves partly as a transport corridor between the hydro powered systems of Norway and Sweden and the fossil and nuclear powered systems of Western Europe. Hence to avoid that the 60 kV distribution systems take part in any power transit on the transmission system, the 60 kV distribution systems is operated as isolated radial systems beneath each 150/60 kV transformer station.

Initial Cell Controller Concept

Presently, the operation of the power system still relies on the ancillary services provided by the central generation units. But ideally, it should be possible to operate the decentralised power system without any central generation or central control. It is therefore necessary to completely revise the whole operating concept to deal with such a situation. This paradigm shift requires a major effort which can only be implemented gradually in order to uphold the security of supply.

Generally each local distribution grid connected to the transmission system could form an active network including all local DG assets and all distribution network operator (DNO) facilities. Following this perception the following experiment of thought was devised as the core of the Cell Controller idea.

If the 60 kV distribution grid below each 150/60 kV transformer is defined as an autonomous (self-regulated) Cell with a fully automated Cell Controller with fast data communication to all DCHP plants, WTs, transformers and load feeders within the Cell area inclusive of synchronization equipment on the breaker in the 150/60 kV grid interconnection point, then this Cell can be given one or more of the following technical functionalities:

- Automated transfer to islanded operation at the instance of conditions on the 150 kV transmission system may lead to a blackout;
- Restore the cell to operation in the event of a complete blackout independently of the grid (Black start);
- Maintain frequency and voltage within the cell within acceptable limits;
- Resynchronisation back to the transmission grid to provide power and voltage support to local parts of the transmission system during the repowering sequence.

Genesis of the Danish Cell Project

In 2002-2004, power systems in North America, Italy, Sweden and Denmark all experienced blackouts of large areas involving millions of consumers in each event. All of these blackouts were caused by voltage collapses due to insufficient reactive power resources available locally.

These blackouts were not seen as isolated events but rather as a consequence of the introduction of market driven power systems indicating that the power systems are operated closer to the limits without timely investment in the necessary reinforcements. Hence it was believed that such blackouts can and will happen again.

This perception, combined with the large DG base already at hand, motivated Eltra, the former TSO of western Denmark, to initiate a Cell Controller Pilot Project (CCPP) with the following ambitions:

- *High Ambition*: In case of a regional emergency situation reaching the point of no return, the Cell disconnects itself from the high voltage (HV) grid and transfers to controlled island operation.
- *Moderate Ambition*: After a total system collapse, the Cell black-starts itself to a state of controlled island operation.

A project based on the high ambition was preferred. The outcome of the project aimed at a full utility scale pilot where the envisioned technical functionalities would be developed and tested live.

As indicated above one of the progressive distribution companies of western Denmark agreed to be part of the CCPP and a suitable full 60 kV Cell of that company was selected as the pilot cell. The Cell area selected contained a large number of DG equally shared between DCHPs and WTs thus locally attaining 50 per cent wind penetration. The project did not include local grids for lower voltages than 10 kV.

The participants of the CCPP were:

- Energinet.dk, Skærbæk, Denmark. The national power and gas TSO of Denmark, which initiated, fully financed and did the conceptual design and overall management of the project.
- Syd Energi A/S (now known as SE), Esbjerg, Denmark. Independent Distribution Company and DNO located at the south of Jutland in which grid the pilot Cell was established.
- Spirae Inc, Fort Collins, Colorado, USA. Provides consultancy services and development expertise within smart-grid design and business infrastructure for distributed energy.
- Energynautics GmbH, Langen, Germany. Provides consultancy services to the energy industry focusing on renewable energies and innovative energy applications.

Cell Controller Pilot Project Test Area

The test area for the Cell Controller pilot project is located in western Denmark (Figure 2) in the Holsted area. This region was selected in consultation with Syd Energi (SE), the DNO project partner, and is referred to as the Holsted Cell. The Holsted substation was the interconnection point between the distribution grid (60 kV and below) and the 150 kV sub transmission grid. Consequently the Cell Controller was configured to leverage assets available in the area and to work within grid constraints associated with the Holsted distribution network. Although the Holsted distribution network contained many of the asset classes found throughout Denmark (and the rest of the world), not all classes were represented. For example, as only Danish-style wind turbines were available within the pilot region, controls for more modern wind turbines with "state-of-the-art" controls (WT type 3 and 4) were not developed during the CCPP.

In addition, the topology of the Holsted Cell guided the general deployment strategy of the Cell Controller. Specifically, the Cell Controller master was deployed at the Holsted substation, intermediate control nodes were deployed at substations found throughout the Holsted distribution network, and the end nodes were deployed

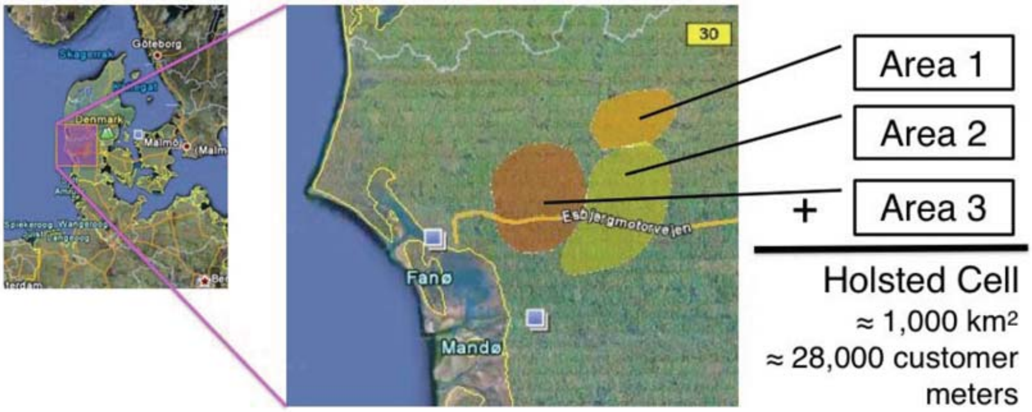

Figure 2. The Holsted Cell (pilot region) located in Western Denmark

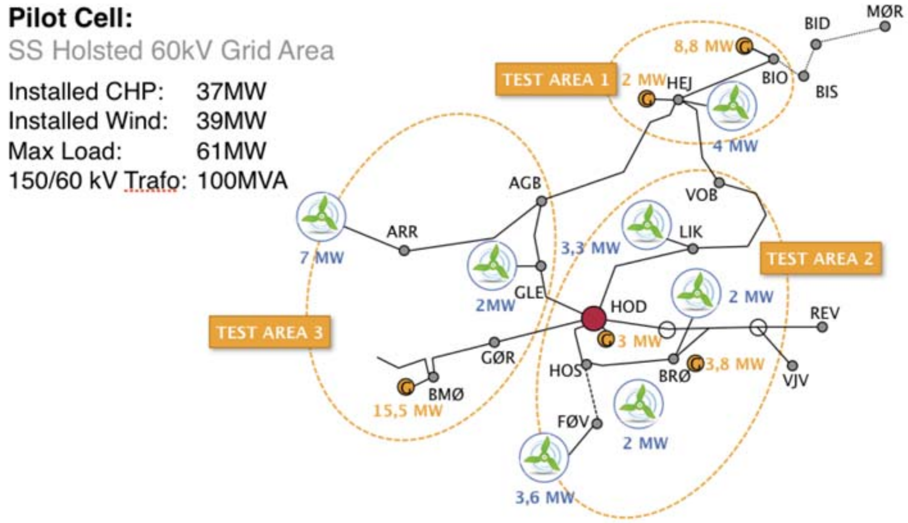

Figure 3. Topology of the Holsted Cell. The cell was divided into three test areas; testing prior to 2008 was performed in Area 1 only; the testing region was expanded to include Area 2 for 2008 and 2009, and all three Areas were involved in the testing done in 2010 and 2011

at each controllable asset such as CHP plants and Wind Turbines. Major Cell Controller design consideration included:

- Prepare for higher penetration renewable DER (current 20 per cent, goal 30 per cent 2020, 50 per cent 2025, carbon neutral by 2050);
- Ensure grid reliability through intentional islanding;
- Enable additional value streams through ancillary services;
- Provide replicable model.

Solving these challenges was expected to yield a robust technical foundation for meeting the ambitious renewables integration and advanced market operations capabilities envisaged by Energinet.dk for future intelligent power system operations. In short, the Cell Controller project had to prove out the technical capabilities needed to foster Smart Grid deployment in Denmark to meet its 2025 goals.

Figure 3 illustrates the topology of the Holsted Cell which was divided into three sub-regions, referenced as Test Areas 1, 2, and 3. The three regions were defined to support a staged deployment strategy. Initial deployment and testing was done in Test Area 1 and the final round of tests included all three areas. Table 1 summarises the assets found within the Holsted Cell; the primary interconnect breaker was located at the Holsted substation in Area 2.

The general strategy employed by the CCPP was to expand the capabilities of the Cell Controller incrementally by first testing and validating solutions at a smaller scale (in the laboratory or on an individual asset), then expanding its reach across multiple assets. Only after “proof of concept” was established would additional functionality be added. Each new phase of the project involved incorporating lessons learned from the previous phase, making modifications to the Cell Controller as needed, adding new functionality, and carrying out model-based, lab-based, and field-based tests in that order.

The CCPP can be roughly divided into three major development phases:

- *2005 – 2007*: Development and deployment of the Cell Monitoring System (CMS) to Areas 1 and 2 of the pilot Cell area; development of the core Cell Controller operations and laboratory testing; procurement of additional field assets and upgrading of the existing CHP plants.
- *2007 – 2009*: Deployment and testing of the Cell Controller in Area 1 of the pilot Cell area.
- *2009 – 2011*: Additions to Cell Controller capabilities; expanded deployment and testing to Areas 2 and 3 of the pilot Cell area.

Capabilities, Deployment and Testing Plan

Islanding of the cell requires an extensive capability set to handle variations in current operating conditions when the island command is received:

- Load shedding to achieve controllable conditions in the case of importing power when islanding;
- Generation shedding in the case of exporting power when islanding;
- Black start in the event no generation is available within the cell when islanded;
- Load restoration when sufficient generation is brought online;
- Frequency and voltage control during island operation;
- Under frequency load shedding;
- Maintenance of frequency and voltage reserves;
- Master synchronization to reconnect to the grid.

The Cell Controller is a complex software application that is distributed across multiple locations and dynamically coordinates the operation of devices and systems at multiple time scales and different geographic ranges to meet specific operational goals. The Cell Controller development team followed a rigorous process of requirements specification, design, development, simulation and lab testing and software release for field testing. Development of the Cell Controller, installation in the test areas, and testing was a multi-year, multi-stage effort:

- Instrument the test area to determine expected operating conditions in the cell;
- Model the cell and perform simulations to validate the model with respect to collected data;
- Validate the control functions against the model;
- Validate the control functions in a physical laboratory environment;
- Install and test the controller and additional equipment in an initial smaller test area;
- Expand and test the controller in larger areas of the cell.

Modelling and Simulation

Cell Controller testing required the implementation of a time-domain simulation model that would behave analogously to the actual distribution network of the Pilot Cell. From the very beginning of the project it was therefore seen as necessary to also build and validate a simulation model of the Pilot Cell electricity grid. The main purpose of the model was twofold:

1. To study the operating boundaries of the distribution system in general, like exploring inherent limits of active and reactive power production in terms of allowed voltage profile boundaries and thermal loading limits;

2. To serve as a test platform for Cell Controller function validation, and testing the algorithms that were developed for distributed voltage control, and frequency control in island operation.

PowerFactory from DiGSILENT was chosen as the power system modelling and simulation tool. Custom interfaces were developed to achieve interoperability with the Cell Controller. The integration strategy was such that the Cell Controller could run on separate hardware, including the hardware to be deployed in the field, with communications between the Cell Controller and the simulation occurring across a network. In this configuration, as far as the Cell Controller was concerned, it was operating the target power system.

In the course of construction, the development of the simulation model followed the strategy of the field implementation: full functionality was first established in Area 1 of the Pilot Cell, and later extended to include Areas 2 and 3. The data collection process included sending questionnaires to grid operators, power plant owners and operators, and manufacturers. All generator sites and substations were visited to collect one-line diagrams, SCADA screenshots, and name plate photographs. This process was repeated for all three stages of the Cell expansion, until all required information had been obtained.

Cell Controller Field Testing

One of the most significant accomplishments of the Cell Controller Pilot Project was the extensive field deployment, testing and the general success of demonstrations on a live power system. As outlined above, much care was taken by the CCPP team to develop, build, and test both the algorithms and the controls in the InteGrid laboratory, hosted in Colorado State University's Engines and Energy Conversion Laboratory in Fort Collins, CO, jointly owned and operated by Spirae and CSU. The algorithms and controls were further refined using comprehensive numerical analysis and simulation. The ultimate payoff was the ability to deploy the Cell Controller incrementally into actual field conditions where testing parameters could not be completely prescribed (e.g. consumer demand, wind conditions, etc.).

The field tests were designed to cover a broad range of operating conditions and usage scenarios and intended to validate technical capabilities that were deemed essential for future power system operations. Some of the most important results were obtained through collection and analysis of field data prior to deployment of the Cell Controller using the CMS, tests to validate the acquisition and deployment of new assets (SLC and SC), then expanding testing to include multiple assets, e.g. testing of a single L1 control, the successful islanding and desynchronizing of the cell with and without wind generation, testing the ability to service multiple parties (e.g. TSO, DNO, BRP) simultaneously.

In order to validate the dynamic models, a series of control system performance tests were conducted at all CHP assets and the synchronous condenser and load bank at commissioning time. The results of the tests were used for model parameter identification, leading to well- validated asset model performance throughout Area 1. Similar to the asset-level testing already conducted in Area 1, commissioning tests for model validation purposes were carried out at the CHP generator units in Area 2 and Area 3. The scope of these tests was adapted from the previous tests as the controllers of the “new” CHP generators were not equipped with the same functions, and additional functions were added in secondary or tertiary control loops.

Despite detailed asset modelling based on manufacturer information, the validation process revealed that significant changes must be made to some controller models, as the measured response could not be matched closely by the model without modifications in the control structure. These changes were applied and the models were re-validated until no further improvement could be achieved from the given set of data recordings.

At this point, after the last CHP model validation in 2010, the model was deemed complete and ready for the preparation of the final field tests in autumn 2010 and summer 2011. This process was started with a series of power system studies, and then continued with extensive Cell Controller testing in scenarios similar to the projected field test cases.

Additional assets for islanding included:

- Secondary Load Controller (SLC): A fast-acting load bank capable of continuous regulation between 0 and 1000 kW on a 40 ms basis.
  — Commissioned 2007
  — Tested 2008 as part of Area 1
- Synchronous Condenser (SC): Rapid reactive power response in the range
  — -250 — +600 kVAR; also equipped with a flywheel for greater inertia.
  — Commissioned 2007
  — Tested 2008 as part of Area 1
- Master Synchronizer (MS): Needed to resynchronize islanded cell with grid.
  — Commissioned 2008
  — Tested 2008 as part of Area 1
  — Moved 2010 to final location in Area 2

Results: Islanding Area 1 (2008)

The first Cell Controller field tests were conducted in Area 1 in late 2008, and were thoroughly prepared by simulations in summer and autumn 2008. After the set of test cases had been specified (determining the set of assets involved in each test, the operating conditions, and the sequence of operation), all scenarios expected during the test were first analysed in load flow calculations. The sequence of events of each test case was then investigated in multiple dynamic simulation runs with the 2008 prototype of the Cell Controller. Total 28 runs of islanding scenarios were tested:

- Of those, 2/3 led to successful resynchronization after islanded operation for at least 15 minutes, never violating grid codes/ protection settings;
- Remaining cases led to brief blackouts. Root causes were identified: not traceable to Cell Controller design or execution.

During the field tests, extensive data recordings were collected at the substations and the generation assets (and the load bank). The purpose of these data was to allow for detailed analysis in case of test failure, further model validation, and development of improved load feeder models. This data analysis was undertaken over several months in 2008 until late 2009.

Results: SLC and SC (2008)

The analysis of SLC and SC was performed to test the Cell Controller capabilities to transition to island and perform island operations in a wind only state. Test Setup and Initial Conditions included the mini-island consisted of a single wind turbine, the SC and the SLC.

The SLC and the SC were able to support the frequency and voltage of the mini-island for more than five (5) minutes. Figure 4 and Figure 5 illustrate very effective control of the cell frequency (black) and voltage (blue), respectively. Figure 4 also shows that the SLC was able to balance the wind generation during the first 5 minutes during island operation. Hereafter the 1000 kW SLC began to dramatically lag during the very large wind transient then occurring resulting in 1100 kW wind turbine production which ultimately lead to blackout of the mini-island.

The mini-island test matched the SLC to a single wind turbine; as soon as sufficient wind energy was put into the wind turbine, the SLC went to its upper limit and stayed there. The SLC had no resources with which to counteract the increasing wind energy and the wind turbine shutdown on turbine over-speed. Analysis of four wind turbines using the data collected with the CMS shows that there can be a significant amount of variation between wind turbine power outputs even when the turbines are geographically close to one another. However the natural variation of the loads typically cancels the variability of generation, thereby implying that the SLC could balance multiple turbines if combined with dispersed loads.

Results: Areas 1—3 Islanded (2011)

In work conducted in parallel to the Area 1 field test preparation and data analysis, the simulation model was extended to cover the further substations in Area 2 (six additional 60 kV substations) and Area 3 (five more). Dynamic models were built for all 43 additional wind turbines and the six additional CHP generators.

- All island operations tested and validated with full cell:

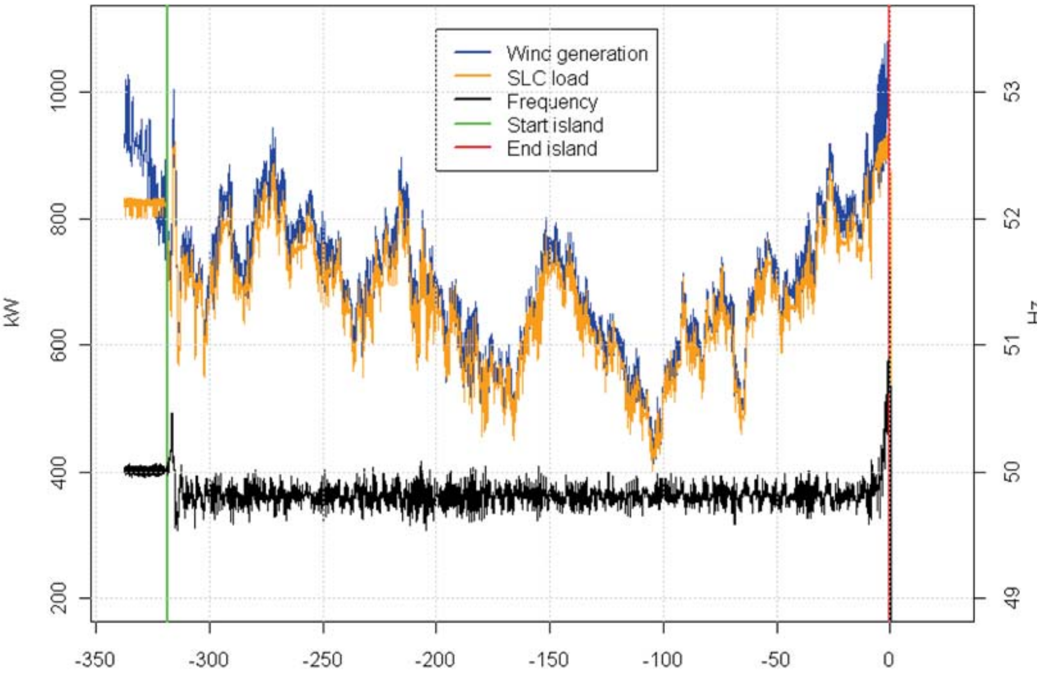

Figure 4. Effect of SLC during the Mini-Island Test. The black trace plots the observed frequency (Hz); the blue and orange traces plot wind generation (kW) and the SLC response (kW), respectively. The Cell Controller was able to maintain a stable frequency (nominal 50 Hz) during the test prior to black out. Note the SLC's ability to balance the wind generation

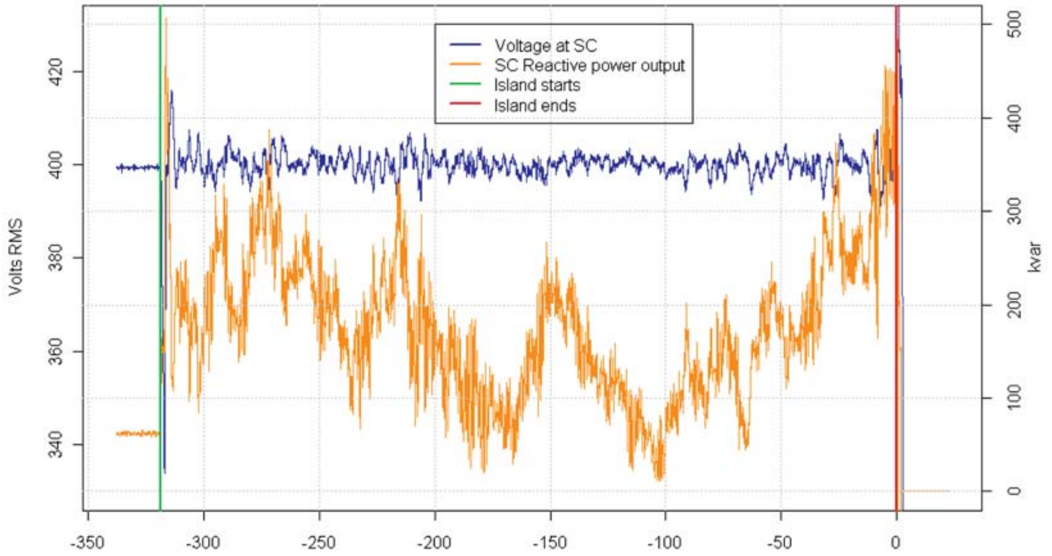

Figure 5. Effect of SC during the Mini-Island Test. The blue and orange traces plot the voltage and kVAR, respectively, measured at the SC. The Cell Controller was able to maintain a stable voltage until black out; as expected, the trace of the SC closely follows the wind generation trace

- Preload plan: rapid shedding of load and/or wind turbines;
- Load restoration;
- Island voltage control;
- Under-frequency load shedding;
- Resynchronization.

Results: Islanded Frequency and Voltage Management

One test was implemented to verify (i) the preload plan (PLP) operation when cell assets were participating in day-ahead market and (ii) the load restoration operation. Test setup included approx. 15 MW load across 9 substations, Approx. 4 MW online wind capacity, 3 CHP plants online.

This test was a complete success: the preload plan functioned as expected, the load restoration was successful, and the cell was resynchronized to the grid after eight (8) minutes of island operation. The cell frequency remains stable throughout the test with a maximum frequency excursion of -0.69 Hz which occurs at 15:21:14 (Figure 6) which coincides with the restoration of the Billund SØK load (Figure 7). Due to the significant presence of wind generation, the Cell Controller successfully dispatched the generation of reactive power to balance the cell as depicted in Figure 7.

Project Outcomes, Conclusions and Lessons Learned

The initial goal of the CCPP was to develop and field test a control system with a distributable control architecture capable of rapidly islanding a distribution network below a 150/60 kV substation upon receiving a one-second trigger signal from the transmission system operator.

The CCPP has successfully achieved this goal by carefully designing, modelling & simulating, building, and testing in both the laboratory and the field a distributed control system (Cell Controller) that safely islanded the Holsted Cell. The Cell Controller coordinated one 150/60 kV substation with tap changer controlled transformer, 13 substations (60/10 kV), 5 CHP plants, 47 wind turbines, 69 load feeders, and numerous additional assets (breakers, SLC, SC, etc.) to separate from the high-voltage transmission grid (150 kV), operate independently, and ultimately resynchronize and re-connect when commanded by the TSO.

The key capabilities of the CCPP were identified as follows:

- Power Import/Export using DER at remote inter-ties;
- Firm wind production using DER;
- Aggregated market participation for DER;

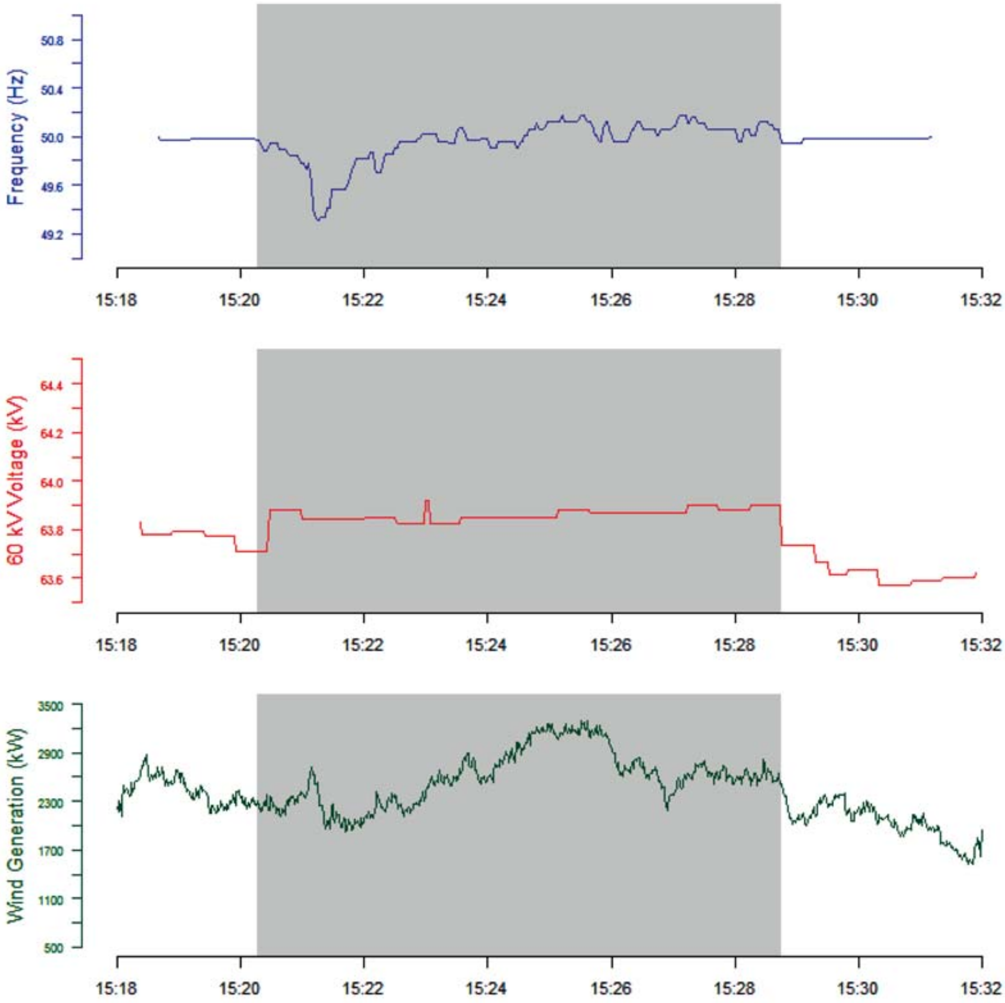

Figure 6. Island Frequency and Voltage Stability during Preload Plan with Small Import Test. The traces plot the cell frequency (Hz), the 60 kV voltage, and the total wind generation (kW). The region shaded grey indicates the time where the primary interconnect was open. The cell was able to maintain stable voltage and frequency in the presence of significant wind generation. The largest deviation in frequency occurs at 15:21:30 which coincides with a drop in wind generation and the restoration of the first load

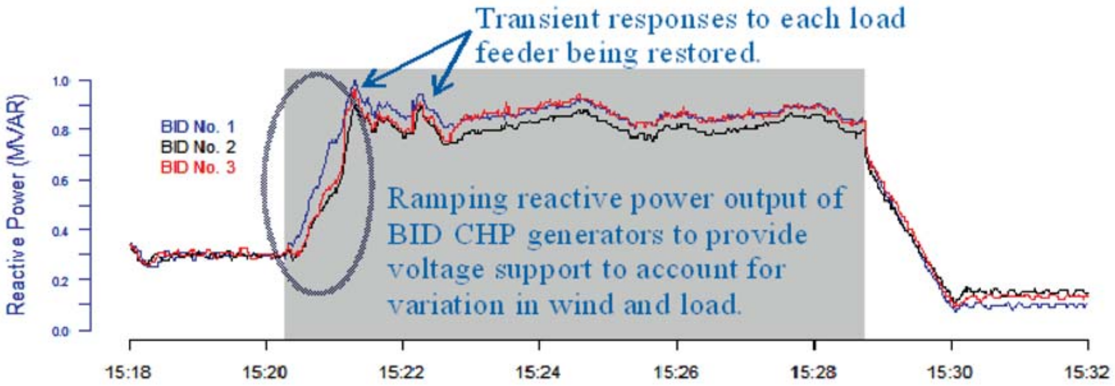

Figure 7. Reactive Power Support during Preload Plan with Small Import Test. Due to the significant presence of wind generation, the Cell Controller successfully dispatches the generation of reactive power to balance the cell

- Feeder Volt/VAR control using DER;
- Fast islanding and resynchronisation.

The benefits of the CCPP include:

- Maximise value of DER by exposing multiple value streams;
- DNO can enable new services to multiple parties;
- TSO leverages assets on distribution network for reliability and optimisation;
- Market Operators can aggregate and dispatch DER to market;
- Same portfolio of DER can be used for multiple applications.

The future of land based energy generation and distribution is clearly moving away from the traditional centralised model. As the penetration level of distributed generation continues to increase there will inevitably be more and more opportunities to define cells (regions where local generation meets or exceeds local loading) to which coordinated control can be deployed. The CCPP successfully demonstrated that coordinated control of DER is not only possible, but adds significant benefits and potential services to all stakeholder levels.

Endnotes

[1] This article draws on *Cell Controller Pilot Project: 2011 Public Report*, published by Energinet.dk. The full report is available at: http://energinet.dk/EN/FORSKNING/Nyheder/Sider/Den-ustyrlige-vind-kan-styres.aspx.

Energinet.dk, based in Erritsø, Denmark, is the national transmission system operator for electricity and natural gas in Denmark which initiated, fully financed and did the conceptual design and overall management of the Cell Controller Pilot Project. Per Lund, Chief Design Engineer, and Stig Holm Sørensen, Chief Project Manager, lead the project for Energinet.dk.

Self-Management Capacity Diagnosis of a Rural Community for a Microgrid Project

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Introduction

Access to electricity is one of the principal needs of the humanity nowadays. Many rural communities don't have this service and renewable power appears as a solution, mostly thanks to the autonomy that it can deliver to the communities off the network of electric power. As far as this type of solutions is concerned, it is necessary to think that the implementation of electric generation technologies will bring about a change in the communities which must be treated as an integral part throughout the project development. In addition, one must consider that the community should be responsible for the project and should ensure its sustainability, that's why the capacity for community self-management will be fundamental to embrace new solutions for the electricity problem.

The objective of this work was to diagnose the capacity of self-management of a rural community for the development of microgrid projects with wind and solar power, to propose a system of self-management which would encourage the community to take responsibility for local power facilities while addressing all dimensions of sustainability (social, economic, environmental, technological, institutional). We understand microgrid as a social concept: it helps meeting community's energy needs, but is also a driver of the local development and gives autonomy to the isolated communities. Given that technological innovation is introduced at a community level, as is the case with the rural microgrid projects, one of the challenges takes root in the non-existence of a permanent local structure for administration and decision-making. This may lead to a situation where innovations do not last long.

It is for this reason why it is necessary to identify the criteria for a local structure that should be responsible for the operation, maintenance and overall sustainability of the project. In this context, we consider creating a local management structure that represents the whole community and is in charge of the local power system. But to propose a model of management, we need to know the characteristics of the community, those who are external actors, who have influence in the area, the existing projections of development, activities that can be promoted by upgrading the electric supply in the locality.

To address the issues identified above, we should stress the importance of an interdisciplinary approach towards this type of projects that will provide a comprehensive vision of the area and could deliver integrated solutions.

Local Sustainable Development Model

Beyond addressing the need for electricity, a microgrid project also aims at creating enabling conditions for the emergence of activities that benefit the local population and contribute to the organisation of the community. It initiates a cooperative social process for the local development with a collective sense.

From this perspective, we understand sustainability in an environmental and social dimension. Environmental sustainability is based on the functioning of the biophysical systems and the rational use of the natural resources, in order to achieve a balanced reciprocal relation between the nature and the human communities, to assure availability of the necessary natural resources in the future for the well-being of the local population. Social sustainability is understood as a process of strengthening of human communities on the basis of the establishment of harmonic relations with their natural and social environment, promotion of dialogue and horizontal relations of the community that is developing a microgrid project. Building on the definition of sustainable development, the community is the principal actor, capable of appropriating the projects. Communities are the drivers and owners of these development projects with the necessary support of external agents as strategic allies.

It is the idea that makes way for itself in the experiences of development where communities and the external agents engage in a partnership and share responsibilities in proportion to their contribution to the design, execution and project evaluation at a local level. But in order that the community takes the responsibility if of the project, it is needed to promote deep processes of participation, self-management and build share capital in line with the priorities of community development. In accordance with the foundations of the proposed development model, the community participation must not be a mere aspiration or a declaration of intention, but it should be fully substantiated in practice through the effective participation of the communities in decision-making relative to all the stages of the project development. Community self-management is considered to be fundamental for the local population to use and control a microgrid project from technical, administrative and social point of view. A related objective is to strengthen human capital that is necessary to fulfill community development proposals. To achieve an effective community self-management, relevant organisations should be fundamentally based on the relations of cooperation. These organisations are related with the third component of the model: share capital. The diverse studies conducted in rural Chilean communities found a low level of community organisation with serious problems of functioning of the formal organisations, a marked individualism, and a questioned leadership. This situation reflects the weakness of communities in front of the challenges that the general model imposes on the development. This said, strengthening of the relations of confidence, cooperation and reciprocity between the community members, fundamental relations to reveal and promote the share capital are of greater importance.

The Project and the Implementation

We take the model of local sustainable development as a theoretical foundation and consider the components and functioning and, in turn, the objectives and goals of a community proposal to develop a microgrid project. The interdisciplinary consideration of the drivers of the local development must be organised in four fundamental variables: technical, economic, social and environmental. The integrated management of these variables enables the social and environmental sustainability of the projects and the sustainability of the local communities at a rural level at present and in the future.

We have conducted a case study to diagnose a community self-management capacity for the development of a microgrid project. One of the objectives of the study was to generate a replicable methodology for other rural communities.

In this study, we considered the following aspects:

- learn how a community is organised in terms of use of local resources;
- evaluate economic, social, environmental opportunities and barriers for the implementation of a microgrid with renewable power in the surveyed community;
- analyse and propose a self-management system for the development of a microgrid project with renewable power in the surveyed community.

The proposed self-management system was conceived with the assumption that the community had interest in making decisions on the design of the initiative and in taking the responsibility of the administration. This setup is appropriate to investigate the development of a microgrid with renewable power, specifically wind and solar, that also relies on the support of an existing diesel engine that generates the electricity for the community at present.

It is also assumed that there is a permanent local structure in charge of the power system with decision-making and administrative functions. A distinction is made between a transition structure and the final structure.

The transition structure is based on the characteristics of the community and accounts for two specific features detected through the study: municipal assistance and a “custom of not paying for the basic services". The structure attempts to achieve a transition in which the community manages to appropriate the project, decrease the municipal assistance and change the mindset as to paying for the electricity. The electricity cost will be defined by all the actors involved on the basis of the level of economic well-being of the community members.

The transition structure corresponds to a hybrid self-management system while the final structure corresponds to the community self-management system.

Self-management Hybrid System

Considering the threat that the municipal assistance represents for the implementation of the microgrid with renewable power in the area under study, it should be gradually eradicated. One goal is therefore to establish a hybrid (transitional) system between the community and the municipality. This step includes setting up a cooperative where the beneficiary of the service participates as a whole and the municipality is represented by a designated official.

The proposed structure appears in Figure 1. The following components may be discerned:

- Administrative agency — involves the community cooperative and the municipal managers of the power system;
- Advisory body — will engage a manager to provide technical and administrative support to the community on the functioning of the microgrid. For this responsibility, contractors of the project may be considered (professionals of the Energy Center, Faculty of Physical and Mathematical Sciences, University of Chile (CE-FCFM) meet the requirements since it possesses the knowledge of the implemented technologies);
- Cooperative body — will handle the contributions to the community that originate from private entities with influence in the area. It is suggested to keep the relation of cooperation, but focus on contributions that are destined for the maintenance of the microgrid.

The cooperative will have to rely on a board that should consider the participation of the natural leaders and the current operators of the system, if there is interest to take part in this organisation. In addition, there will be a designated representative of the municipality on the board, so that the municipality has a stake in the functioning and decision-making of the cooperative. The responsibilities of the cooperative will include:

- *Report to the community*

Reporting on the system operation, disclosing the accounts, inviting to meetings when it is necessary to take decisions, report in case of faults of the system, and identify response upon the information from the advisory body.

- *Maintenance*

Maintenance of the microgrid for which it will have to implement a protocol as advised by the CE-FCFM (which is part of the advisory body).

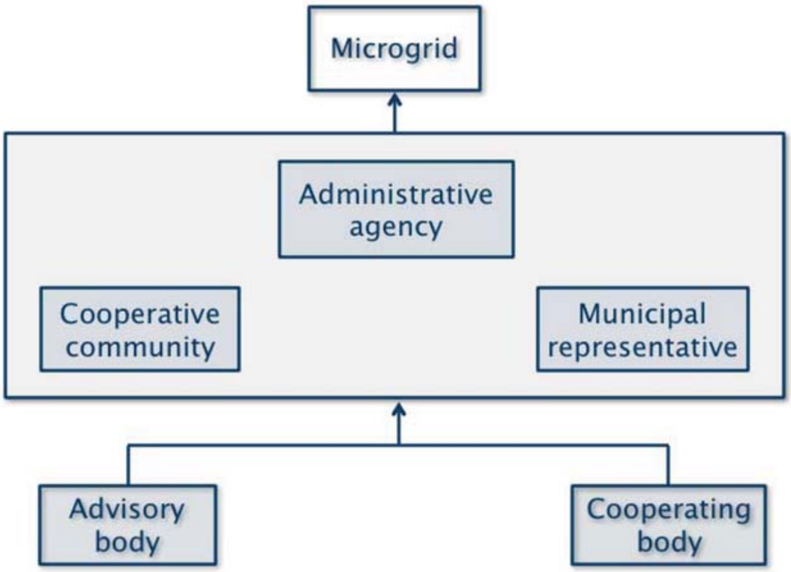

Figure 1: Self-managed hybrid system

- *Operation of the system*

The system will serve the members of the local community for which the cooperative will be the manager of contracting personnel, considering those persons who have the intention to support the system. In addition, the cooperative will coordinate technical training for the members of the advisory body.

The cooperative will be shaped prior to the construction of the microgrid in the stage of socialisation of the project via workshops that will be developed by the project contractors. These meetings will help raising awareness of the community members and will allow them to take part in setting up the cooperative. As soon as the community knows the advantages and disadvantages of the project, it will have to choose the board to represent the whole cooperative and to fulfill the functions described above. The campaign to raise the community awareness will be targeted to ensure a good understanding of some of the core cooperative principles: the service is produced completely by the community, it will be necessary to pay for this service. However, it should be made clear that for the transition period, the community will not pay all the costs associated with the system and the costs will be covered by the cooperative agents and the municipality. Besides, the community should understand that during the transition period, the municipality will continue to be a stakeholder, reflected in the active participation of a municipal civil servant in the board.

Once the board is established, it will conduct training for the community members and instruct them on technical topics of the operation and maintenance of the microgrid as well as administration. CE-FCFM will be technically responsible for the training.

Self-management Community System

As soon as the transition period expires, the full community management will take shape. This is a self-management community system, with the modifications that may be summarised as follows:

- cooperative formed only by the community;
- municipality performs the role of an overseeing body;
- “Pay for the electrical service!” At this stage, the cooperative will terminate the membership in the board of a municipal representative and will have the meetings and performance of the cooperative evaluated. If the cooperative doesn’t fulfill the initial objectives, it would undergo a change, otherwise it will continue with the current functions.

When the municipality is not present any longer in the board of the cooperative, it will assume an overseer's role. The municipality will be in charge of auditing the cooperative and reviewing its adherence to the existing protocols. At this stage, the board will have to take charge of the payments of the service according to the scheme selected by the cooperative. For this purpose, it will have to contract personnel that would read the meters and ensure that this personnel had attended the training organised by the board of the cooperative.

The structure that will work at this stage supports engaging collaborators which will contribute to the operation of the system when it is necessary but will keep their interventions at a minimum. This scheme in a hierarchic form appears in Figure 2.

This self-management system ensures that the community takes responsibility of the electric system. It should maintain a decision-making process directed by the board of the cooperative which will involve the whole community as a leading stakeholder in the power system.

An important aspect of which the cooperative will have to take charge, is decision-making related to the functioning of the system. Those decisions that should be approved at the board level are the most important:

- organisation of the meetings on the part of the board;

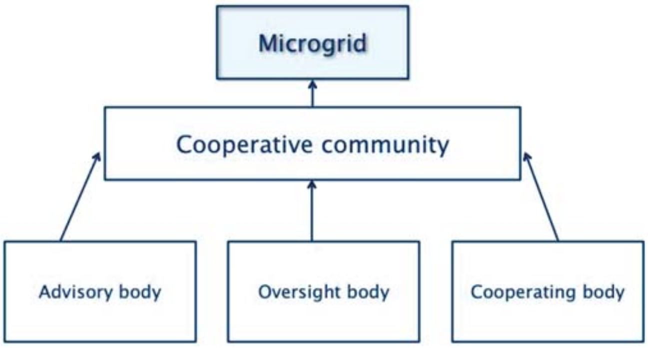

Figure 2: Self-managed community system

- accountability to all the actors of the system, including the presence of a representative in the advisory body;
- willingness to provide background information, in a clear way, on the situation that needs a decision.

All the actors together will have to choose the best solutions.

As regards another aspect for the development of energy projects, it is essential to involve the target community in the whole process, beginning with the presentation and validation of the selected project setup. A common way to raise awareness is arranging a series of workshops that explain the project, its benefits and the participation that is expected from the community.

For this system, it is also necessary to reserve the possibility of generating share capital in the community, besides reducing responsibility of the electric system to the municipality.

This self-management model also offers an advantage associated with other actors since they would become stakeholders of the community electric system. Meanwhile, a local managing body that is the cooperative would assume all the responsibilities of the functioning of the system.

A weakness typical to this system takes root in that the functioning of the cooperative depends on the degree of motivation on the part of the board members. As was revealed by true community experiences, there is a high probability that the motivation of the members of the cooperative is unstable.

Testing the Methodology: a Microgrid for Ollagüe Village

The implementation of the proposed model is currently in progress in a northern village of Chile, Ollagüe (see Figures 3, 4). It is a remote village at the Chile-Bolivia border, about 215 km northeast of the city of Calama and it has the population of 131 persons (in 2011). Overall result is that people showed interest and availability to participate in the self-managed structure, trained by the expert entity that supports them in the first years.

More specifically, lessons already learnt from this pilot project indicated the following positive outcomes:

- participation in social organisation;
- interest in a high quality power system;
- emergence of natural leaders;
- current system operated by people in the community;
- interest in promoting tourism;
- external actors have interest in being part of the solution;
- promotion of the microgrid facilities as a tourist route;
- economic benefits.

Figure 3. Ollagüe village, North of Chile

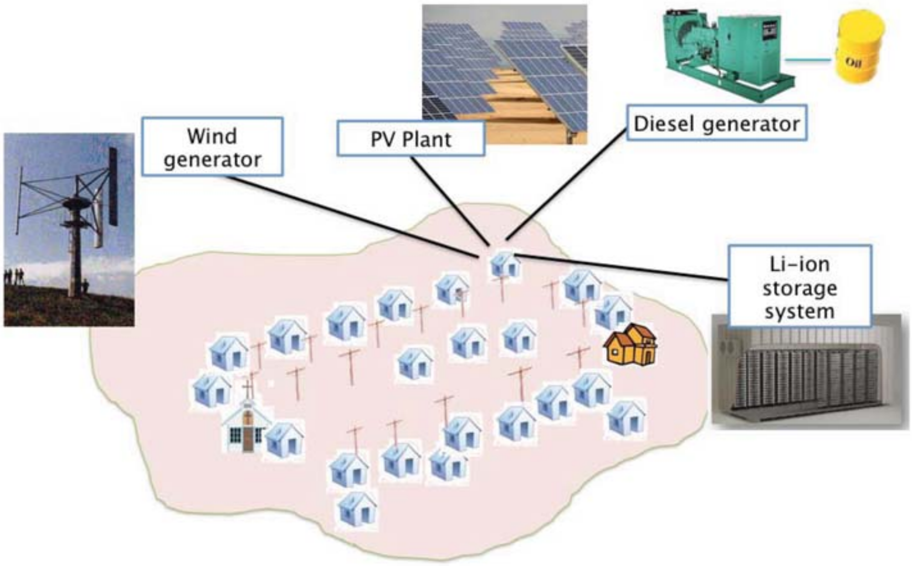

Figure 4. Outline of the microgrid for Ollagüe village, Chile

Meanwhile, the pilot revealed the following shortcomings:

- lack of social cohesion;
- lack of social capital;
- lack of experience in community projects;
- “welfarism”;
- high migration;
- project underperformance relative to the needs and expectations;
- community without energy efficiency behavior;
- no payment for services.

Future work will therefore include:

- validate the results with the community and bring them into the whole process of project development;
- support and advise on the creation and operation of the cooperative;
- develop an action agenda and / or an energy efficiency plan;
- launch trial run period and differential subsidy system in the first months of the implementation of the project.

Microgrids in Alaska

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Introduction

Kotzebue Electric Association Inc. (KEA) is a small utility that operates a generation and distribution system in Kotzebue Alaska 30 miles above the Arctic Circle. The city of Kotzebue is located 67 deg. North latitude, 162 deg. West longitude at the tip of the Baldwin Peninsula on Kotzebue Sound in Northwestern Alaska (see figure 1). Climatic conditions at Kotzebue are characterised by long cold winters and cool summers.

This report is intended to cover several topics related to microgrids. The issue of governance is discussed as it relates to the capability of the utility to make decisions related to technology demonstrations that in other circumstances would not have happened. Projects as they relate to the economic development for the community are also described. The report shows that in order to incorporate renewables a lot of innovation and perseverance was required. Also described is the level of accomplishment while minimising risk to the consumer.

Rural Alaskan Utilities

Small stand-alone utilities are a standard part of the landscape in rural Alaska. There are 183 PCE (Power Cost Equalisation) communities that are off grid, not connected to any road system and are diesel powered. These islanded electric grids provide central station electric service to their communities either independently, or as part of a larger cooperative.

These small grids can be defined as microgrids with the added note that they are critical in the protection of infrastructure i.e. state supported schools in each community, water and sewer systems, and municipal buildings. These diesel utilities usually have three engines per utility, the majority of which are less than 300 kW in size.

Practically all of the communities are located in a coastal area or are on one of the major rivers in the state. Fuel is typically purchased for the entire year in an annual delivery during the summer barge season. The majority of the communities in the northern and western part of the state are only ice free for 3-4 months each year. A number of communities do not have barge access and receive their fuel by air transport. These communities pay a premium for air delivery which can add 30-70 per cent to the delivered cost. These logistics create increased cost for all goods and services.

There are a growing number of rural utilities that are adding some form of renewable energy (mostly wind) to their systems to reduce the cost of energy. Distances from population centers are significant for these communities and travel to the largest state cities usually involves travel to a hub community and then a transfer to a jet or commuter plane to complete the journey.

Energy costs double from the rail-belt (the area served by the Alaska Railroad including Anchorage and Fairbanks) to the hub communities Barrow, Bethel, Dillingham, Kotzebue, and Nome. These hub communities serve as the regional transportation, medical and educational centers for the respective regions. Prices double again with the additional transportation link to the smaller villages (air or barge).

Kotzebue Electric Association (KEA) first generated electric diesel power in 1954. This was after first receiving a loan from the REA (now called RUS for the Rural Utility Service). KEA provides power for Kotzebue Alaska, a community of over 3,500 people and a service hub for all villages in this northwest region of Alaska. KEA has a fulltime staff of 16 people, including powerplant operators, diesel mechanics, linemen and administrative staff. KEA has a peak electrical load of approximately 3,700 kW. In addition to operating the local utility, KEA has agreements

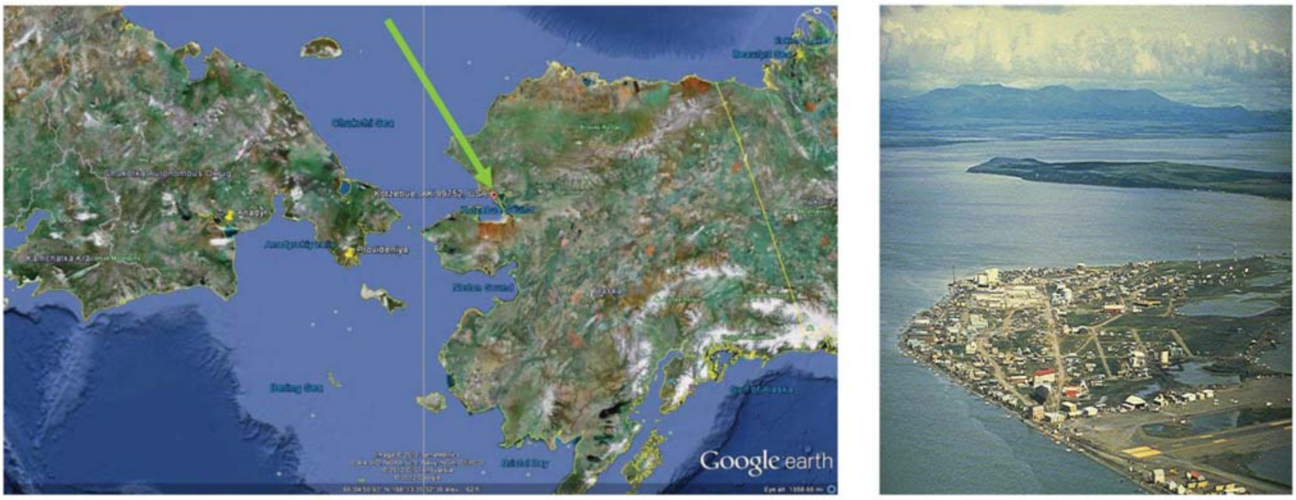


Figure 1. Location and an aerial view of Kotzebue Alaska

with other communities in the region to provide utility operations and maintenance assistance. The utility currently has 1,272 meters, 17 miles of distribution, and 22 million annual kWh sales.

Power Cost Equalisation

In 1982, the State of Alaska created a programme to reduce the cost of electricity for the residential customers and municipal services in rural communities that operated on diesel. This was done in recognition that the more populous areas of Alaska had received state funded infrastructure that did not help the rural areas of the state. The programme has had several name changes over time but is currently called the "Power Cost Equalisation" (PCE) programme. A few highlights of the programme are listed below.

- PCE programme reduces cost (1st 500 kWh) for residential consumers;
- The cost is based upon the average of Anchorage, Juneau and Fairbank's cost of power;
- The subsidy applies to all kWh that are used for public facilities, such as streetlights, water plants, police and fire stations public buildings etc.

In 2011, the State of Alaska paid over US$ 31 million to fully fund the programme (mostly from the PCE Endowment Fund). There is no similar programme to address heating costs and although PCE helps rural residents they still pay 30-40 per cent of their disposable income for energy compared to 10-15 per cent for urban consumers.

Development of Wind as a Resource

Kotzebue Electric Association embarked on a wind programme in the early 1990's to prepare for the loss of the PCE programme which at that time was under constant threat of elimination by the legislature. Although the programme has continued a larger threat to the utility appeared in the form of escalating fuel cost. In simple terms the cost of fuel doubled from 2002-2005, and then practically doubled again from 2005-2008.

In 1995, KEA acquired a 148 acre site leased from Kikiktagruk Inupiat Corporation (KIC), the local Native village corporation. The site is located about 4.5 miles to the southeast of Kotzebue, Alaska on the northwest coast about 30 miles above the Arctic Circle. It is located about 0.5 miles inland from the coast and is about 50 feet above mean sea level. It is relatively flat, with a surface characterised as tundra. It is underlain by permafrost and is officially classified as "wetlands". The tundra is characterised as well vegetated with mossy plants, with other low-growing plants (berry bushes and scrub). The area is completely treeless. There are bird populations, typically various types of gulls, shore birds, and migratory waterfowl with most being ground nesters. At times, there are transient caribou, moose and musk ox which pass through the site. The site is not visible from the town of Kotzebue.

Kotzebue Electric Association's first construction venture was to establish a three turbine wind farm, installed on the site with KEA and State of

Alaska grant funds. The turbines are fully functional and are connected back to the KEA power plant. Full operation was achieved in August 1997. Although the weather is severe the turbines performed very well for many years as reported in the US DOE Turbine Verification Programme. The turbines selected were the Atlantic Orient Corporation 15/50 machines that were made in Vermont. The turbines were selected for 2 reasons: (1) AOC was interested in working in the North, and (2) KEA was supporting US DOE cold weather research. The initial design for the AOC turbines came from the 14/40 Enertech first made in the 1980's. Several bankruptcies (AOC/EWS: Entegrity Wind Systems replaced AOC and also went bankrupt) and equipment issues have affected the operation of the equipment over time.

The Cooperative Model of Business in Rural Alaska

KEA is a non-profit consumer owned electric cooperative, governed by a nine-member Board of Directors elected from the membership. In Alaska, over 50 per cent of all utilities are cooperatives including the largest utility in Alaska, Chugach Electric which serves the Anchorage area. Another 30 per cent of Alaskan utilities are municipally owned, which makes Alaska a mostly Public Power State.

The Cooperative structure has worked well in Alaska and is based upon 7 principals which are listed below.

1. Voluntary and Open Membership

Cooperatives are voluntary organisations, open to all persons able to use their services and willing to accept the responsibilities of membership, without gender, social, racial, political, or religious discrimination.

2. Democratic Member Control

Cooperatives are democratic organisations controlled by their members, who actively participate in setting policies and making decisions. The elected representatives are accountable to the membership. In primary cooperatives, members have equal voting rights (one member, one vote) and cooperatives at other levels are organised in a democratic manner.

3. Members' Economic Participation

Members contribute equitably to, and democratically control, the capital of their cooperative. At least part of that capital is usually the common property of the cooperative. Members usually receive limited compensation, if any, on capital subscribed as a condition of membership.

Members allocate surpluses for any or all of the following purposes: (1) developing the cooperative, possibly by setting up reserves, part of which at least would be indivisible; (2) benefiting members in proportion to their transactions with the cooperative; and (3) supporting other activities approved by the membership.

4. Autonomy and Independence

Cooperatives are autonomous, self-help organisations controlled by their members. If they enter into agreements with other organisations, including governments, or raise capital from external sources, they do so on terms that ensure democratic control by their members and maintain their cooperative autonomy.

5. Education, Training, and Information

Cooperatives provide education and training for their members, elected representatives, managers, and employees so they can contribute effectively to the development of their cooperatives. They inform the general public, particularly young people and opinion leaders, about the nature and benefits of cooperation.

6. Cooperation among Cooperatives

Cooperatives serve their members most effectively and strengthen the cooperative movement by working together through local, national, regional, and international structures.

7. Concern for Community

While focusing on member needs, cooperatives work for the sustainable development of their communities through policies accepted by their members.

On a larger scale there are over 900 cooperatives in the US that act in unison to protect their customers, lobby congress, provide insurance and pension services and have a research component CRN (Cooperative Research Network). It was cooperative money from CRN's predecessor the RER (Rural Electric Research) that was the source of the initial grant that began the process of KEA's progression to having a reliable wind power plant.

Alaska Wind Background

In the early 1980's, the State of Alaska invested in the installation of over 140 small wind turbines

Figure 2. The Electric Cooperative Network in the United States

across rural Alaska. These investments met with limited success not only because the equipment was poorly designed but also because little was known about how to service and maintain the equipment to obtain optimum performance. After this experience the state was unwilling for a period of years to invest in wind equipment.

Timeline of KEA Wind Activities/Progress

- 1992 — Received a grant from the Rural Electric Research, the research arm of the National Rural Electric Cooperative Association (NRECA) for "Power Quality Study with Induction Wind Turbines". This grant brought valuable industry recognition. It should be noted that this cooperative based grant opened the door for many future wind activities.
- 1992 — Joined the "Utility Wind Interest Group" This group provided research and was an important source of information regarding wind integration activities.
- 1993 — Found a company willing to work in Alaska, Atlantic Orient Corporation.
- 1993 — KEA Board committed US$ 250,000 to develop a wind project.
- 1995 — Kotzebue Electric Association and the State of Alaska Department of Community and Regional Affairs Division of Energy (DCRA) entered into an agreement to develop wind energy systems for rural communities. The Kotzebue Wind project was begun in 1995 to demonstrate the viability of operating wind turbines in rural Alaska. The goals of the Kotzebue turbine test programme were to evaluate the commercial viability of wind energy in rural Alaska, gain field experience with mid-sized commercial wind turbines, describe the experience gained and problems encountered, and then transfer this experience to other communities across the state. KEA later received additional funds from the U.S. Department of Energy to expand this test programme to six turbines, and then to ten machines.
- 1997 — Installed initial three AOC 15/50 turbines, becoming the first utility wind farm in Alaska.
- 1997 — KEA was approached by the State of Alaska and NREL to develop a high pen-

etration wind diesel project Deering AK was first selected but the project was moved to Wales AK due to its higher winds.

- The Wales project began as a joint effort of the National Renewable Energy Laboratory (NREL), KEA, the State of Alaska and AVEC (Alaska Village Electric Cooperative) to develop high penetration wind project. This project started with an Environmental Protection Agency (EPA) grant. Other contributors were the Alaska Energy Authority (AEA), the Alaska Science and Technology Fund (ASTF) and the US Department of Energy. *The project is no longer operational and has finished its demonstration phase. The project is credited with being instrumental in moving Alaska wind/diesel efforts forward.*
- 2001 — Established Federal Grant with US DOE that allowed for the purchase of additional wind turbines. "Demonstration of Wind Energy for High Latitude Village Applications" submitted in response to the US DOE — STEP Pilot Programme.
- 2002 — Installed 1st Commercial North Wind 100 kW. This project was funded in part by the National Science Foundation for cold weather testing for South Pole deployment:

— The North Wind 100 was at the time tied up in patent issues;
— Kotzebue provided a good cold weather test site;
— This opened the North Wind 100 to the Alaska market;
— Alaska Village Electric Cooperative (AVEC) has purchased over 24 turbines;
— Unalakleet Valley Elec. Cooperative recently installed six North Wind 100 turbines.

- 2005 — KEA Installed two more AOC 15/50 turbines of 66kW.
- 2006 — KEA Installed two more AOC 15/50 turbines.
- 2006 — Installed new SCADA system (diesel/wind/jack-water/fuel, see figure 3).
- 2006 — KEA Installed the first Vestas V-15 turbine.
- 2007 — KEA Installed one more AOC 15/50 turbine.
- 2010 — KEA awarded State of Alaska — Renewable Energy Fund grant that was leveraged into a US$ 11 million project to develop wind project with battery storage.
- 2012 — Installed two EWT 900 kW — wind turbines.
- Project was leveraged with funding from the Denali Commissions Emerging Energy Technology Fund for the storage component.

The ability of KEA to move to larger wind turbines came through the State of Alaska "Renewable Energy Fund Grant" administered by AEA. This programme is considered probably the most successful renewable energy programme in the country. Some highlights about the programme are listed below.

Renewable Energy Fund Grant Recommendation Programme

- State of Alaska "Renewable Energy Fund" was legislated in 2008.
- US$ 125 million appropriated in FY2009, FY2010.
- AEA recommended up to US$ 66 million for FY2011.
- AEA recommended up to US$37 million for FY2012.
- Advisory committee helps develop criteria for grants.
- Selection criteria:

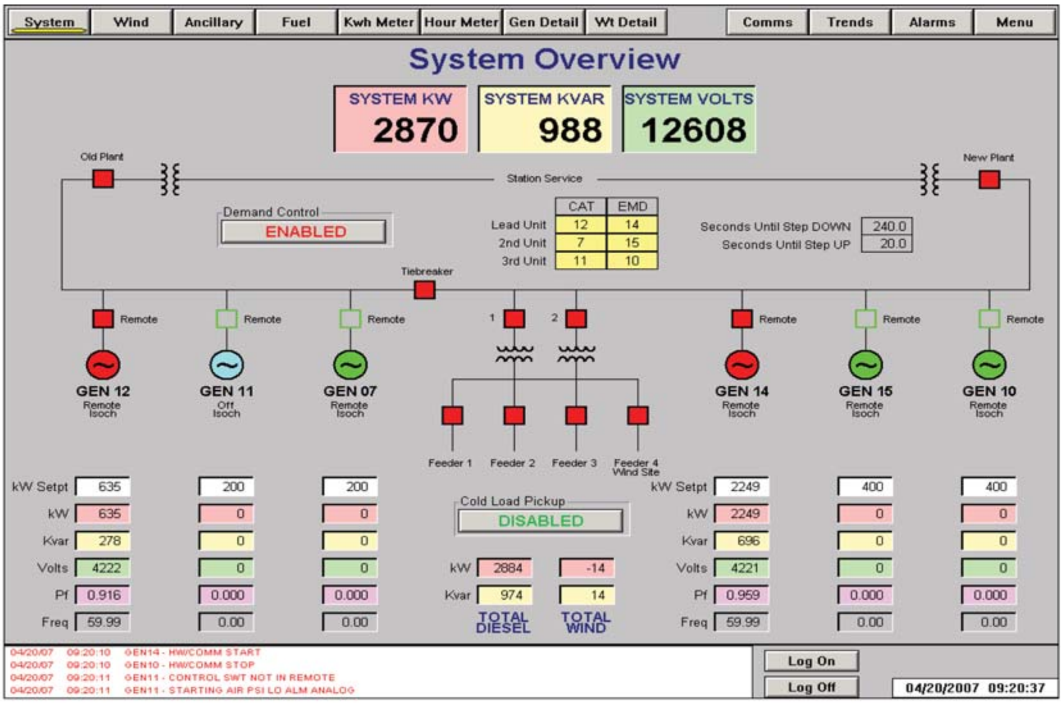
— Economic and technical feasibility;
— Energy cost per capita;
— Statewide balance;
— Matching funds.

In order to move into higher levels of wind on the system KEA needed a SCADA system (installed in 2006) and wind turbines with more flexibility than the previous induction machines (AOC's/Vestas). The machines with the required power output qualities needed had direct drive generators Another reason to select them was to reduce the possibility to bring a crane back to Kotzebue to overhaul drive trains (cranes must overwinter to work during frozen conditions).

Turbine Selection EWT 900

- Larger tower height available (more production).
- Variable Pitch.
- Controllable Power.
- Cranes were available in Alaska for this size turbine.

In the process of developing the project a number of innovations were developed. KEA



SYSTEM KW 2870
SYSTEM KVAR 988
SYSTEM VOLTS 12608

Demand Control ENABLED

	CAT	EMD
Lead Unit	12	14
2nd Unit	7	15
3rd Unit	11	10

Seconds Until Step DOWN 240.0
Seconds Until Step UP 20.0

	GEN 12 Remote Isoch	GEN 11 Off Isoch	GEN 07 Remote Isoch	GEN 14 Remote Isoch	GEN 15 Remote Isoch	GEN 10 Remote Isoch
kW Setpt	635	200	200	2249	400	400
kW	635	0	0	2249	0	0
Kvar	278	0	0	696	0	0
Volts	4222	0	0	4221	0	0
Pf	0.916	0.000	0.000	0.959	0.000	0.000
Freq	59.99	0.00	0.00	59.99	0.00	0.00

Cold Load Pickup DISABLED

	TOTAL DIESEL	TOTAL WIND
kW	2884	-14
Kvar	974	14

```
04/20/07   09:20:10   GEN14 - HW/COMM START
04/20/07   09:20:10   GEN10 - HW/COMM STOP
04/20/07   09:20:11   GEN11 - CONTROL SWT NOT IN REMOTE
04/20/07   09:20:11   GEN11 - STARTING AIR PSI LO ALM ANALOG
```

04/20/2007 09:20:37

Figure 3. SCADA system installed in 2006

pioneered the use of freeze-back pilings for wind turbines, and now was able to improve the design working with engineers and the construction firm selected. The addition of thermal siphons has improved the design further.

Batteries

A part of the Renewable Energy Fund grant was the purchase of a 3.7 MW Zinc/Bromide flow battery. The battery was ordered, passed Factory Acceptance Testing and was shipped by barge to Kotzebue. The company Premium Power was not able to commission the unit due to cold weather issues that caused problems with the unit. They have taken the unit back to the Boston area for a redesign.

Smart Grid

- KEA is one of 26 Utilities that are participating in a National “Smart Grid Project”.
- NRECA sponsored the programme using US DOE funds from the American Reinvestment and Recovery Act (ARRA).
- This is a 50/50 matching grant project.
- KEA will install meters with bi-directional control, pre-paid metering, consumer in home displays to create energy efficiency awareness.
- The grid project includes distribution and thermal switching related to the wind system, and electronic VAR compensation to assist with wind penetration power factor and frequency issues, and smart thermostats to deliver thermal energy from excess wind power.

Other Community Projects

Solar Thermal Project

KEA submitted several successful grant applications with the Denali Commissions Emerging Energy Technology Fund. One was for a Solar Thermal Demonstration Project. The goal was to demonstrate the feasibility of using different designs and configurations to measure effectiveness.

- Kotzebue and area’s above the Arctic Circle have higher solar gain in the spring than states in southwestern US.
- This grant was used to install the equipment on 6 elder’s homes.
- Worked with two vendors on the project.
- Tried evacuated tube and flat plate.
- Solar heating displaced over 40 per cent of heating costs for one of the installations.

Figure 4. Installation of an EWT 900 wind turbine

Absorption Thermochiller

Energy Concepts approached the AEA about a project using a design to create ice using power-plant exhaust heat. KEA was the only utility that was willing to try this technology, but before becoming a partner wanted the unit redesigned to be used with jacket water heat to accommodate maintenance and account for future deployment criteria. Although the project was a short term demonstration the initial unit ran for 10 years and a replacement unit is now in place. Having this ice-making capability has meant the survival of the fishing industry in Kotzebue Sound.

The new unit is slightly larger than the initial unit and is a "TC 20 THERMOCHILLER" which supplies 20 tons of refrigeration at 0°f, and is powered by 160°f engine jacket coolant.

KEA has a stated interest in the research and development of products and technologies that can lower the cost of energy for its member/owner's. Many doors have been opened to allow this small utility to take on a larger role in the research and deployment of renewable energy. The principles we adhere to as a cooperative are evident in the philosophy we follow to develop projects.

KEA Philosophy

- Develop in-house expertise, create jobs and local project management capability.
- Reduce risk to community and consumers by working with funding, cooperative and vendor partners.
- Leverage projects whenever possible with low cost loans, grant funds, and vendor in-kind participation.
- Work with legislators to build advocacy and to gain government support, both political and financial.
- Review all technologies that reduce cost and specifically fuel cost to the cooperative and our members.
- Bring matching funds to a project (have skin in the game).

This is how electric cooperatives can affect the economic ability of the communities which they serve. Concern for community is one of the guiding principles for strategic planning.

Village Renewables-Enabled Microgrids

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Introduction

Energy poverty is a serious global challenge, facing 1.4 billion people worldwide, roughly 20 per cent of the world's population. More than 675 million people in Asia and the Pacific lack access to electricity — mainly in rural and remote areas. A desperate need for new delivery mechanisms and fuel sources exists throughout the world. A challenge facing much of the developing world is the creation of a robust electricity distribution system that provides access to reliable and affordable power.

The proposed project aims to develop a scalable, sustainable model that would provide access to affordable, reliable, cost effective, and environment friendly electricity. The model should also demonstrate that good and transparent governance at local level is integral and essential to effective energy management.

The team's collective research to date shows that in the developing nations there are many clusters of villages and communities underserved by electricity, sanitation, health services, education, and job creation. Such clustered communities appear to be the right size for a microgrid solution that enables multiple renewable resource technologies.

A microgrid is a localised, scalable, and sustainable power grid consisting of an aggregation of electrical and thermal loads and corresponding energy generation sources. Microgrid components include: distributed energy resources (including both energy storage and generation), control and management subsystems, secure network and communications infrastructure, and assured information management. Relevant renewable energy resources that are often considered for microgrids, include combinations of wind, solar, battery storage, waste and biomass to energy plants, and combined heat and power systems. A technical complexity for microgrids is the sensing, monitoring and resultant control of distributed energy resources due to the significant degree of local imbalance caused by variable energy resources, such as wind and solar.

This project will consider not only the geographic specific opportunities, but will also take into consideration broader international organisation interests. As other international organisations provide insights into elimination of energy poverty, this project will incorporate those ideas that are consistent with the work of this project; including policy, technology and social implications.

Development Challenge and Expected Outcomes

Historically, the energy industry has expanded services to rural areas outwardly from the urban centers using the same infrastructure model that made sense in the dense urban areas where there are hundreds of energy users per kilometer. But, as the infrastructure is moved outward, only a few energy users per kilometer in the rural area are supporting the expensive infrastructure. Thus, where the traditional, centrally-developed, centrally-managed expensive infrastructure is available to many energy users per kilometer (in urban areas), distributed communities (especially in developing nations) are most often left with little or no access to affordable energy solution.

Compounding this, the mostly state-run Indian electricity sector is plagued by significant supply shortages, financially insolvent utilities, and the inefficient delivery of what supply is available. Utilities pay high charges for overdrawing power from the grid, provide free or low cost electricity to a handful of large farmers that use electrified pump-sets for irrigation, and deal with high levels of electricity theft in urban areas. All of this makes it unlikely that state utilities can afford to make needed upgrades in urban areas, let alone expand distribution into rural areas.

In India, as in other developing countries, families seeking access to improved wages, health, and education often move to a large urban area. Such migration has two significant impacts:

- Pressure on urban infrastructure stretches national resources;
- Leaving rural communities behind worsens the urban rural divide, and contributes to the decline of local knowledge and local culture.

The solution is not to move the families into urban areas, but to move affordable energy to the rural, distributed communities to enable jobs, health, education, and a quality of life that maintains or expands the local culture.

Access to a real and sustainable energy solution to the energy poverty problem has been identified as the "missing Millennium Development Goal".[1] The UN Millennium Goals now seek to set goals for global partnerships to proliferate the availability and accessibility to new technologies, especially information technology (IT) and communications[2]; plus the development of environmental sustainability by integrating sustainable development into country policies and programmes.[3]

The lack of affordable, reliable, and accessible energy is a significant challenge in many parts of the developing world, affecting sanitation and health, economic development, education, and other important factors in quality of life:

- Energy enables economic development of commercial and industrial businesses that lead to more jobs and better jobs;
- Energy enables sanitation and health — energy to run sanitation processes for water and waste water, energy for health care facilities, etc;
- Energy enables education — energy for schools, expansion of lighting for evenings for student study, expanded access to educational media, etc;
- Energy enables environmental improvements — VREM energy is much cleaner than using kerosene or fuel oil for cooking, lighting, and heating;
- Energy enables agriculture economic development. Not only will energy provide for sustainable farming, it significantly reduces product spoilage by enabling crops to move to market quicker, cooler and cleaner.

The proposed village-based renewable resources enabled microgrid (VREM) can leverage interconnected variable renewable resources, develop a locally-managed energy infrastructure, help promote expertise in electricity market concepts, and demonstrate a model for programme development of low income clustered communities. More importantly, a VREM can provide access to affordable energy, allowing for increased economic development, better health and educational opportunities.

The Objective of the Proposed Project — Stage 1, Pre-feasibility

The goal of the VREM pilot project is to provide reliable, cost-effective, and environmentally sustainable power that meets both the electricity and thermal needs of the approximately 60,000 residents of Rahitmatpur and surrounding villages in Maharashtra. Rahimatpur has four educational institutes and a young population ready to launch itself into the services and manufacturing sectors. This area is underserved by the power sector, which supplies only intermittent electricity. As we want the community members actively engaged in supporting and benefiting from the project, we also want to demonstrate that good, transparent governance is essential to energy management.

In the first stage of the project, we will conduct a pre-feasibility analysis of the site. Successful application of distributed generation requires a portfolio-type system perspective that views generation and associated loads as an integrated and autonomous subsystem or a "microgrid". Distributed generation operating within a microgrid is a viable energy efficiency option and has the potential to greatly improve energy reliability.

A project relying on various waste-energy technologies can also help resolve the challenges of waste management and sanitation issues. Small-scale gasification waste-to-energy (WTE) systems are a perfect fit for community microgrids, which can use locally-generated solid waste, wastewater sludge, agriculture waste, or specific energy crops, promoting new agricultural techniques.

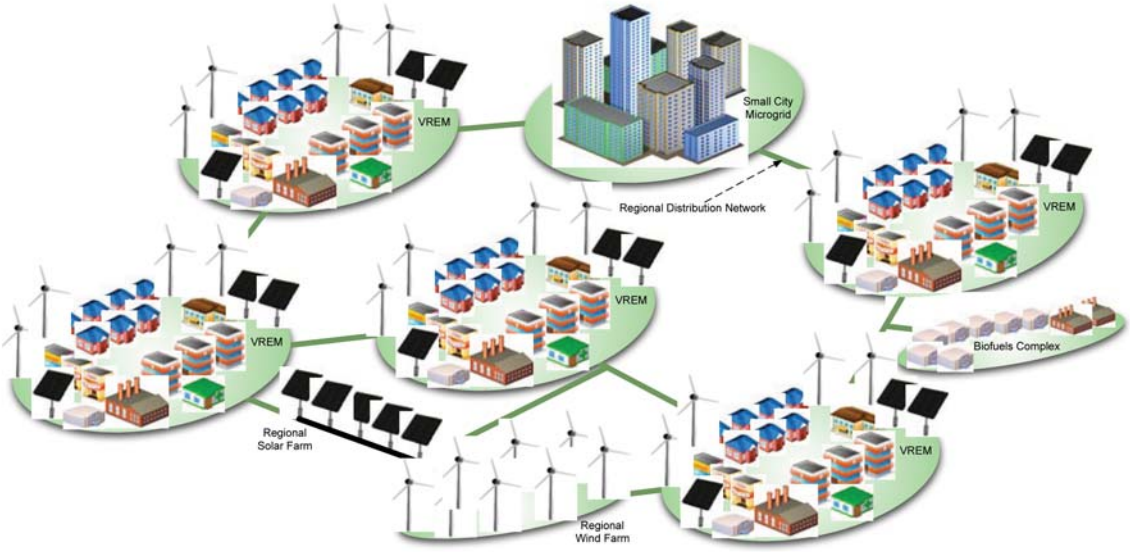

Figure 1: Series of Interconnected Village Renewables-Enabled Microgrids (VREM)

The VREM can be viewed as cells (microgrids) that are networked to form a collaborative and distributed power system (see Figure 1).

Each cell addresses a local focus, yet is available to supply adjacent cells with power address peak demand needs or failure recovery. Adjacent cells can be leveraged to provide sustaining power when a neighboring cell cannot support its peak demand, or scheduled as a planned failover. The adjacent cell concept presents an opportunity for each class of microgrid operator to generate revenue by bidding excess generation capability into a future wholesale energy market or potentially to negotiate collaboration directly with a neighboring cell.

Smart Grid technology is implemented to create an automated, widely distributed energy delivery network characterised by a two-way flow of electricity and information, capable of monitoring and responding to changes in everything from local power plants to customer preferences to individual appliances. Building a ‘smarter’ grid is an incremental process of applying information and communications technologies to the electricity system, enabling more efficient delivery, reliable supply, and better access to energy. Microgrids provide a unique solution to addressing the unique challenges to rural electrification, incorporating the market development of renewable energies as well as addressing environmental and water issues, providing a sustainable model for high-growth, low-carbon economic development.

Stage 1 Pre-Feasibility Approach

The project team approach upon award is to conduct a data gathering site visit to Rahimatpur and Solapur (alternate) village clusters in India. The data gathering will follow the Horizon Energy Group microgrid feasibility study template plus add essential socio-economic data about the local village clusters, and determine the current state of area services such as health care, sanitation, education, water, agriculture, and energy. Upon completion of the data gathering step, the team will analyze the data, develop a detailed plan for Stage 2, Stage 3 and beyond, and develop a Stage 1 report on all the above. See Figure 2.

Fundamentally, Stage 2 will be the stage for developing the first VREM, associated programmes, and shared funding programme. The DIV Stage 2 funding will be the leverage for international and country funding of the VREM and associated pilot programmes.

Stage 3 will be the full roll-out of the VREM deployment programme. This includes development of the shared funding programme, the design/build programme, and the programme support.

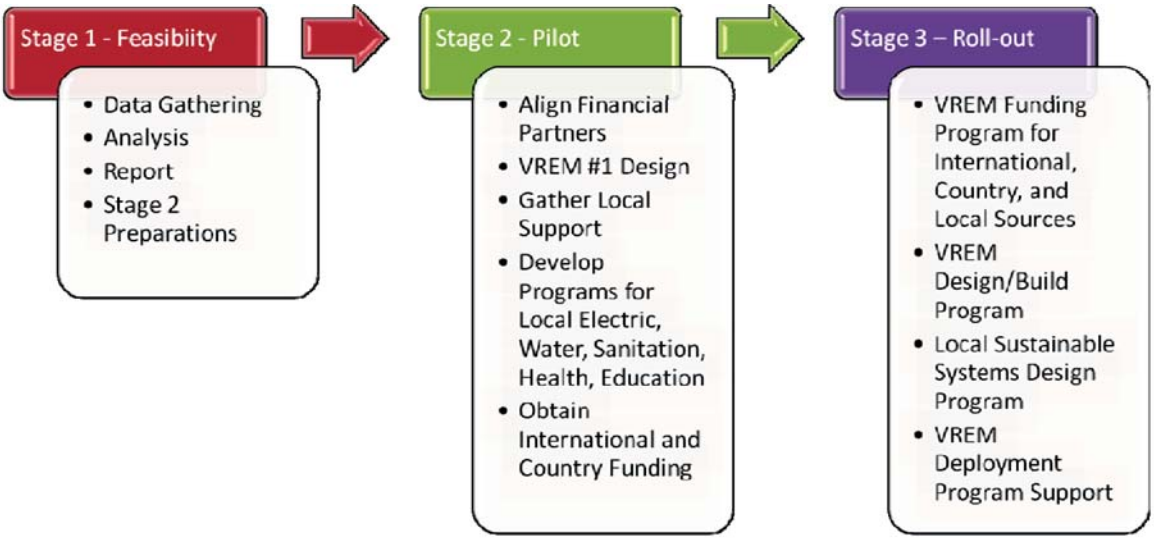

Figure 2: VREM Approach Overview

Innovative Solution within the Competitive Landscape

This project takes advantage of advances in information technologies to integrate power generation from a variety of renewable resources that are appropriate for the target pilot areas to provide reliable power generation to villages independent of a large centralised distribution power grid network. Most distributed energy sources in non-urban areas rely on imported fuel stock, such as fuel, diesel, natural gas, and in some cases coal. India is challenged with the provision of petrochemical feedstock for power generation in non-urban areas. A micro-grid will be able to integrate power from various renewable energy streams, such as wind and solar, to optimise the reliable delivery over a twenty-four hour period.

This project concept is revolutionary, by incorporating renewable energy generation, networking microgrids, and integrating distributed energy resources for localised power generation as well as providing for the opportunity of connecting to other nearby villages. Indian utilities in many cases lack the basic hardware or software, which would be required to deploy a Smart Grid. Most utilities have not yet adopted on a large scale what are considered basic enterprise IT systems (i.e. Geographical Information System (GIS), Outage Management System (OMS), Supervisory Control and Data Acquisition (SCADA), Distribution Automation, or Management Information System (MIS). This project utilises each of these components, providing a prototype for scalability.

In addition, this project will be testing the effectiveness of using duckweed, a form of algae, as a feedstock for a methane digester to produce biogas.

The initial evidence for the VREM concept is compelling. VREM is a microgrid, and there are multiple microgrid projects operating worldwide. In the US, there are three true microgrids operating today, with 20 additional microgrids in development with many going operational in 2012. Consider three examples.

The Borrego Springs microgrid in California is for a remote desert community that has a single, troubled electrical connection to the main grid in California. This microgrid (5 MW) incorporates locally-owned solar photovoltaic arrays, diesel generators, energy storage, demand response, and electric market pricing influences. The microgrid incorporates all power resources, circuit switching, voltage and reactive power management, management of electric demand, and energy storage to deliver the improvements the community desires — affordable energy, better reliability, and reduced emissions.

The Kythnos microgrid on Kythnos Island in the Agean Sea is a small (100 kW) microgrid that connects all resources (PV arrays) and loads in a system that is autonomously managed by software agents who interact with each other to arbitrate the optimal electric service to all loads.

There is one project in State of Maharshtra: a 17 MW MicroGrid at Alamprabhu Pathar. The emphasis here is on wind turbines based on the topography of the area. Bagasse-based generators are used for the project. The microgrid includes 2.4 MW of natural gas based generators, 0.5 MW of biomass-based generators, and 14.3 MW of wind turbines. These various resources are being installed at various locations in the Microgrid. While microgrids present non- traditional electric infrastructure challenges, the world-wide body of work in microgrids has proven that all the challenges are addressable with the right design and integration.

The VREM concept was derived from these example microgrids as well as a dozen other microgrids in development.

Also considered is cutting edge technology with duckweed gasification process. This concept pilot actually has its roots in the concept pilot out of North Carolina. Researchers at North Carolina State University have proven that duckweed is ideal as a biomass crop that can be manipulated to have a very high protein or starch content. The researchers used hog wastewater streams as the duckweed feedstock, proving initial proof of concept the positive economics of duckweed for ethanol production.[4]

Business Plan

A village renewable-enable microgrid (VREM) pilot project that incorporates solar, wind, battery storage, biogas, and/or biomass resources, can provide sustainable, reliable electricity to the Rahimatpur village cluster. The proposed VREM will be a locally-managed power grid serving only the needs of the village cluster, or a locally-managed power grid that also connects to a nearby industrial power plant. Both business models can be scaled beyond Rahimatpur. Since the goal of the project is to scale via the private sector, the feasibility study (Stage 1) will allow us to determine which model best meets the needs of the village cluster, by providing the greatest sustainable social and environmental benefits at the lowest cost.

The goal of the VREM pilot project is to provide reliable electricity to the approximately 60,000 residents of the Rahimatpur village cluster.[5] Few — if any — decentralised generation projects in India are networked. With the possible inclusion of one of the nearby industrial power plants into the microgrid, the project could operate both as island for the village cluster, as well as be a networked microgrid. The networked option is more sustainable — i.e. generation available beyond the household and agricultural needs of the village cluster — with sales to industrial consumers, who currently rely on expensive diesel for their back-up power generation.

In Maharashtra, rural, grid-connected consumers receive about 8-10 hours of electricity per day during off-peak hours.[6] Currently, the average household uses approximately 300 kwh of power per year, mostly for lighting needs.[7] To provide 24-hour electricity that meets the agricultural and household lighting needs of the village cluster would require ~1 MWh per household per year.[8] A project designed for 23 MW of installed capacity could meet this requirement and possibly meet the needs of a nearby industrial plant, allowing for greater rural integration in Maharashtra's industrial development.

The development and installation of a 23 MW VREM requires US$ 115M of capital. We are looking to finance the VREM as a joint public/private partnership, where the capital investment is split three ways (US$ 46M, US$ 46M, US$ 23M):

- 40 per cent international grant (UN, UN Foundation, USAID, or other foundations);
- 40 per cent national grant (Ministry of Economic Development, RGGVY Electrification, Ministry of Non-Conventional Energy Sources, etc.);
- 20 per cent repayment by the VREM consumers at 0 per cent interest for 20 years.

The VREM annual operations and fuel expenses combined are US$ 0.071/kWh (Rs. 3). Carrying this debt for a 20-year period at 0 per cent interest would add US$ 0.029/kWh (Rs. 1) to the operating costs. This requires residents in the village cluster to pay US$ 0.08/kwh (Rs. 4). Grid-connected consumers receiving power 8-10 hours/day pay Rs. 2 or US$ 0.04/kwh. Including the costs of procuring kerosene for lighting needs when grid-connected power is not available, most households in India spend approximately Rs. 11 or US$ 0.20/kwh.[9] The VREM cost of or Rs. 4 or US$ 0.08/kwh is not only economically viable, but a better option.

Scaling Plan

The VREM pilot project we envision (Stage 2) relies on funding from various sources, and is intended to scale as a joint public-private venture (Stage 3).

There are two key issues with making the VREM sustainable and scalable:

1. Financing the project in such a way as to not unduly burden the village cluster within the VREM with a large, long-term mortgage;
2. Providing training to local entrepreneurs to operate and maintain the micro-grids, which, beyond the build phase, creates lasting new jobs in the region.

The project can scale both within India and within other developing countries. Creating 10 VREM projects within India for similar-sized village clusters could lead to over half a million users in India alone in 10 years.[10] Expanding the project outside of India in other developing countries could lead to millions more.

Depending on the business model adopted — either a stand-alone microgrid serving only the village cluster or a microgrid connected with an industrial power plant — the VREM may fund part of its own expansion. With major reliance on government incentives for distributed generation projects in rural areas,[11] scaling beyond India will require capital needs that may be financed through international organisations and/or participating countries. Depending on the available capital funding, the rate of expansion could be adjusted upwards.

Following the same business model outlined in section 4, financing 22 VREMs across developing countries would require US$ 2.5 billion in capital investment. We see opportunities to engage private sector capital in each of the funding streams:

- International community funding could come from one of the multi-lateral banks, the United Nations Development Programme, or the Global Environment Facility;
- Participating countries could provide bank loans with sovereign guarantees;
- Village clusters could take on some private debt in later years, assuming increased energy usage as economic development increases.

Since this is a renewable energy-based project, the potential for Clean Development Mechanism Carbon Emission Reduction credits could also be used as a funding source for the project expansion. In addition, as the pilot project and initial deployment projects are successful, private equity could be interested in financing additional projects.

Conclusion

A key indicator of success for our project is access to affordable, reliable, and sustainable electricity. Following the World Bank report mentioned earlier, we will verify the current cost of electricity for lighting needs per household, considering any costs associated with grid-connected power, as well as the costs of procuring kerosene. We will also determine the greenhouse gas emissions associated with both resources. Finally, we will compare the costs of extending the current grid infrastructure with the cost of implementing the VREM. A key economic indicator will be the lower costs associated with procuring electricity from the VREM project, and a key environmental indicator will be the lower or avoided greenhouse gas emissions.

The sustainability of our project is dependent on how well we integrate members of the village cluster, by empowering them to play an active role in the development, maintenance, and ongoing management of the VREM project itself. We expect a number of social benefits: increased agricultural productivity, greater food security, improved health and sanitation, employment generation (both as a result of the VREM project itself and related economic development), all of which contribute to this empowerment. In addition, we expect improved waste management techniques in the village cluster, as we plan to utilise various waste streams with gasification and/or anaerobic digestion technologies in the VREM.

Endnotes

[1] http://www.iea.org/index_info.asp?id=1847

[2] Goal 8F UN Millenium Goals http://www.un.org/millenniumgoals/

[3] Goal 7 UN Millenium Goals http://www.un.org/millenniumgoals/

[4] See additional information on North Carolina State University duckweed projects at:

http://www.biofuelswiki.org/bin/kinosearch/Home/WebSearch?search=duckweed&web=Home

[5] Rahimatpur (20,000), including the eight villages with approximately 5,000 people in each.

[6] "Empowering Rural India: Expanding Electricity Access by Mobilising Local Resources." 2010. South Asian Energy Unit, Sustainable Development Department. The World Bank.

[7] Ibid.

[8] Average household requires 30 kwh/month at 8 hrs/day. For 24 hrs for one year would be about 1000 kwh.

[9] "Empowering Rural India: Expanding Electricity Access by Mobilising Local Resources." 2010. South Asian Energy Unit, Sustainable Development Department. The World Bank.

[10] 10 village clusters of 60,000 each = 600,000. Moreover, expanding this project in India could double the current per capita energy consumption of about 734 kwh to close to 2000 kwh in less than five years — a number not quite at the consumption level of the developed world, but a figure that could represent a lower-middle class level of electricity consumption.

[11] Such as the Rajiv Ghandi Grameen Vidyutikaran Yojana initiative for rural electrification, and other incentives available through the Ministry of Non-Conventional Energy Resources.

Energy for Freedom

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Power industry of the XX century was the engine of industrial development, including the construction of nuclear and hydro power plants, the formation of powerful territorial production clusters. The large-scale power industries — with paternalistic governance — are on the verge of moral and physical deterioration, and at the same time are faced with a global challenge to provide knowledge-based economy with energy resources.

People tend to live in places that have higher concentration of industries, factories, the places where mineral resources are available for development. The man is closely connected with the energy infrastructure. When the state of world markets change, minerals are exhausted, companies go bankrupt, a problem of demographic shifts appears. In Russia’s Far East and Siberia regions, abandoned villages and the deplorable condition of infrastructure of large and municipal energy, are becoming a widespread phenomenon of today. Failure may be observed everywhere: people, nature, government, the economy and business.

However, life does not stand still and the world is changing. New intelligent technologies lead local power systems to a new level, make them flexible and adaptive to the use of renewable or local primary energy resources, help managing the consumption schedule, provide a new level of reliability in any territory and climate conditions. Innovative local power will provide sustainable development of remote and insular areas, will be a key factor to address the problems of backwardness in social and economic development. The main advantage of the widespread implementation of new energy systems based on microgrid technology is the increasing role of the consumer.

The philosophy of life is changing along with the scientific, technical and socio-cultural progress. Now it already affects the macroeconomy and geopolitics. Economic globalisation, space information technologies, increasing virtualisation of financial markets, climate changes and environmental disasters raise new requirements for energy policy in different countries.

The XXI century power, first of all, should be a tool for increasing the comfort and quality of human life. Now, the power industry has to come to a point where the life of the mankind is easy and comfortable. In today's world, space and place lose their key value for realisation of people’s personal potential. More precisely, now a human should not be dependent on the existing infrastructure so much. But a person is truly free in his choice only if he has such an ability to choose.

Here we can also see people’s initiative: with their own resources and creative cooperation enthusiasts from different countries provide finance as a private charity and introduce modern energy technologies in the Russian regions of North Asia.

As regards the environmental dimension energy, large-scale power industry is not focused on environmental issues, which are always secondary, and, unfortunately, a residual priority. Distributed, alternative, "green" energy therefore should break into the energy space. The main mission of humanity is to preserve the nature!

Another challenge is that the globalisation assimilates ethnic diversity. There are social groups — indigenous peoples — that take this issue as critical given that it is intertwined with the preservation of their national identity. Culture, traditions and language can be stored in a traditional way of life. Energy supply, in this respect, is the key factor in shaping the living conditions. Nowadays, the industrial development of northern territories should have the motto "From the development of land to the development of life" It means that the North should be considered as an area of life where the man will deploy innovative technologies in energy, communications, transportation, and will build new types of autonomous communities, new systems of production. In general these are new approaches to the organisation of life with due account of the traditions of the indigenous peoples.

APEC members will benefit from defining the relevant ideology, working together on public policy measures, facilitating technological and financial assistance to local communities to enable them implementing local power projects in the areas of their historical residence. Desirable deliverables include launching of pilot infrastructure projects in remote, insular, inaccessible rural areas of developing APEC economies. Not only private owners and enthusiasts locally, but the government must have a stake in the development of these projects. It is worth outlining a plan for future collaboration in APEC.

Small-scale distributed and alternative energy — is energy for freedom, featuring the free man and the natural world.

Microgrids: APEC and Global Context

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Relevance of the Microgrid Concept

Energy systems across the world gradually evolve toward a new paradigm where two-way power flows and greater reliance on distributed generation encourage new technology development. Some forms of distributed generation — especially variable renewable resources such as solar or wind — create a greater need for smart grid solutions, such as microgrids.

Peter Asmus from Pike Research explains that Microgrids are really just miniature versions of the larger utility grid (localised smart grid network), except for one defining feature: when necessary, they can disconnect from the macrogrid and can continue to operate in what is known as “island mode.”[1]

An important case is remote microgrids that never connect to a larger grid and develop in several key segments including village power systems, weak grid island systems, industrial remote mine systems, and mobile military microgrids. A relevant and useful description is provided by the Alliance for Rural Electrification: “A mini-grid (also sometimes referred to as a micro-grid or isolated-grid) provides electricity generation at the local level, using village-wide distribution networks not connected to the main national grid. The production is managed by an operator who can take different legal forms and who supplies electricity to several distinct and autonomous end-users against payment or participation.”[2]

So microgrid definition may indeed vary depending on the context, but it may be already concluded that microgrid is a critical technology for (1) smart and efficient integration of intermittent renewables an (2) supply of electricity to remote, off-grid areas. This APEC project in fact focused on remote microgrids that are especially relevant for vast disadvantaged territories of many APEC developing economies.

APEC Context: From Early Village Power Applications to Smart Communities

APEC members reviewed off-grid remote energy systems as early as in November 2002 when the 20th EGNRET meeting in Korea focused on economy-specific Village Power opportunities and challenges.

The follow-up activity, the APEC Village Power Workshop, was organised in 2004 in Canterbury, New Zealand. The Workshop built on the NREL Village Power Programme and NREL/World Bank global village power conferences in 1998 and 2000 and pursued the following objectives: (1) to introduce and explore renewable energy technology options and solutions for village power applications; (2) to share information on renewable energy for village power applications (lessons learned, best practices, experiences); and (3) to explore establishment of a regional network of village power champions, proponents, and practitioners.

The workshop provided an opportunity for representatives of APEC member economies to obtain information and learn about the current status of various renewable energy technologies for rural off-grid or remote locations. The workshop helped to expose APEC representatives to the experiences and lessons learned by village power practitioners and experts in the field. The experts represented government, public and private sector energy service providers, non-governmental organisations, and financiers who have been involved in energy sectors related to rural development, agriculture, water and small and medium enterprises.[3]

It was concluded that many APEC economies supported rural electrification, though more than 1.5 billion people continue to lack access to electricity. Renewable energy has the potential to make a significant contribution to providing and increasing access to modern energy services for those unserved and underserved, and to do so in a way that enhances economic and social development.

The Workshop revealed that for some APEC economies including Indonesia, Korea, and the Philippines, there are thousands of inhabited islands in each. In Indonesia and the Philippines decentralised use of renewable energy systems is expected to be an important source of clean fuels and electricity; in Korea the hybridisation of solar, wind, and biomass energy electric power systems with existing diesel generators can reduce the long-run costs of diesel minigrids and reduce their unit greenhouse gas (GHG) emissions.

In Australia, Chile, China, and Mexico, where most of the populations have grid electricity, there are significant programmes for bringing modern energy services to the remaining off-grid communities, using a mix of renewable and fossil fuel-based technologies. Vietnam is developing a national renewable energy programme, including a component for off-grid rural communities.

The APEC Village Power Workshop therefore extended and deepened the APEC network of village power practitioners and related organisations and programmes. However, the proposed APEC regional Village Power Network did not evolve into a viable undertaking. One reason might have been that the awareness of the relevant microgrid technology development and market readiness were not yet mature enough to support these smart proposals. Besides, the only APEC-wide umbrella that could provide the necessary policy support was the APEC 21st Century Renewable Energy Development Initiative that primarily focused on renewable energy generation not smart communities or consumers (one of the activities under the initiative addressed Distributed Resources and was led by New Zealand).

It was not until 2010 that microgrid-enabled distributed generation moved again to the focus of APEC members' deliberations on energy. The topic re-emerged as a part of the APEC Smart Grid Initiative and the Energy Smart Communities Initiative. The Fukui Declaration from the Ninth Energy Ministers Meeting in June 2010 instructed EWG "to start an APEC Smart Grid Initiative (ASGI) to evaluate the potential of smart grids to support the integration of intermittent renewable energies and energy management approaches in buildings and industry." Further, Japanese Prime Minister Kan and U.S. President Obama announced the Energy Smart Communities Initiative (ESCI) on the occasion of the APEC Leaders meeting in Yokohama in November 2011. ESCI includes pillars for smart power grids, smart buildings, smart transport and smart jobs and education. The smart power grid pillar includes tasks on smart grid road maps and a smart grid test bed network.

Formally, the ASGI includes four components: (1) Survey of Smart Grid Status and Potential in APEC member economies; (2) Smart Grid Road Maps; (3) Smart Grid Test Beds; and (4) Smart Grid Interoperability Standards.

The actual outputs of the ASGI are series of studies, reports and workshops on various applications of smart grid technological innovations.

A distinctive feature of the ASGI is ongoing coordination of activities with the International Smart Grid Action Network (ISGAN) that was established through a Clean Energy Ministerial (CEM) process, inaugurated in Washington in July 2010 to link together the smart grid activities of the G20 and other major economies. A joint APEC-ISGAN initiative is the proposal of a Smart Grid International Research Facility Network (SIRFN), an Annex to the ISGAN Implementing Agreement, which can draw upon the road maps and test bed network established through ASGI and ESCI. The founding parties agreed to exchange more detailed information on planned and ongoing testing activities in six areas: Renewable and Distributed Energy Resources Integration, Buildings Automation, Electric Vehicles Integration, Microgrids, Distribution Automation, and Cyber Security.[4]

Implementation of Russia's project proposal "Piloting Smart Microgrid Projects for Insular and Remote Localities in APEC Economies" led to the introduction of a Road Map for Development of Microgrids in the ASGI Smart Grid Road Maps pillar. However, this section of the ASGI is yet to be filled with specific activities and deliverables.

Up to date, ASGI or ESCI has not produced reports that explicitly focus on microgrid technology or project development. However, the report on "Using Smart Grids to Enhance Use of Energy-Efficiency and Renewable-Energy Technologies", prepared for the EWG by the

Pacific Northwest National Laboratory (US) and released in May 2011, briefly reviewed microgrid deployment across the Asia Pacific as a part of the larger smart grid framework. The report surveyed APEC economies, described the status of smart grid activities and identified APEC economies that are actively pursuing smart grid capabilities to address environmental and economic sustainability goals. Finally, the report explored the potential application of smart grid capabilities to resolve renewable integration and energy-efficiency concerns (such as variability and uncertainty in amount of renewable wind or solar generation). In certain cases, the report used the term "smart micro-grids" to describe the progress in individual APEC economies.[5]

The report reviewed microgrid in relation to smart grid development and recognised its village or rural applications:

"Micro-grid concepts can be applied at a village level to balance limited generation resources or variable resources, such a solar and wind, with storage technology and basic, but smart, control technology to balance supply and demand in a prioritised manner. Incremental steps such as this also can lend themselves to the development of a weakly- connected transmission network that may interconnect multiple micro-grids so that they can share energy during some portions of the day, but then should the overall system become unstable, each micro-grid can disconnect and service its own territory in the best way possible. In this way, such economic regions can gain from smart grid micro-grid enhanced real-time operations efficiencies." (P.3.26-3.27).

Importantly, in the concluding section, the report stressed the need for specialised roadmaps, including for off-grid locations:

"Specialised smart grid roadmap development can be oriented to types of application, such as off-grid or micro-grid, grid connected rural, and grid connected urban environments. A characterisation of economies by types can be used to identify a range of smart grid decision-making and roadmap development tools, depending on economy characteristics (e.g., highly developed/agrarian, rural/urban, central/federated, technical level of labor pool, etc…)." (P.5.4-5.5).

The report implicitly acknowledged that remote renewable or hybrid microgrids in an off-grid environment may be an important case of delivering innovative energy supply solutions to the energy-poor.

Individual Projects and Policies in APEC Economies

Unlike smart grids, microgrids are not entirely new and have been wide spread in the energy systems of APEC economies. These were old style autonomous diesel-fuelled generating facilities that supplied electric power to the many isolated areas. For example, Korea at the EGNRET 20th meeting (2002) reported that it had over 3,100 inhabited islands and all had power supply, mostly via diesel mini-grids. This has been common for the remote areas with no access to centralised electricity network. More recently, microgrids intelligently combined power from multiple local sources, including both diesel and renewable power, into smarter and cleaner localised energy systems.

As explained by Peter Lilienthal[6], off-grid or remote microgrids are more typical for developing economies where most common applications include daily energy supply to islands, mines, village power and, recently, ecotourism. Developed economies typically design microgrids for emergency services, military bases, campuses and to integrate renewables and electric vehicles. Hence, the drivers for microgrid development are somewhat different in developing and developed economies. Varied policies or approaches to microgrids and existing demonstration projects clearly exemplify this.

Indonesia considered a smart micro-grid pilot project on the island of Nusa Penida to the Southeast of Bali. The grid on Nusa Penida is powered by a series of diesel generators with a peak load of 1.2 MW. In 2005 the state owned electricity company, PLN Indonesia, established a renewable energy park on top of a hill in Kelumpu village, in the highest Puncak Mundi area of the island. Seven wind turbines were erected in the park, each capable of generating 80 kWh and a solar plant able to produce 32 kWh. The turbines were installed to reduce the diesel fuel consumption of the island and their electric power output used to pump up underground water thus providing cheap healthy water for the community. Wind power was reported to supply about 14 per cent of the total generated power, but its intermittency has caused grid instability.[7]

PLN Indonesia has also come up with the "1000 Islands Scheme" targeting one thousand islands in Indonesia to be powered by solar energy by 2014. Several projects have already been commissioned in Pulau Panjang, Pulau Balang Lompo, Pulau Tankake, Pulau Kelang and Pulau Bunaken where integrated hybrid solar systems were installed.[8]

In *the Philippines*, the Alliance for Mindanao Off-grid Renewable Energy (AMORE) Programme is a partnership of governments, principally of the United States through the United States Agency for International Development and of the Philippines through the Department of Energy, and private sector partners from the energy industry such as the former Mirant Philippines Foundation and Sunpower Corporation. The island of Mindanao has more than a third of the landmass of the Philippines and is home to one-fourth of the country's population. The AMORE Programme energises poor, remote, and mostly conflict-affected communities that cannot be connected to the power grid using clean and indigenous stand-alone renewable energy systems such as solar and microhydro. The rural electrification programme is administered by Winrock International, a US-based non-profit organisation.[9]

Malaysian government supported the installation of remote microgrids with varied success. The village of Tanjung Batu Laut on a small island off the coast of Malaysian Borneo houses a hybrid microgrid that has been successfully feeding electricity to approximately 200 people in the village for two years. In the control center, computers manage power coming from the solar panels and from diesel generators, storing some of it in large lead-acid batteries and dispatching the rest to meet the growing local demand. Before the tiny plant was installed, the village had no access to reliable electricity, though a few families had small diesel generators. Now all the residents have virtually unlimited power 24 hours a day.

A less cheerful example is the village of Kalabakan, located in a remote part of northeast Borneo. The village had no proper paved road until a few years ago, and residents made do with a couple of hours of electricity at night. Three years ago, the Malaysian government funded a microgrid there, and power demand skyrocketed. New customers included a pair of sawmills that service the local logging industry. Unlike its newer counterpart in Batu Laut, however, the microgrid in Kalabakan is underperforming due to improper maintenance and lack of management expertise.[10]

China realises that microgrids are an important part of the country's smart grid programmes and are also related to national development strategies. Government support for microgrid deployment provides additional incentives to bring social and economiec benefits to remote regions, thus extending reliable energy to its citizens.

China is dedicated to renewable energy expansion and has 8 completed pilot projects, with many more underway. One such project was completed in Zuo'anmen at Beijing City, where 50 kWp PV, 30 kW microturbines, 72 kWh energy storage was installed. Other microgrids were installed in the Henan Province, in Tiajin City, Mongolia, Foshan City, and Foshan Island. These projects are reported to have had tremendous success and focused mainly on PV and wind energy, as well as storage.[11]

More developed APEC economies have also embarked on microgrid development to augment their electricity grids to remote and isolated areas. Late 2010 *Chinese Taipei* unveiled plans for an 8MW offshore wind demonstration project to be operational by the end of 2012 on and off the Penghu Islands where the capacity for wind power generation proved to be high. In March 2011 a five-year, US$273.6 million project to turn Penghu into a world-class low-carbon island was formally launched. Renewable energy will account for 56 per cent of the county's total energy demand by 2015 and when the wind turbines produce excess electricity, it will be transmitted and sold to Chinese Taipei via an underwater cable. A key feature of the plan is to invite the Penghu County government and local residents to become stakeholders in the project. They are expected to acquire a 55 per cent of the company that will operate the wind farm, with the rest open to outside investors.

Penghu will also play a major role in Chinese Taipei's efforts to harness ocean energy, a high priority for the government and their Industrial Technology Research Institute (ITRI). The national target is for a 200 MW installed capacity by 2025. According to ITRI, studies have shown that the north-east offshore region has wave potential of several hundred megawatts, while the east coast's Kuroshio path and the Pescadores Channel (off Penghu) have tidal current energy that could theoretically be tapped at gigawatt scale.[12]

Interestingly, such a small economy as *Singapore* with virtually no remote areas is in the process of implementing a smart micro-grid with clean and renewable-energy technologies. Pulau Ubin is a 10 km^2 island, located northeast of Singapore, where "off-grid" and the new micro-grid infrastructure will replace the diesel generators currently being used on the island. Currently, Pulau Ubin does not draw electricity supply from the main power grid. It is not economical to lay power transmission cables from mainland Singapore to Palau Ubin due to its modest electricity consumption of around 2,500 MWh per annum with maximum demand estimated at 1.7 MW. The Energy Market Authority (EMA) has embarked on a pioneering project to transform part of Pulau Ubin into a model 'green' island powered entirely by clean and renewable energy. Aside from solar panels and using waste as fuel for energy generation, electricity could also be produced from a hydrogen fuel cell plant, biofuels or turbines powered by wind or waves.[13]

Chatham Islands represent a well known case of hybrid local power system development in *New Zealand*. Chatham Islands Electricity Ltd seeks sustainable options to augment or replace existing network distributed diesel generation. Key objectives are to lower current costs, provide long term price security, and reduce environmental cost. Wind and hydro options have been evaluated and the commissioned report considers both stand-alone and integrated generation systems. Because wind is a plentiful resource and micro-hydro plant more site specific, there were strong drivers to prioritise wind development. In July 2010, CBD Energy completed its renewable energy project with installation of two 225kW wind turbines and associated control systems, which it has integrated with the local electricity grid and diesel generation plant. The turbines are expected to supply 47 per cent of the islands' electricity, reducing diesel use by around 300,000 litres each year.

In May 2009, The Department of Conservation and Telecom New Zealand installed a 5.8 kW photovoltaic solar electricity generation system that was integrated into the local grid. A proposal put forward by Chatham Islands Marine Energy Ltd to install a shore-based device to capture wave energy was awarded $ 2.16m in July 2010 under the government's Marine Energy Deployment Fund. The project will see the construction of an oscillating water column to power two 110 kW Wells turbines. The device will be installed on the southwest coast of Chatham Island and will be able to supply another quarter of the island's electricity needs.[14]

Korea launched a national smart grid programme to help it become a low carbon economy and a society capable of recovering from climate change. The first phase of the project has been to build a Smart Grid Test Bed on Jeju Island. The overall programme and Test Bed have five implementation areas: 1) smart power grid, 2) smart consumers, 3) smart transportation, 4) smart renewables, and 5) smart electricity service. The goal of the smart renewables sector of the project is to build smart renewable-energy generation across the nation using micro-grids to enable houses, buildings, and villages to be energy self-sufficient with the desire that 30 per cent of households are energy self-sufficient by 2030.[15]

There is also a "Green Village" ongoing project that encourages the creation of energy independent villages which only uses renewable energy. Local governments make proposals with grouping of at least 10 households and the central government evaluates those to decide on the support The target is to have 200 sites covered under the project until 2020.[16]

Japan has taken action to reduce existing energy costs for residents of remote islands. The regional utilities are required to provide electricity to every customer at the same price. The high cost of supplying power to remote regions is therefore shared equally within their service territories. In 1999, the Okinawa Electric Power Company developed the world's first seawater pumped-storage facility. The system consists of a reservoir with a storage capacity of 564,000 cubic meters 150 meters above sea level. The power station is located 136 meters below the reservoir, and can produce up to 30 MW of electricity, which is around 2 per cent of the maximum power demand for Okinawa Island.[17]

New Energy and Industrial Technology Development Organisation (NEDO) leads systemic microgrid project development and research. In 2003-2007, NEDO implemented at least 4 microgrid projects in various locations across Japan. Test Projects for Next-generation Energy and Social Systems are planned for 2011-2014 and centre around major cities, including Kyoto, Yokohama. NEDO's microgrid projects are typically more complex and feature many on-grid elements such as electric vehicle charger stations.[18]

In *Canada*, the federal ecoENERGY for Aboriginal and Northern Communities Programme, an initiative through Aboriginal Affairs and Northern Development Canada (AANDC), provides funding up to $250,000 for the planning of renewable energy projects and up to $100,000 for the design and construction of energy projects integrated with community buildings. Since 2007, the ecoEnergy project has provided close to $10 Million in grants to over 125 projects.

AANDC is actively working with Aboriginal communities that are not grid connected to examine sustainable alternatives to diesel fuel generation for the purpose of enhancing economic development opportunities. These solutions may include community-owned renewable energy projects or grid connection (where feasible). During interviews, AANDC highlighted efforts made by the Strategic Partnerships Initiative to improve energy infrastructure for remote communities in Ontario and BC (provinces with the highest numbers of off-grid Aboriginal communities) for the purpose of creating favourable conditions for economic development. AANDC is working with 25 Aboriginal communities in Northern Ontario to examine long term sustainable solutions, such as a regional transmission line and renewable energy projects. The Strategic Partnership Initiative is also working with off-grid Aboriginal communities in British Columbia to assist them in transferring the operations and management of their off-grid generators to the regional utility, BC Hydro. This will allow the communities to take advantage of the subsidies offered by BC Hydro as well as to upgrade and properly maintain their diesel generators, maximising efficiency and lowering the overall cost of energy production. Communities will also have enhanced opportunities for the development of community-owned renewable energy projects through supports from BC Hydro's 'Remote Communities Electrification' programme.[19]

Federal programmes, institutions, and the private sector are increasing microgrid development and deployment in the *United States*. To date, the bulk of the US Department of Energy's work has been on microgrid demonstrations. Key drivers are reported to include ensuring energy security and reliability, integrate renewables and address costs (peak load reduction, demand charges). The applications include military installations, hospitals and other critical facilities, universities.

However, existing active players which have effectively employed microgrid innovations are rural energy cooperatives, totaling more than 900 across the US. Some of the more successful cooperatives with highest renewables penetration originate from Alaska rural communities.[20]

Among American developing APEC members, *Chile* has been very active in deploying microgrids for energy supply to off-grid communities. These include Robinson Crusoe Island in the Juan Fernandez Archipelago, Chiloe Archipelago, Ollagüe village.

Russia has only recently begun exploring smart grid and microgrid concepts to enhance an augment its mostly large-scale generation and centralised grid. Inadequacy of energy supply is observed in the scarcely populated Russian Far East where rural areas are five times energy-poorer than urban centres. High costs of diesel transported far from other parts of Russia is the principal driver behind the move toward alternative and renewable energy. Republic of Sakha (Yakutia), one of the most isolated and remote regions of Russia, saw its first wind turbine of 250 kW installed in 2007. It is estimated that after 5 years in operation, it produced 328 thousand kWh of green electricity and saved 84 tons of diesel fuel.

In 2011, the first solar power plant was built with capacity of 10kW to produce electricity in parallel with diesel generators. For one year in operation it produced about 10 thousand kWh that helped save 3.4 tons of diesel fuel. There are plans for further expansion of both wind and solar facilities are, but grid connection and load management are an issue.[21]

Overall, microgrids represent an energy generation and distribution model that can have varied applications to the circumstances of all APEC member economies. It offers an intelligent way to combine different power sources and therefore to offset the intermittence of renewable energy. It also encourages energy independence and, importantly, consumer responsibility and self-organisation. As some analysts elegantly phrase it, microgrids are starting to draw comparisons to cell phones in the developing world, where many poor people never had landlines and went straight to mobile.[22]

According to Pike Research, for a variety of reasons North America (and especially the United States) still represents the best overall market for microgrids for most application segments — even the most lucrative remote/off-grid segment, thanks to Alaska. Key factors include pockets of poor power quality scattered throughout the United States and the structure of markets for DER. The latter has stimulated creative aggregation possibilities behind the meter at the retail level of power service. Instead of being driven by grid operators, which is the case in Europe, the microgrid market in the United States is customer-driven. Microgrids can offer a quality and diversity of services that incumbent utilities have not been able to offer up to this point in time. Still, due, in large part, to the superior revenue profiles of remote microgrids, the Asia Pacific region actually leads the world in terms of total revenues.[23]

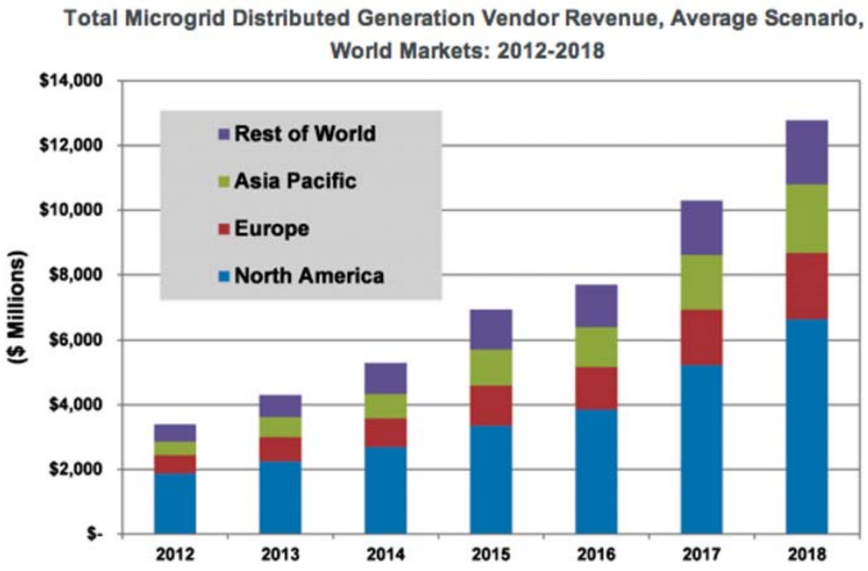
The chart below estimates the vendor revenue from microgrid distributed generation in North America and Asia Pacific, that together roughly equal APEC, at around two thirds of the world total. This suggests that microgrids are not only an technology innovation with promising future, but also a commercially demanded product.

Global Context

A significant part of the global population is reported to lack electricity — half billion to one billion people according to available estimates.[24] Most of these are rural dwellers in developing countries. In India, for example, 268 million people are without electricity in rural areas, but only 21 million in cities.[25] As of 2012, some five million Chinese people living in remote villages in mountainous or border areas are currently without electricity[26], but this may be a moderate estimate.

The International Energy Agency has estimated that in order to reach the objective of achieving universal access to modern energy by 2030, the solution for some 60 per cent of the global population currently lacking access to electricity is likely to be a combination of mini/micro-grid and off-grid technologies, with an emphasis on micro-grids. Meanwhile, many countries with existing micro-grid infrastructure are adding renewable energy generation to offset high fuel costs.[27]

In their attempts to address accessible energy issues, many regional and international institutions therefore included microgrid research and development in their programmes. United Nations Environment Programme (UNEP) launched



Source: Pike Research http://www.pikeresearch.com/author/peter-asmuspikeresearch-com the Sustainable Energy for All initiative in 2011, led by the UN Secretary General (http://www.sustainableenergyforall.org). This is a multi-stakeholder effort that aims to achieve the following broad ojectives by 2030: (1) ensure universal access to modern energy services; (2) double the global rate of improvement in energy efficiency; and (3) double the share of renewable energy in the global energy mix. The initiative succeeded to bring in more than 50 developing countries, mobilise more than $50 billion from the private sector and investors and encourage multi-lateral development banks in Asia, Europe and Latin America to commit tens of billions of dollars for the relevant projects.

As part of Sustainable Energy for All, the United Nations Foundation launched a global Energy Access Practitioner Network in 2011, which now has more than 630 institutional and individual members. The Network focuses on market-based sustainable energy applications, emphasising mini- & off-grid solutions, and catalyzing energy service delivery at country level towards achieving universal energy access. In a recent survey of the members, 43 per cent of respondents reported working on decentralised solutions and mini/micro-grids.

In September 2012, a full-day workshop under the auspices of Sustainable Energy for All brought together experts from the OECD and developing countries to explore state-of-the-art business models, technologies, policy and legal frameworks for facilitating universal energy access through the enhanced use of mini/micro-grids.

World Bank does not have a dedicated programme to address microgrid development opportunities, but supports renewable and hybrid power through its International Finance Corporation (IFC). A recent IFC publication "From Gap to Opportunity: Business Models for Scaling Up Energy Access" looks at all aspects of Energy Access: devices, mini-grids and grid extension, outlines case studies of successful companies, provides wide range of reference materials.[28]

International Energy Agency (IEA) created a mechanism for multilateral government-to-government collaboration to advance the deployment of smarter electric grid technologies, practices, and systems through its Implementing Agreement for a Co-operative Programme on Smart Grids (ISGAN, http://www.iea-isgan.org). However, this organisation is only taking initial steps toward specifically supporting microgrid project development and cooperates with APEC in that area as indicated earlier in this paper.

Recognising that Asia is perhaps home to the majority of people without access to electricity, Asian Development Bank has been very active in supporting appropriate solutions. ADB established the Energy for All Initiative (http://www.energyforall.info) to provide reliable, adequate, and affordable energy for inclusive growth in a socially, economically, and environmentally sustainable way. Within the core initiative, an Energy for All Partnership was formed by the in 2008 to build platforms for cooperation, exchange, innovation, and project development for solutions to widespread energy poverty. ADB brought together key stakeholders from business, finance, government, and NGOs for a singular purpose: to drive action towards a goal of providing energy access to 100 million people in Asia and the Pacific Region by 2015.

The Energy for All Partnership includes a mini-grid working group that focused on providing knowledge about financially viable mini-grid models, sharing experiences and expertise in this area and developing systems with the potential of scale. The group acknowledges that in archipelagos and island nations, it is economically more attractive to promote mini-grids that can provide electricity 24/7 even to small remote communities. Compared to individual solutions such as solar home systems, mini-grid systems can easily power both household and local business applications.

One particular ADB project pushed forward through the Energy for All Initiative will promote energy security and access to clean energy in Lao People's Democratic Republic. The proposed project will assist the Government of Lao PDR in pursuing its ambitious target of electrifying 80 per cent of villages and 90 per cent of households by 2020. The project will implement 5.5 MW of distributed off-grid capacity with (i) solar photovoltaic (PV) home systems; and (ii) mini-grids powered by RETs (PV, micro/pico-hydro and mini-wind). It will also include institutional and beneficiary capacity building in procurement, operation and maintenance (O&M), and monitoring.

Concluding Remarks: What APEC Should Do?

A brief analysis in this paper suggests that initial political support, public awareness, technical and economic expertise exist in APEC region and worldwide to promote smart microgrid-based solutions. Besides, the potential market for clean off-grid solutions is tremendous, according to the IFC.[29]

Remote microgrids indeed appear as a standalone, ultimate case of decentralised electricity and a way towards energy independence. Many of these microgrids are designed to reduce diesel fuel consumption by integration of solar photovoltaics, a technology that is the primary driver for remote microgrids over the next 6 years. Pike Research forecasts that the global remote microgrid market will expand from 349 MW of generation capacity in 2011 to over 1.1 GW by 2017, an amount that equals or perhaps even surpasses all other microgrid segments combined that are in the current planning stages or have already been deployed.

But the challenge is to find business models that would be commercially viable and could be configured to meet specific requirements of individual economies and communities. APEC which brings together developed and developing economies and ensures the presence of both government and businesses at the discussion table, is well positioned to effectively address this task.

Thanks to its scope and cross-cutting nature, APEC Energy Smart Communities Initiative pursues a comprehensive and balanced approach to encourage smart energy project development. Momentum continues to build there and a niche opens to promote true smart energy communities at a micro or local level, energy self-sufficient and green.

APEC Energy Working Group should indeed re-introduce microgrid within the ESCI as a core paradigm to build smart communities in a decentralised energy environment. APEC makes distinction for its flexible, cost-efficient capacity building projects, and the members should utilise APEC approach to foster training and raising awareness of microgrid project and technology development. HOMER training that was organised within the programme of the workshop “Microgrids for Local Energy Supply to Remote Areas and Islands in APEC Region” (Vladivostok, Russia, October 15-17, 2012) was a good example of such result-oriented activity where the participants learnt the basics of the modelling of hybrid renewable microgrids.

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Mark Sardella is a professional engineer, writer and speaker with nearly twenty years experience developing residential, commercial and community power systems for stand-alone, grid-intertie and microgrid applications. His work on energy systems has been featured on CNN, presented in keynote addresses at national and international conferences, and profiled in the 2009 book, *Voices of the American West*.

Mark is currently Chairman of the Board and Executive Director for *Local Energy*, a nonprofit organisation that has carried out more than US$ 2 million in research, education, and demonstration projects on energy self-reliance. Prior to founding *Local Energy*, Mark co-founded the *Southwest Energy Institute* (*SEI*), where he researched, developed and lobbied for energy policies including net metering, grid-access rights, feed-in tariffs and electricity deregulation. While a director of *SEI*, Mark worked with the *Institute of Electrical and Electronics Engineers* to develop *Standard 1547*, which defines the technical requirements for interconnecting electrical generators to the U.S. power grid. Prior to his work in energy, Mark developed spaceflight instruments for weather and research satellites at *ITT Aerospace* and for the *University of Maryland Department of Space Physics*.

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He published numerous articles including "*Russia's Network State Strategy: Construction of Energy Pipeline Network*" (2009), "*The International Politics of Climate Change and Prospect of U.S.-China Relations*" (2011), "*Global Network Politics of Russia's Oil and Gas Pipeline Network Construction toward Northeast Asia*" (2012), and also edited several books including *The Challenges of Eurasia and International Relations in the 21st Century* (2007).

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Alexander Solonitsyn graduated from Kharkov Institute of Radio Electronics (now Ukraine) in 1979. In the former USSR, he was involved in defense projects. He became an executive officer at a Russian-American JVC in 1993 and turned to the local energy business in 2002 when he joined Hydrotex Scientific-Production Company and the Far East Federal University.

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Anatoly Chomchoev is a military engineer with higher military education. He served in the Armed Forces of the Soviet Union from 1969 to 1990. Since December 1990, he worked as the leading specialist in the Supreme Council of Yakutia, a senior researcher of the Institute of Economy of the Siberian Branch of the USSR Academy of Sciences, head of a district administration of Yakutia, a member of the Government — Chairman of the State Committee for Emergencies in Yakutia, a member of parliament of Yakutia. In 1999, he became a top manager of the energy system of Yakutia. Since 2011, Anatoly has been the Director General of the Test Bed of the Cold LLC, a small business enterprise of the Innovative Technologies Centre of the Academy of Sciences, Republic of Sakha (Yakutia).

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Peter was the Senior Economist with the International Programmes Office at NREL from 1990 — 2007. He has a Ph.D. in Management Science and Engineering from Stanford University. He has been active in the field of renewable energy and energy efficiency since 1978. This has included designing and teaching courses at the university level, project development of independent power projects, and consulting to industry and regulators. His technical expertise is in utility modeling and the economic and financial analysis of renewable and micro-grid projects. He was the lead analyst and one of the creators of NREL's International and Village Power Programmes.

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Irina Volkova is Doctor of Economics, Professor and Deputy Director of the Institute of Pricing and Regulation of Natural Monopolies, National Research University Higher School of Economics in Moscow. Irina has a long experience in teaching, research and consulting activities on strategic and innovative development of the power industry — more than 20 years. She has been actively involved in the recent energy development based on the concept of intelligent energy systems, including microgrid. Irina is an expert of the project "Legal and Consumer Market Aspects of Smart-Grid Technology in The U.S. and Russia", implemented under the Russia–U.S. Presidential Commission.

Irina is the author of more than a hundred scientific and educational papers, including 4 monographs.

Larry Adams

Larry Adams has more than 30 years of experience in design and development of real-time controls for electric power systems. He currently is a Senior Controls and Power Systems Engineer at Spirae, Inc. He designs control algorithms and systems for industrial and utility power generation and provides modeling and simulation services utilising DIgSILENT PowerFactory. He provided the overall design concept and detailed control specifications for Spirae's BlueFin Distributed Energy Management System to directly control networked distributed and renewable energy resources, to form microgrids or virtual power plants, to optimise distribution grid operations, to supply ancillary services, and to intentionally island and resynchronize microgrids with the distribution network.

As Chief Engineer at Encorp, Inc. he implemented a hybrid wind turbine and diesel engine generator control system for use in remote locations such as islands and isolated villages for a project funded by a Department of Energy (DOE) and National Renewable Energy Laboratories (NREL) research grant. He was the principal engineer in a DOE, NREL, and Gas Research Institute (GRI) research project for development of controls and protection to meet the IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems. He has been awarded a number of U.S. Patents including a method of detecting islanding of an industrial power source.

Larry received a bachelor's degree in Electrical Engineering from Wichita State University in 1974 and a master's degree in Computer Science from Colorado State University in 1992 with specialisation in operating systems and intelligent machine control.

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Karen Ubilla is in charge of the Territorial and Social Intervention Area of the University of Chile, is an Engineer of Renewable Natural Resources of the same University, and is currently studying Renewable Energies. Hew experience includes investigation in Local Sustainable Development and Community Self- management.

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Brad Reeve

Brad Reeve is the General Manager of Kotzebue Electric Association, a position he has held since 1988. Brad is known as a pioneer and early adaptor of wind energy. He implemented the first utility-grade wind turbines in the state of Alaska. In addition to his cutting-edge work in wind energy, Brad is currently the project manager of several emerging technology projects including work with a multi-megawatt zinc bromide flow battery and a solar thermal demo project to heat homes for elders in the community.

During his career at Kotzebue Electric Association, Brad has successfully procured more than US$ 15 million in renewable energy grants. His honors and awards include an R&D Wind Energy Achievement Award from the Cooperative Research Network; a Utility Leadership Award from the American Wind Energy Association, and, under his leadership, his cooperative received a Community Service Award from the National Rural Electric Cooperative Association, and received the IEEE Alaskan "Company of the Year" award.

Brad retired this year after serving 8 years as President of the Alaska Power Association Board of Directors, the Alaska statewide association. He is also Chairman of the Northwest Alaska Boys and Girls Club Board of Directors. In addition he serves on the NRECA Cooperative Research Council, the Utility Variable Generation Integration Group (UVIG) Board of Directors, and the Denali Commission Energy Policy Committee. Brad holds a Bachelor of Science degree in business administration from Kennedy Western University in Cheyenne, Wyoming.

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Steven Pullins is the President of Horizon Energy Group and has more than 30 years of utility industry experience in operations, maintenance, engineering, and renewables project development. He previously led the nation's Modern Grid Strategy for DOE's National Energy Technology Laboratory. He has worked with more than 20 utilities in Smart Grid strategies, renewables strategies, power system optimisation with Smart Grid technologies, operations transformation, and RTO/ISO operational processes. Horizon Energy Group is focused on Smart Grid project deployment, and actively architecting and designing microgrid and energy storage solutions. Horizon Energy Group was named a Company to Watch in the book, "Perfect Power" by former Motorola Chairman, Bob Galvin, and former EPRI CEO, Kurt Yeager. Steven is listed as one of the "Top 100 Movers and Shakers in the Smart Grid Movement" by GreenTech Media (2009 — 2012).

Steven is the vice-chair of the IEEE PES Intelligent Grid Coordinating Committee, a member of the Smart Grid Interoperability Panel, and the OpenSG (Smart Grid) group. He has advised several international utility and government organisations on Smart Grid technologies and operations, microgrid development, integrating intelligence, new power generation, and waste to energy issues. He holds a BS and MS in Engineering.

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Fedor Lukovtsev is the Director of the Institute of North Asia and Integration Proccesses (Zabaykalsky Territory, Russia). He also serves as the President of Associations of Private Pension Funds of the Far East and Siberia (based in Khabarovsk Territory, Russia) and Chairman of the Board of Trustees of the Erel Private Pension Fund.

Fedor graduated from the Faculty of Law, Saint-Petersburg State University. In his recent publications he reviewed new models of pension for the village population of the Russian Far East: "*Russian village: regional experience of pension provision*" (2009), "*Russian village and pension problem" (2010)*, "*New models of Pension provision need*" (2010), "*Culture — the main basis of the past and future*" (2012).

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Abbreviations and acronyms

AANDC	Aboriginal Affairs and Northern Development Canada
ADB	Asian Development Bank
AEA	Alaska Energy Authority
AMORE	Alliance for Mindanao Off-grid Renewable Energy (the Philippines)
AOC	Atlantic Orient Corporation
APEC	Asia-Pacific Economic Cooperation
ARRA	American Reinvestment and Recovery Act
ASEP	autonomous sources of electric power
ASGI	APEC Smart Grid Initiative
ASTF	Alaska Science and Technology Fund
AVEC	Alaska Village Electric Cooperative
BRP	Balance Responsible Party
CCPP	Cell Controller Pilot Project
CE-FCFM	Energy Center, Faculty of Physical and Mathematical Sciences (University of Chile)
CEM	Clean Energy Ministerial
CHP	combined heat and power plant
CMS	cell monitoring system
CRN	Cooperative Research Network (US)
DCF	discounted cash flow
DCHP	dispersed combined heat and power plant
DER	distributed energy resources
DG	distributed generation
DNO	distribution network operator
DPP	diesel power plant
EGNRET	Expert Group on New and Renewable Energy Technologies (APEC)
EMA	Energy Market Authority (Singapore)
EPA	Environmental Protection Agency (US)
ESCI	Energy Smart Communities Initiative (APEC)
EWG	Energy Working Group (APEC)
EWS	Entegrity Wind Systems
FEFD	Far Eastern Federal District (Russia)
FIT	feed-in tariff
FY	financial year
GeoPP	geothermal power plant
GHG	greenhouse gas
GIS	Geographical Information System
GW	gigawatt
HV	high voltage

IPCC	Intergovernmental Panel on Climate Change
ISGAN	International Smart Grid Action Network
ITRI	Industrial Technology Research Institute (Chinese Taipei)
IEA	International Energy Agency
KEA	Kotzebue Electric Association (US)
KIC	Kikiktagruk Inupiat Corporation (US)
kV	kilovolt
kW	kilowatt
kWh	kilowatt per hour
LC NPP	low-capacity nuclear power plant
LoES	local energy system
MIS	Management Information System
MS	master synchronizer
MW	megawatt
NEDO	New Energy and Industrial Technology Development Organisation (Japan)
NRECA	National Rural Electric Cooperative Association (US)
NREL	National Renewable Energy Laboratory (US)
OMS	Outage Management System
PCE	power cost equalisation
PV	photovoltaic
PVP	photovoltaic plant
RER	Rural Electric Research (US)
RES	renewable energy sources
RET	renewable energy technology
RUS	Rural Utility Service (US)
SC	synchronous condenser
SCADA	Supervisory Control and Data Acquisition
SE-FEFU	School of Engineering of the Far Eastern Federal University (Russia)
SHPP	small hydro power plant
SIRFN	Smart Grid International Research Facility Network
SLC	secondary load controller
TSO	transmission systems operator
UNEP	United Nations Environment Programme
US DOE	US Department of Energy
VREM	village renewable-enable microgrid
WPP	wind power plant
WT	wind turbine
WTE	waste-to-energy