# New Regulatory Frameworks for Grid Flexibility

WÄRTSILÄ WHITE PAPER

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# Executive Summary

The trend toward increasing variability and the potential uncertainty in power generation is characteristic of all power systems where non-dispatchable renewable energy generation (mainly wind and solar) is implemented.

As the amount of renewable energy ("RE") increases, power systems face new challenges not only in maintaining system reliability and resilience but in balancing net load demand to maintain system stability. Without adequate and detailed planning, the overall cost of generation may increase despite the addition of lower capital cost RE. Only advanced new planning tools and methodologies, coupled with the appropriate balancing technology and energy storage, will ensure that high levels of RE generation can be achieved within a grid system while reducing the overall cost of generation.

In the very near future RE will become the baseload in power systems and flexibility will be the enabler. Without flexible power generation to balance the system, and provide critical power, significant RE penetration cannot be achieved and the savings that low cost RE promise will not be realized.

This paper attempts to describe the path to a 100% renewable energy future and the role of flexibility in making this a reality. In some cases 100% RE may not be economically viable or desirable, however, the methodology described in this paper are equally valid. The traditional approach to planning based only on the lowest levelized cost of energy (LCOE) does not work in the RE system of the future and should be abandoned in favour of the use of modern chronological expansion models that maximize RE penetration and define and value the flexibility necessary to ensure a reliable and resilient grid at the lowest possible system cost. Electric sector policy and new regulatory frameworks are essential to ensure that a renewable energy future is achievable.

# 1.0 Introduction

The modest addition of RE generally has little impact on most power systems and is easily managed and balanced by the existing generating assets and conventional system controls. However, unless policy, regulations, long term resource planning, modern power system analysis tools and the appropriate technologies are implemented, the penetration of RE will be limited and generation costs will increase – all coupled with an overall reduction in system reliability and resilience.[1] Germany and California are examples where RE penetration has caused major system problems and has increased costs and uncertainty, albeit not necessarily for the same reasons, some of which are by policy design. Lessons can be learned from these pioneers in RE implementation.

This paper attempts to address the factors to be considered in developing policy frameworks to enable successful high penetration of RE into conventional energy systems with the goal of achieving a resilient, reliable, and low cost zero carbon grid.

The path from conventional energy generation to a truly zero carbon generation is challenging, but not insurmountable. According to the International Energy Association[2] the addition of RE generation up to approximately 20% in most systems is technically quite straightforward and requires little more than a regulatory framework that allows for renewables to be contracted and compensated. At this modest level of RE, system “disruption” may go unnoticed and is in any event generally manageable – it is probably suboptimal regarding any anticipated cost / emissions reduction benefits.

Figure 1.0 illustrates the development of the RE system. Inflexible generation is redundant by the time RE becomes the de facto baseload. Inflexible generation includes coal plants, combined cycle gas turbine and simple cycle frame gas turbine plants. At some critical point (the “Tipping Point”), further addition of RE will either destabilize the grid or increase generation costs (or both) if flexible generation and energy storage are not added to balance the system.

As the addition of RE continues (in conjunction with the appropriate flexible generation and energy storage) a limit will be reached (nominally 80% in Fig 1.0) where the cost of adding further “non-dispatchable RE” (primarily wind and solar) will become uneconomical.

The incremental addition of such “non-dispatchable RE” will be at considerable expense and will severely undermine system resilience and reliability. Overcoming the “last 20%” (the “Final Push”) will require the addition/conversion of dispatchable, flexible thermal units to operate on synthetic fuels (e.g. hydrogen, biogas, biofuels etc.). These fuels may be synthesised within the grid system using excess RE (e.g. from excess wind and solar).

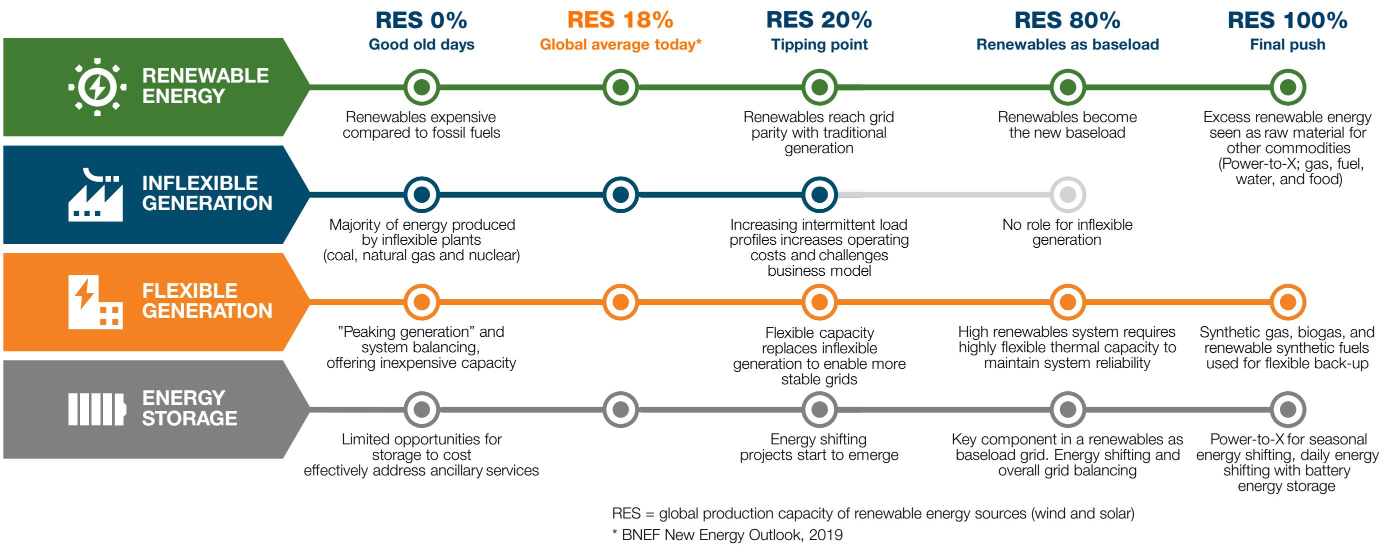



**Figure 1.0.** RES – Renewable Energy System

1) Based on over 60 detailed Plexos, a modern power system model, on actual grids globally when compared against planning based on traditional LOCE models.

2) Source: INTERNATIONAL ENERGY AGENCY (IEA). The power of transformation: wind, sun and the economics of flexible power systems. Paris, France. OECD/IEA, 2014

Every grid (and sub-grid) is unique and detailed analysis and planning is essential to determine the Tipping Point, the optimal generation mix, and in understanding the challenges in overcoming the Final Push. However, in all cases the key to success is to start with a policy framework that plans for a 100% renewable energy system and planning using modern power system tools. It is then a matter of working backwards to define the path, appropriate platform, and implementation schedule to achieve the goal of 100% RE generation and the implementation milestones. Inflexibility in generation and in fuel supply must be eliminated if RE is to be achieved at the lowest possible cost.

# 2.0 The Zero Carbon Grid

**2.1 A zero carbon grid** is one where the net emissions of $CO_2$ resulting from electrical power generation, transmission, and distribution activities is zero. This paper focuses solely on electrical power generation since this is in many cases the greatest source of greenhouse gas emissions. Emissions associated with transmission and distribution (T&D) are not addressed. Other sources of greenhouse gas emissions such a methane released naturally (hydro reservoirs) are not considered, nor are fugitive releases of methane from natural gas fired thermal generation, LNG receiving terminals and the release of boil off gas from operations such as floating storage regasification units (FSRU). These emissions must also be considered in any Zero Carbon Grid policy. Methane, a greenhouse gas, has a global warming potential 34 times more than $CO_2$ over 100 years and 86 times more potential over 20 years according to the latest IPCC report (AR5).

**2.2 A 100% renewable energy grid** may be considered zero carbon grid. This does not eliminate thermal generation from the grid providing that the fuel is, in and of itself, carbon neutral.

**2.3 In practice the 100%** RE grid will require some amount of flexible thermal generation if only to ensure grid reliability and resilience and to balance the uncertainty and intermittency of wind and solar.

**2.4 Renewable Energy grids** are being implemented today in several countries. In each case the grid requires five key elements for success as illustrated in Figure 2.4. These five elements form the basis (the “Platform”) for RE integration to be successful above the Tipping Point.

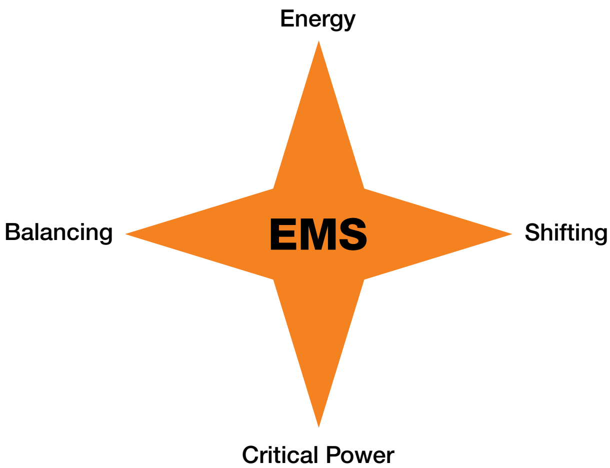



Figure 2.4

**2.4.1 Energy.** The electrical energy necessary to serve the grid load is generated by RE (hydro, wind, solar, geothermal, biomass, etc.) with the objective to ensure that energy is the de facto base load – regardless of it being dispatchable or not. Depending on grid physical characteristics and the specific operating environment it may be necessary to install wind and solar in quantities that are several multiples of the peak load demand of the system. See **Appendix A1:** the generation mix determined by Ascend for the Oahu, Hawaii plan to achieve 100% RE by 2045 and **Appendix A2** showing the modelled path for Chile to achieve 100% by 2050.

Modern tools allow for a high degree of accuracy in predicting both wind and solar performance (subject to time horizon constraints), however, both forms of generation are highly susceptible

3) https://publications.iadb.org/es/vulnerabilidad-al-cambio-climatico-y-medidas-de-adaptacion-de-los-sistemas-hidroelectricos-en-los
4) https://publications.iadb.org/en/contribution-variable-renewable-energy-increase-energy-security-latin-america

to physical damage due to natural events (windstorm and seismic activity etc.) and the future uncertainty of climate change. The IDB has published studies on this subject[3&4]. Forecasting errors must be factored in. Flexible generation, if carefully selected, may also provide for the emergency backup and to future proof the grid. Flexible generation is the essential enabler of RE when combined with energy storage.

**2.4.2 Shifting.** Solar is typically the least cost form of RE and, in most cases, the installation of solar should be maximized. There comes a point however where the addition of solar beyond that needed to satisfy the daytime demand may make economic sense – as determined by the system model. This "excess" solar energy should be stored rather than wasted or "spilled". Various technologies exist to store this energy and to release it at an appropriate later time – so-called "Shifting". Energy storage may take the form of battery storage, pumped hydro, compressed air storage, and cryogenic energy storage. Battery shifting is currently economically viable for modest shifting and as the technology improves and prices continue to drop, it will become ever more viable. See Figure 2.4.2

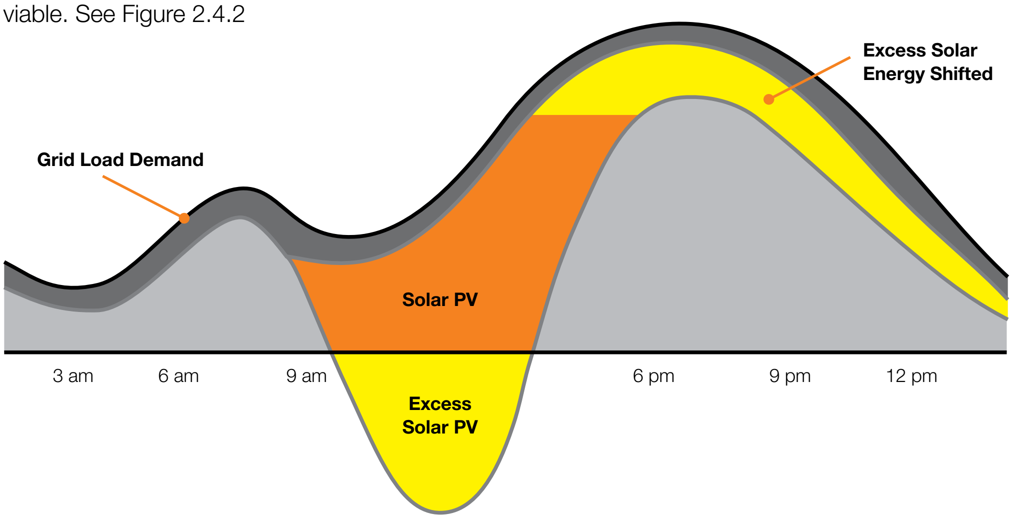



**Figure 2.4.2.** Example of Energy Shifting

**2.4.3 Balancing.** A means of balancing the intermittency and variability in solar and wind generation is an essential element of the RE grid. Balancing is necessary in real-time and is needed on a milli-second time basis to maintain frequency and on minute, hourly, and longer periods to ensure that the load demand is reliably met. The need for balancing depends on the characteristics of the environment, grid, and generation mix. Hydro, for example can provide balancing, however, climate change and other demands on water resources may place limits on hydro for balancing. Flexible thermal generation and energy storage systems are the only viable solution in many systems, such as islands, where hydro generation is not an option. By way of example, the real-time markets in ERCOT Texas, U.S.A. compensate highly flexible gas fired reciprocating engine generation to balance the intermittency of wind in the five-minute, hourly and day ahead markets. An optimally balanced RE system does not need "spinning" or "frequency" reserve – which add costs to the grid.

**2.4.4 Critical Power**. Climate change, windstorm, storm surge, hurricanes, seismic events, sea level rise, and planning uncertainties all present a potential threat to the RE grid. Solar and wind turbines are susceptible to destruction in environments ranging from Argentina to the Caribbean. Geothermal resources may dry up. Prolonged periods of drought may threaten hydro generation. It is therefore essential that resiliency and reliability be factored into all RE system planning. In many systems, especially in islands susceptible to seismic and hurricane damage it may be prudent to install reliable, dispatchable capacity close to the total RE installed capacity as backup ("Critical Power").

In some cases, the complete replacement of the inflexible thermal generation may be cost effective as shown in the example in Figure 2.4.4, where a small Caribbean island was modelled to define a path to 100% RE. The cost of implementing this model was demonstrated to cut the variable cost (fuel + O&M) in half- even considering the overall developed cost of implementing the plan. In this case the outdated thermal generation could not be integrated into the system and would increase generating costs by adding RE and would reduce reliability significantly.

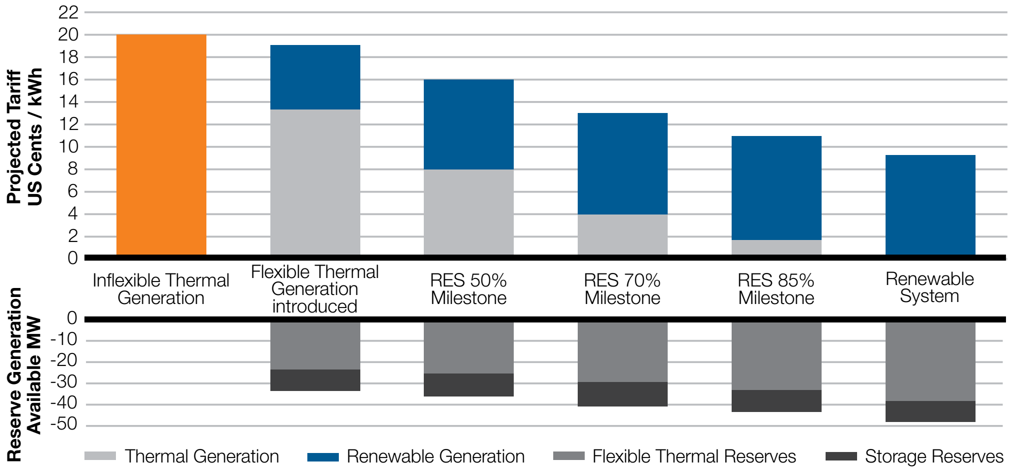



**Figure 2.4.4.** Projected Tariff on the Path to 100% Renewable Future

Thermal generation by its very nature is resilient, reliable and dispatchable – if the fuel supply chain is robust. Conventional thinking is to simply keep existing thermal generation in reserve or to install inexpensive backup generation to cover the need for Critical Power ignoring the need for flexibility. Many grids have taken this approach. Modern power system modelling typically demonstrates that this is suboptimal and may miss the opportunity to provide a Platform for RE growth.

“Flexible Generation” is therefore not only generation that meets the definition in section 3.0, but generation that provides the Platform for the future RE grid by providing Energy, Balancing and Critical Power throughout the evolution of the grid.

Although not planned as such, the fully flexible thermal units within the Brazilian system installed after 2010 that now form the Critical Power for maintaining hydro reservoir levels during drought conditions are perfectly suited to balance the considerable wind and solar growth that the system is experiencing. During the extended drought conditions from 2012-2015 these plants ran in base load efficiently. The technology is ideally suited to RE balancing – only a regulatory environment to permit this is lacking today.

**2.4.5 Energy Management System (EMS).** Manual dispatch of the grid becomes less and less efficient and near impossible as the percentage of RE increases. Each of the elements described above must be automatically managed through an intelligent “Energy Management System” (“EMS”) using Artificial Intelligence to optimize the overall performance of the system and to minimize total generation cost. The customary human dispatch interface is an obstacle to RE growth and cost optimization. The EMS must be capable of reliably and efficiently running the entire generation for the grid. Beyond the Tipping Point, the EMS forms an integral part of the Platform. The EMS will simultaneously receive and analyze data for load demand, current generation state, weather forecasts, load variations, fuel costs, the optimal amount of system reserves, energy storage status, and use thermal units heat rate curves to optimise to manage generation. Choice of the appropriate EMS is critical to success. Such systems are already managing small grids and in the U.S.A. are used in optimizing energy storage and unit dispatch.

# 3.0 Flexibility Defined

**3.1 Flexibility** is the ability of a generating unit or plant to provide Energy, Balancing and Critical Power efficiently and cost effectively in response to changes in grid load demand and/or available generation.

Flexibility in a grid is necessary regardless of the degree of penetration of RE and is essential when the Tipping Point is reached. Failure to provide adequate flexibility by the time the Tipping Point is reached will inevitably halt the cost-effective addition of RE generation and negatively impact grid reliability and resiliency.

**3.2 Generation** on a unit basis must exhibit the following characteristics at all anticipated site ambient conditions to be considered "Flexible":

- **Multiple, discrete units:** Distributed multiple unit generating plants are necesary to provide reliability and resiliency to the system while maintaining a high thermal efficiency across a wide range of electrcial ouput. Large centralized single units pose a significant threat to the grid and generally have very poor part load efficiency. Spinning reserve is eliminated in an efficient RE grid.
- **Automatic Generation Control (AGC).** The ability of each unit to be remotely started, stopped and adjusted by the EMS is an essential element of flexibility and RE integration.
- **Unit Start and Stopping.** Starting and stopping times must be very short. At a minimum, individual units and the entire plant must have the ability to achieve full load within 5 minutes of receiving an EMS start signal from standby. Equally, the unit must be able to shut down in less than 5 minutes from an EMS signal. Unit starts today in RE grids may be in the order of 1,500 times per year and may be considerably higher in the future. Unlimited starts as a criteria must be specified. Starting reliability is a critical feature of Flexibility.
- **Starting Costs.** Many types of thermal generation have a cost directly or indirectly associated with starting. A flexible unit must have negligible or no associated starting cost. Some units may impose costs of over US$ 20,000 per start – for a unit having over 1,500 start per year this imposes a cost of over US$13m to the grid. During planning the modern system model must consider starting costs.
- **Minimum Unit Uptime.** Flexible units do not require a minimum run time after starting. Some technologies, once started, cannot be stopped for up to 4 hours. This imposes additional costs on a grid system and may result in wind and solar being spilled (wasted).
- **Short Minimum Unit Downtime.** Flexible units do not require more than a 10 minute minimum downtime after receiving an EMS shut down signal. Technologies with longer downtime requirements impose additional costs on the grid.
- **Ramp Rates.** Flexible units must exhibit the ability to be ramped (change load) at very high rates (typically expressed in percentage of maximum load per minute). This is essential to match changes in renewable generation in real-time.
- **Turn-down & Flat Heat Rate**. The turn-down ratio of units must be high (down to less than 25%) and the heat rate (efficiency) curve relatively flat over the load range for a unit to be flexible.
- **Fuel Flexibility.** The ability of a unit to run on alternative fuels (for example gas and diesel or gas and biofuel) may be desirable or essential in certain grid systems where the fuel supply may be interuptable. The Caribbean islands are especially exposed to fuel shortages resulting from natural events or where dependent on a single source of fuel (e.g. a dedicated LNG supply facility, FSRU or recieving terminal). Take or pay fuel supply contracts restrict RE penetration and may impose increased costs on the grid by forcing generation to run.

# 4.0 The Role of Flexibility in the Grid

**4.1 Grid Reliability.** The North American Electric Reliability Corporation (NERC) defines grid reliability as a combination of grid adequacy (having sufficient generation to meet load) and grid security (having the ability to withstand disturbances) but states that it is a conceptually sound but incomplete framework for the United States 21st century smart grid. NERC requires a grid that adapts to both large-scale environmental and unnatural events and remains operational in the face of adversity – minimizing the catastrophic consequences that affect quality of life, economic activity, national security, and critical-infrastructure operations. NERC further states that the concept of reliability must be augmented with a resiliency approach – one that considers the grid not strictly as a flow of electrons but as a grid that services, interfaces with, and impacts people and societies. Put another way, it is the consequences, not outages per se, that matter. Distributed generation helps in this regard.

**4.2 Grid Resilience** is by design the hardening (locational and physical) of the the entire grid system against natural and human-made risks. Today these include not only natural catastrophies but risks associated with cyber attacks and terrorism. A fully integrated grid, controlled by a software based EMS communicating via internet, wireless and third party telecommunication lines leaves the entire grid potentially exposed. A resilient grid therefore must be protected against third party interference and against natural catastrophies – all in the context of climate change and globalization. A stringent program of cyber security, continous monitoring, and updating of software and hardware is essential for the entire grid and especially for Critical Power generation facilities. In conjunction with is the need to seperate the grid into isolatable regions via distributed generation.

# 5.0 Valuing Flexibility

**5.1 Flexibility** is the key factor in lowering the overall cost to meet load demand in an RE system. Evaluating the value of flexibility in monetary terms requires a sophisticated power system modeling approach based on optimized chronological dispatch; an approach that is significnatly more complex than the traditional LCOE modeliing techniques. The LCOE approach alone corrupts system modeling results and invariably results in the selection of a technology which will inhibit the growth of RE and increase system costs. LCOE is useful for evaluating energy only solutions (RE) and may be used in conjunction with modern power system modeling.

**5.2 Electric Sector Policies** should address the need to perform regular analysis of the entire integrated grid system as opposed to the common practice of simply looking to add generation assets with the lowest calculated LCOE. Traditional power system modeling does not consider RE system flexibility needs – modern modeling takes this into account and yields the correct results and values flexibility. Figure 5.2 shows how modern modelling versus conventional modelling may result in an significant reduction in system generation costs – in this case 8% overall system savings. Studies conducted on more than 80 systems globally have shown potential savings in the hundreds and even billions of Dollars when adding the appropriate flexible generation versus the use of conventional models.

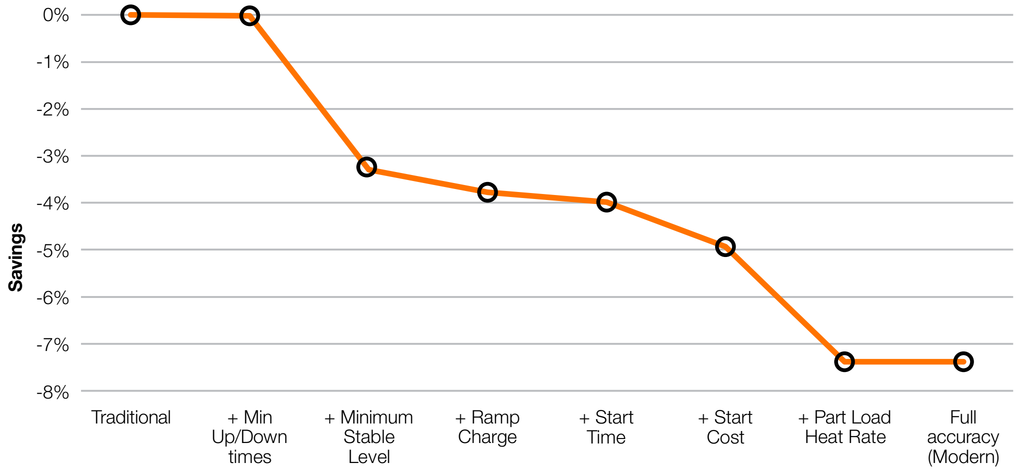



**Figure 5.2.** System Cost Savings Traditional vs Modern Modeling [5]

By taking a somewhat holistic view, modern power sytem modelling can be used to develop the optimal, least cost, grid solution by requiring that the models (as opposed to technical bias) develop the grid to promote RE solutions first and then to solve for the least cost of providing Balancing, Shifting, and Critical Power. Contraints on RE additions may have to be considered in the modeling to account for practical and physical challenges such as available land or location. Modelling may also include contraints on the system to force $CO_2$ emissions reduction; it is being understood that the addition of renewables does not automatically guarantee a reduction in emissions. RE implementation constraints based on available funding, generation retirement targets and construction lead times may be factored in. Figure 5.2.1 provides a simplified comparison between LCOE, conventional and modern models. Unfortunately today the majority of power system consultants do not possess the right tools to analyze RE system and in many cases have little or no incentive to aquire them. Open source modelling tools are available however in many cases are technology specific and may lack the ability to an entire system analysis. In many cases, a super computor is required to run a modern power system model.

**5.3 Arguably, the value of Flexibility** may be derived by comparing the potential savings from modelling a flexible system versus that of a conventional or inflexible system. Developing regulatory models that incentivize and compensate developers to install the techncaolly approptiate flexible generation is the challenge and there may not be a single one-size-fits-all solution available. It should be obvious that the integrated resource plan (IRP) should utilize modern system modeling to yield the optimal generation mix and technology to maximize RE at the lowest possible system cost based on the balance between fixed and variable costs. The IRP should be considered a living

5) Graph based results from an analysis of traditional vs modern power system modeling by Wärtsilä – 2019.

document that is routinely reevaluated and actual performance should be benchmarked against the system model on an annual basis and the regularly IRP revised. Once the type and capacity of flexible generation has been identified, transparent, international bidding for the turnkey provision of the technologies (EPC or IPP) meeting the required characteristics for flexibility is essential.

| 1 Project level LCOE analysis | 2 Traditional power system modelling | 3 Modern power system modelling |
|---|---|---|
| • Investors compare technologies on project level to find out which one provides the best feasibility for them<br>• These comparison models do not provide information on how well the technologies perform in a power system<br>• Traditional PPA dilemma:<br>• Project evaluation criteria<br>→ prioritize highest efficiency<br>→ get inflexibility<br>→ system optimized for base load, not for the future | • Provides system level information on capacity adequacy<br>• Real system balancing costs are not calculated, and are left for the grid operator to manage<br>• Neglects most of the challenges and costs of frequent starts/stops, cycling etc. caused by variability of renewables<br>• Gives a simplistic and too rosy picture of total system costs | • As accurate a picture of the future as possible<br>• Includes system balancing costs and enables understanding the impact of renewables and error forecasts<br>• Discovers the true value of flexibility & enables true portfolio optimization |

Figure 5.2.1

**5.4 One Size does not fit** all and when it comes to developing specifc regulations for Latin America and the Caribbean. However, a policy framework that sets forth a clear mandate to achieve a 100% carbon free (renewable) future within a defined timeframe may find common ground. In each case, the policy should address the need to add RE and the necessary flexible generation and energy storage to achieve the lowest possible cost of system generation while maintaining a defined standard for resiliance and reliability.

**5.5 In the vertically integrated** utility model determining the value of a flexible generator is fairly straightforward. Using a modern power system model the IRP may be developed to create a path to 100% renewable generation within a defined timeframe. The required flexibility will be determined by the model. Implemention is a simple matter of installing the recommended generation mix.

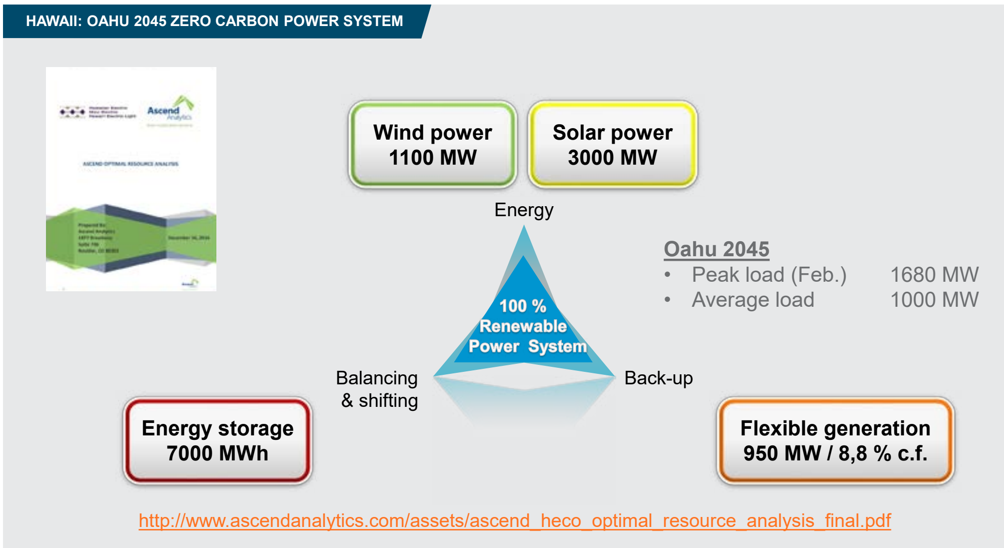
**5.6 Merchant markets** with high granularity and transparancy, such as in the ERCOT (Texas) market continue to attract flexible generation to support RE. The ERCOT Day-Ahead Market (DAM) matches willing buyers and sellers, subject to network security and other constraints, whereby energy is co-optimized with compensated ”Ancillary Services” and certain ”Congestion Revenue Rights”. The Real-Time Market dispatches resources based on economics and reliability to meet the system demand while observing resource and transmission constraints. In the Real-Time Market the IPP developer is incentivized to evaluate and build assets that can be monitized in the hour-ahead or five minute ahead markts. The market renumerates the generation that can capture value. Market forces determine the optimal generation mix and experience proves that inflexible units have limited and ever decreasing value – as proven by the retirement and bankruptcy of coal plants and highly efficient combined cycle gas turbine plants. Market forces lead to solutions that can best support the installation of low cost RE. RE leads, and flexibility follows, based on market supply and demand.

**5.7 Unbundled markets** that are not merchant pose challenges and require detailed study and creative solutions to reward and encourage flexibility. Brazil, by way of example, is currently developing a model for rewarding flexible generation within the interconnected system via its sucessful auction system.

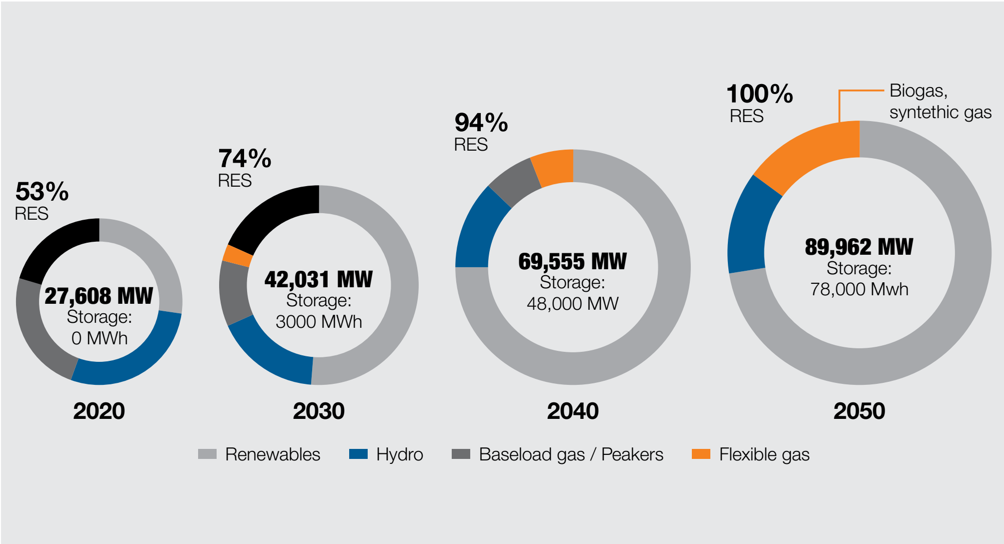
The Brazil solution will probably be based on annual simulations to solve for the value to consumer of flexibility within the system and then to create incentives that will reward flexible generation to participate competitively at auction. This, at its core, requires that the value of flexibility be converted into a capacity charge that will set the cap for biding at auction.

In PPA markets supplying a utility, the power system model will determine the technology and a PPA may be entered into after competitive bidding for the resource.

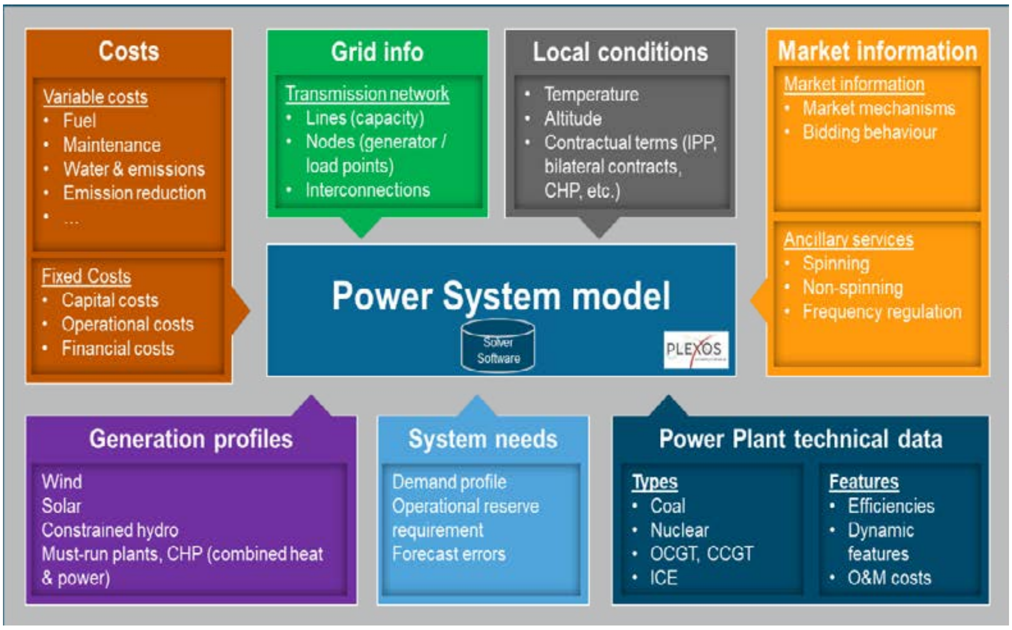
# Appendix A




**A1.** Oahu, Hawaii – zero carbon power system plan.




A2. Chile – the path to zero carbon.




A3. The Modern Power System Model inputs

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