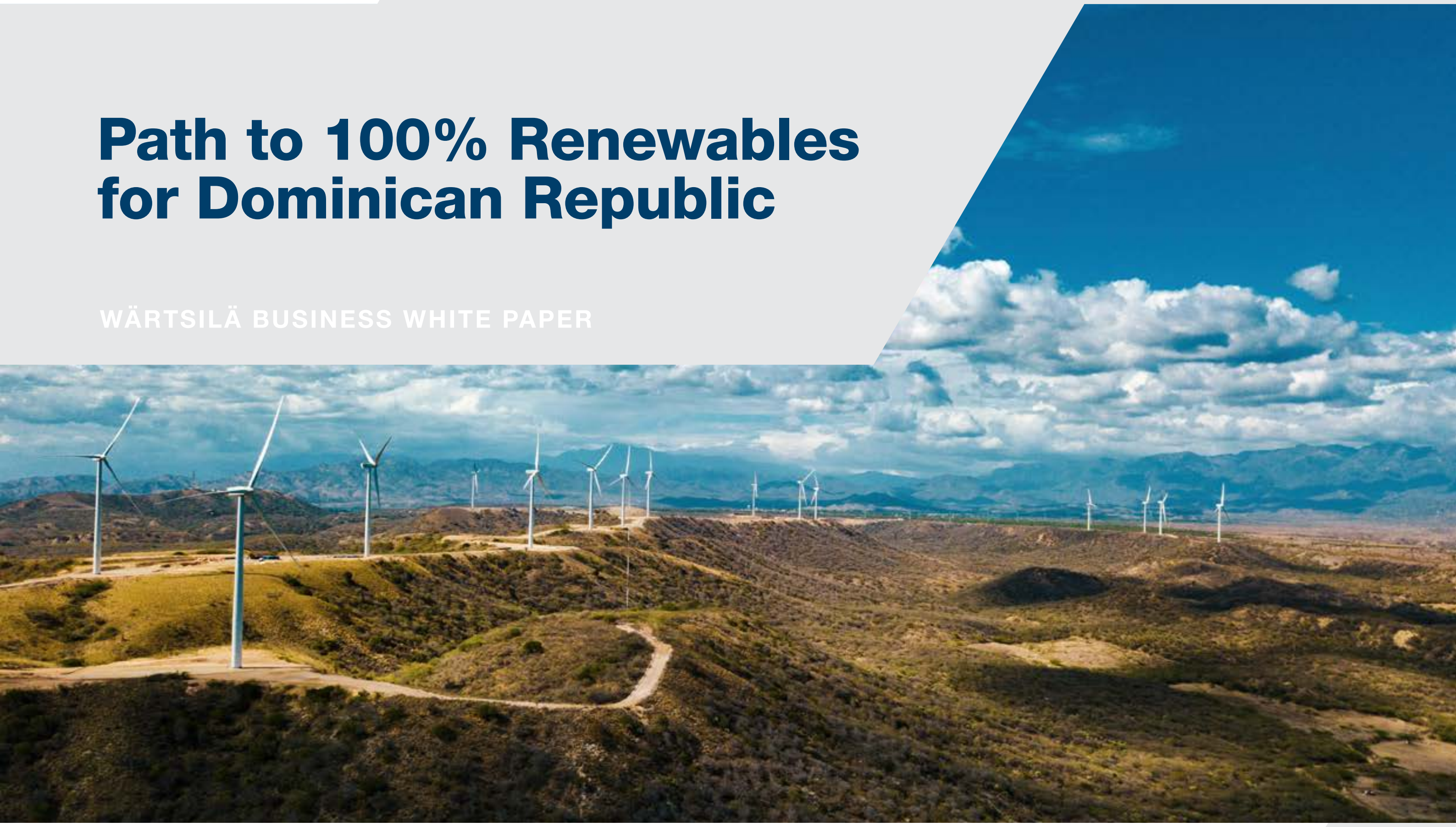
Path to 100% Renewables for Dominican Republic

WÄRTSILÄ BUSINESS WHITE PAPER



Introduction to the Dominican Republic

The Dominican Republic is considered a leader in energy and policy in the Caribbean. At the end of 2018 the Dominican Republic approved a Nationally Determined Contribution (NDC) Action Plan to reaffirm the countries pledge to maintain the targets set by the Paris Climate Agreement. This being one of the actions showing the Island nation´s commitment to reducing emissions and increasing the amount of renewable energy in their power system.

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The popular tourist destination is not only setting targets with the objective of reducing their carbon foot-print but also for economic reasons. The falling price of renewable energy across the world is a welcome sign to an Island nation like the Dominican Republic that is heavily dependent on imported fossil fuels.

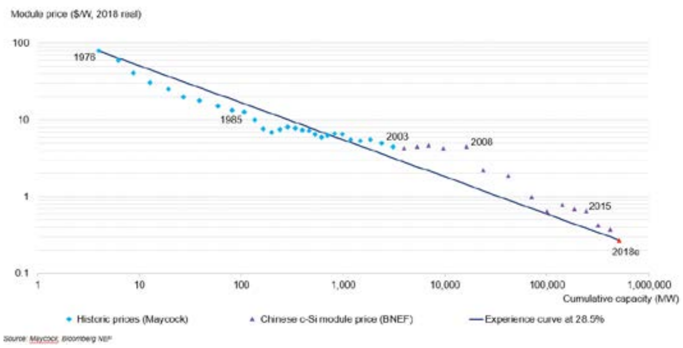


Figure 1. Global declining trends for capital expense of solar PV panels (left) and wind power plants (right). Source: Bloomberg New Energy Finance (BNEF)[1]

The country´s dependence on imported fuels, like coal, heavy fuel oil (HFO) and gas, makes utilities, and thereby the nation, vulnerable to fuel price increases. The introduction of Renewable Energy Sources (RES) like wind and solar would reduce this dependence on fossil fuels and reduce the country´s carbon footprint. In order to accomplish this, the country has announced a target that at least 27% of energy must come from RES by 2030. In addition, RES must make up 32% of the countries generating capacity by 2023. At the 2019 UN Climate Conference COP25 in Madrid it was announced that Latin America and the Caribbean Region has set a renewable target of 70% by 2030.

A challenge that comes with adding larger quantities of variable renewable resources is the inflexibility of the existing power system, mainly consisting of large combine cycle gas turbines and/or coal plants. Examples in Germany and California have shown how such plants effectively block the efficient utilization of renewable energy. The problems become visible in the form of curtailing renewable generating resources, and in reliability issues – to avoid back-out risks, the system operators operate the inflexible coal and gas plants continuously on part load even though there are times when they would not be needed. Past power system expansion studies have demonstrated that inflexible centralized power plants should be gradually retired from the system and replaced by flexible gas power technology.

Flexible gas assets can react and respond instantly on changes in weather – in other words they can quickly shut down or re-start multiple times per day, when needed. This way the use of fossil fuels is minimized. Flexibility of generating assets is defined by the technical capability of operating in such changing conditions, and the economic benefit of not increasing the maintenance costs of the plants. Ultra-flexible assets constantly interact with the system, balancing renewable intermittency when necessary, and allowing the inflexible assets to operate at the best operation point with highest efficiency and lowest emissions.

The purpose of this paper is to contribute to the conversation in the Dominican Republic and analyse the most cost-effective ways forward for the country’s power sector. This study contemplates several scenarios and compares the outcomes to the country’s current strategy.

This study provides the necessary information to understand the impact of certain decisions, taken today, on future factors such as the total cost of power, system emissions and reliability, and the ability to reach renewable targets set forth.

1)https://about.bnef.com/new-energy-outlook/

Objectives and Inputs for the Study

Main Objectives

- This Power System Expansion Study will objectively investigate multiple possible scenarios for the Dominican Republic power sector development, searching for the optimal path forward
- The Study contemplates the addition of renewable resources based on the country´s targets while also optimizing the system to determine how much renewable energy the system is able to incorporate without curtailment and risks for security of supply
- To provide multiple realistic scenarios to compare and to use for the analysis when selecting future capacity additions.

In order to remain objective, transparent and accurate, the following steps were taken:

- Utilization of globally recognized data sources for forecasting future price curves of wind, solar PV, and battery storage
- Current wind and solar PV prices stated at the International Renewable Energy Agency (IRENA) report for Dominica Republic dated 2016
  - Future price learning curves for Renewable Energy Sources (RES) and storage technologies from Bloomberg New Energy Finance
  - The Model incorporates Power System Flexibility Parameters. These parameters are essential in order to accurately reflect the realities of the future – the capability and behaviour of each asset, and the additional costs that they may have when supporting and balancing the variability or intermittence of wind and solar power. Without these parameters the modelling would give different and unrealistic results and the optimum power system would seem very different. These parameters will also assist in the calculation of emissions generated and security of supply when the share of renewables grows. It is important to note that many modelling software's do not allow incorporation of all such parameters and are therefore not suitable for analysing power systems with high renewable share.
- Refer to Appendix 3 for more information regarding expansion modelling parameters and input data.

The Model

The Power System Study has been conducted utilizing PLEXOS® Energy Simulation Software. Plexos is a software developed by Energy Exemplar. Plexos has a robust simulation capability across electric, water and gas systems focusing on full user control, transparency and accuracy across numerous constraints and uncertainties. This software is widely used by system operators, utilities and consultants for power system analysis as well as system planning and dispatch optimization.

The studied time span is from year 2020 to 2030. As stated previously, the Capacity Expansion Modelling has the objective to find the optimal power system capacity mix, capable to supply the future electricity demand, with given boundaries such as future price curves for different technologies, fuel prices, and variable operation and maintenance costs (VO&M). The optimal generation capacity will supply the demand at the lowest cost, over the studied period. The reported costs include all three components (1) Capital costs (CapEx) (2) Fixed operation and maintenance costs (FO&M) (3) Variable operating costs (VO&M) such as fuel and start-up costs (OpEx).

The model is based on true chronological dispatch with hourly data for future load, wind and solar production, for the ten-year horizon. This approach provides the most accurate picture of the systems actual dispatch, and provides accurate analysis of costs, fuel usage, emissions and system reliability. However, current Power Purchase Agreements (PPA) are not considered in the dispatch as the information is not publicly available.

The study allows the software to pick technologies in any quantity as long as this provides the lowest cost option for the power system generation costs. For each technology, characteristics such as size of plant, minimum stable load, part load heat rates, VO&M, FO&M, start-up cost, min up/down times, and investment cost are included.

System level constraints are originated from the demand, which the generating capacity needs to meet chronologically every hour. The model also includes necessary system operational reserves for maintaining the balance and reliability of the system. Primary and contingency (n-1, the biggest unit failure) reserves are included together with additional future reserve requirement for wind and solar PV balancing due to weather forecast errors.

Model Inputs

The Plexos input data was received from the resources below:

Organismo Coordinador (OC)	Comisión Nacional de Energía (CNE)	Bloomberg New Energy Finance (BNEF)	Wärtsilä
● Hourly demand ● Load growth forecast ● Grid data ● Fuel pricing	● DR Renewable targets	● Global trends ● Learning curves	● Dynamic parameter for technologies based on global references

The study is a dispatch optimization for energy and operational reserves which comprehensively considers hourly energy balancing and required additional ancillary service needs caused by intermittent renewable generation. Ancillary services are considered by ensuring that 20% of wind and solar production in MWs is always available from fast reacting reserves allocated from thermal power plants to cover possible forecast error in RES production.

Although transmission costs are not considered in the optimization, Appendix 2 further discusses the transmission cost impact and calculates the cost of transmission upgrades and the potential system savings from adding more RES.

The country has a continuous need for load shedding which on a system level makes up approximately 15% of the energy. A high priority on political agenda's in the DR is to stop load shedding and to ensure that the demand is met. This model assumes a 15% increase on top of current demand in order to provide the necessary electricity to meet increasing energy consumption. Annual 3.7% demand increase is applied to consider demand growth on the island.

New Build Candidates

Table 1 summarizes new build candidates and technology inputs used in this study. Appendix 3 provides more details, modelling settings and dynamic technology parameters. Plexos can choose to add these types of power plants and storage to the power system in any quantity, if it makes economic sense.

Property	Unit	Combine Cycle Gas Turbine (CCGT)	Reciprocating Engine -Flexicycle	Wind	Solar	Energy Battery 4h
Capacity	MW	Optimised	Optimised	Optimised	Optimised	Optimised
Full load net efficiency (LHV)	%	52	49	-	-	85% round trip
Start-up cost	USD/ MW	60	0	-	-	-
VOM	USD/ MWh	3,5	7	-	-	-
CapEx	USD/ kW	1000	825	1500-2500 (***	1000 (*	1000 (**
FOM	USD/ kW/a	20	15	60	10	-
Capacity factor	%	Optimised	Optimised	~40%	~20%	Optimised

Table 1. Inputs for the study (*) IRENA price, BNEF price curves applied for future prices
(**) BNEF estimated and price curves applied for future price
(***) Wind CapEx sensitivities done with 1500, 2000 and 2500$/ kW

Legend for Figures

Technology	Description	Color
Wind	All wind capacity	
Solar	All Solar capacity	
Hydro	All Hydro capacity	
Engine HFO	All existing engine capacity running on HFO	
New Engine Gas	All new build engine capacity running on gas	
Engine Gas	All existing and converted engine capacity running on gas	
New CCGT	All new build CCGT capacity running on gas	
CCGT	All existing CCGT capacity	
Steam Turbine Coal	All existing steam capacity running on Coal or biomass	
Battery Storage	New build battery capacity for energy shifting	

Price and Learning Curves

Renewable Energy Sources (RES) and battery technology price learning curves are displayed in Figure 2 and Figure 3 in more detail.

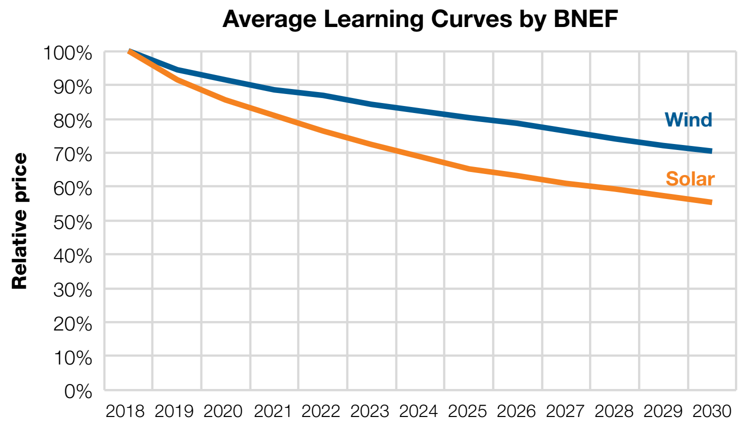


Figure 2. Price curves for wind and solar PV power plants in the long-term model.

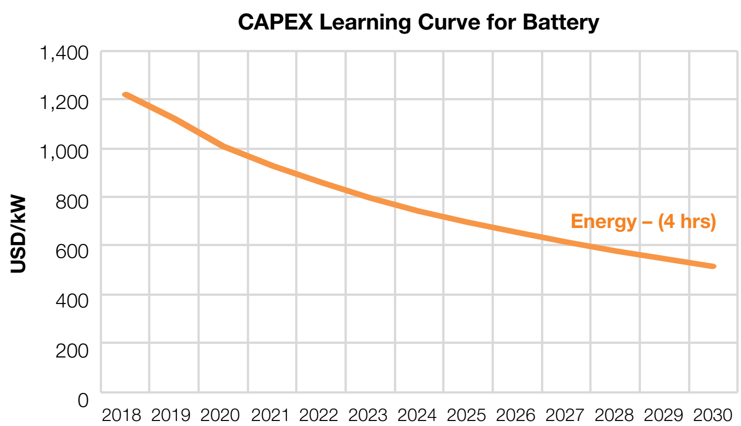


Figure 3. CapEx for battery energy storage systems (BESS)

Fuel Availability and Pricing

Today, liquified natural gas (LNG) is available on the island to a limited extent with one terminal supplier. The possibility of adding new LNG terminals and an expansion of the existing terminal is being discussed as the demand for gas is anticipated to increase when new power plant capacity is added. In this study, gas pricing is uniformed from 2024 onwards based on the pricing curves provided by CNE.

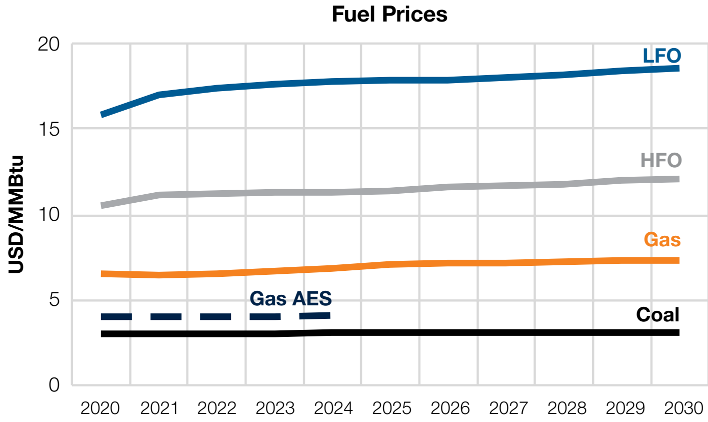


Figure 4. Fuel prices used in the model

Gas Conversions

In this study, it is assumed that several power plants will transition from liquid fuels to gas: 650 MW of engine power plants and 1040 MW of CCGT´s will be using gas as the primary fuel by 2020.

Summary of Scenarios

The Table below presents the scenarios modelled in the study:

Scenario	Purpose	Added Thermal Capacity	RES Capacity
Base Case	Current plan	600 MW CCGT build in 2024	Buildout targeting 2 GW by 2030 (70% solar and 30% wind)
Base Case -Engines	Alternative thermal technology for base case	600 MW Gas Engines build in 2024	Buildout targeting 2 GW by 2030 (70% solar and 30% wind)
Optimal	Least cost mix of RES and thermal	Thermal optimized – capacity, technology and schedule	RES optimized – capacity, technology and schedule
100% Renewable Energy Vision	Optimal path to 100% Renewable DR power system by 2030	Thermal optimized – capacity, technology and schedule	System is forced to reach 100% RES target by 2030. Power to Gas (P2G) *
Appendix Sub Scenarios			
Optimal A with “2000 wind CapEx”	To test the impact of higher wind CapEx on Optimal scenario	Thermal optimized – capacity, technology and schedule	Higher wind CapEx is used ($2000/ kW)
Optimal B with “2500 wind CapEx”	To test the impact of higher wind CapEx on Optimal scenario	Thermal optimized – capacity, technology and schedule	The highest wind CapEx is used ($2500/ kW)
Optimal C – optimized Punta Catalina dispatch	To see the impact of not forcing coal base load capacity to operate	Thermal optimized – capacity, technology and schedule	RES optimized – capacity, technology and schedule

Table 2. Summary of studied scenarios (*) Power to Gas process outlined in more detail within the 100% Renewable Energy Vision scenario

Punta Catalina Coal Plant – For every scenario above (except for Sub scenario Optimal C), 70% of the generating capacity of the Punta Catalina coal plant is required to be dispatched on the system. This assumption is based on the country´s current resource plans.

Scenario Results

This section presents the scenario simulation results. The results of each scenario are first introduced, and then each scenario is compared to the previous ones with focus on total power system generation costs and emissions.

Base Case

The Base Case scenario follows the country's current expansion plan to build 600 MW of Combined Cycle Gas Turbine (CCGT) power plant capacity in the year 2024. It also follows the current targets of the DR to install 2 GW of Renewable Energy Sources (RES) by 2030. Those RES consist of 70% Solar PV and 30% wind generation, and with those additions the DR renewable share raises to 27% in 2030. This RES capacity is just able to meet demand growth but not to reduce thermal production, fossil fuel imports and CO_2 emission. Figure 5 displays the generating capacity and energy share from 2020-2030.

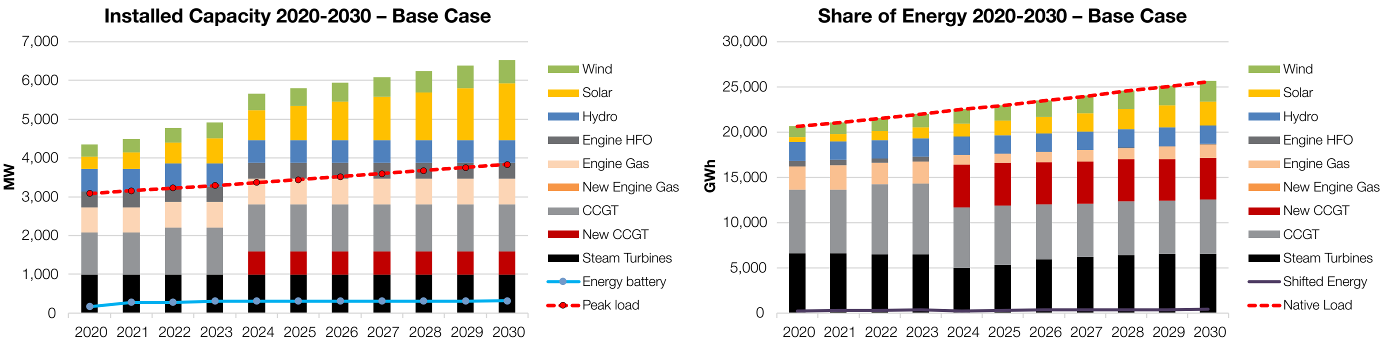


Figure 5. Base Case installed capacity by technology (left) and share of energy by technology (right) from 2020-2030.

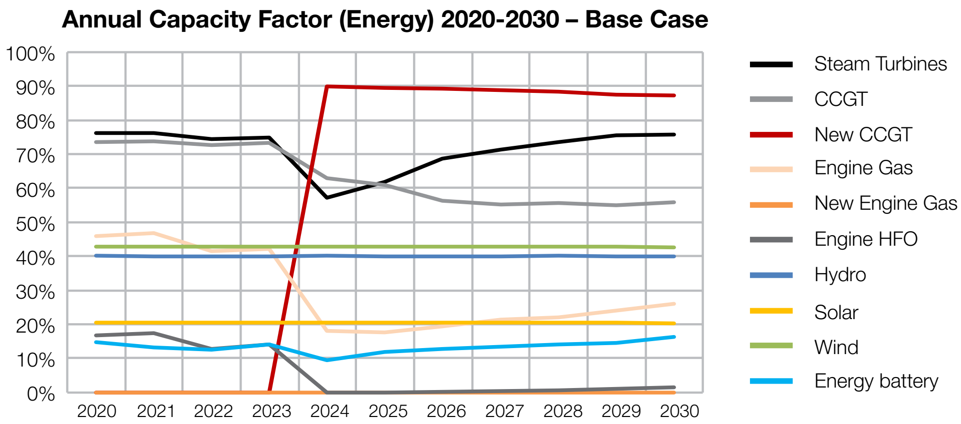


Figure 6. Base Case annual capacity factor for each technology from 2020-2030.

Observing the annual capacity factors in Figure 6 its clear that adding more efficient and lower marginal cost CCGT base load capacity to the power system decreases the capacity factors of the other base load power plants in the system. These less efficient baseload power plants, like the coal burning steam turbines or older CCGT, are not only forced to compete with newer more efficient assets in merit order but also struggle with lower average capacity factors, worse heat rates, lower running hours and increasingly more frequent starts and stops. This type of plant operation causes higher system cost and rapidly increases overall system emissions. These disadvantages overshadow the benefits provided by the highly efficient new CCGT.

The daily generation from 2020-2030 displayed in Figure 7 (left) shows the amount of load being met by the newly installed CCGT (red) after the year 2024. The remaining load then must be met by older generating units.

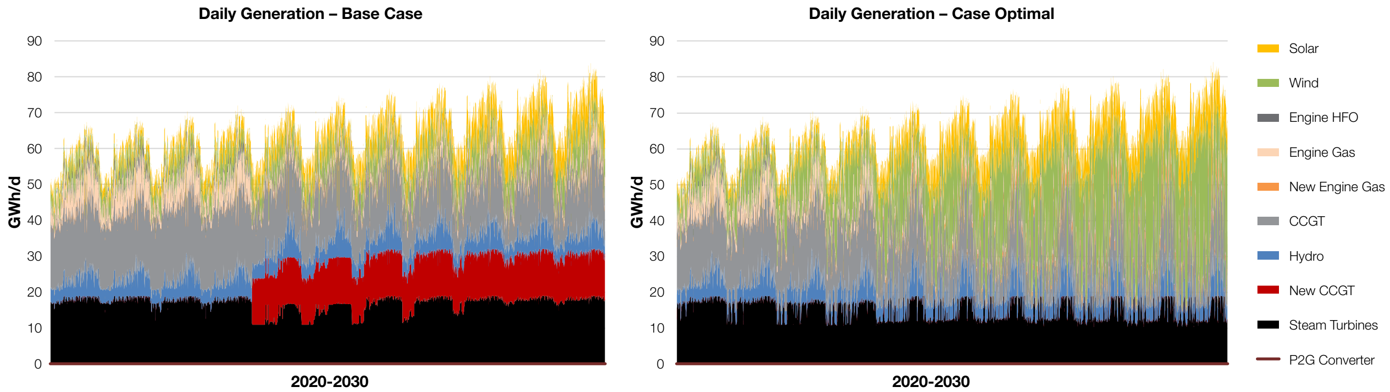


Figure 7. Base Case daily generation during 2020-2030 (left) and weekly dispatch for an example week in 2030 (right). Note: Green, yellow and blue (hydro) are emission and fuel free technologies

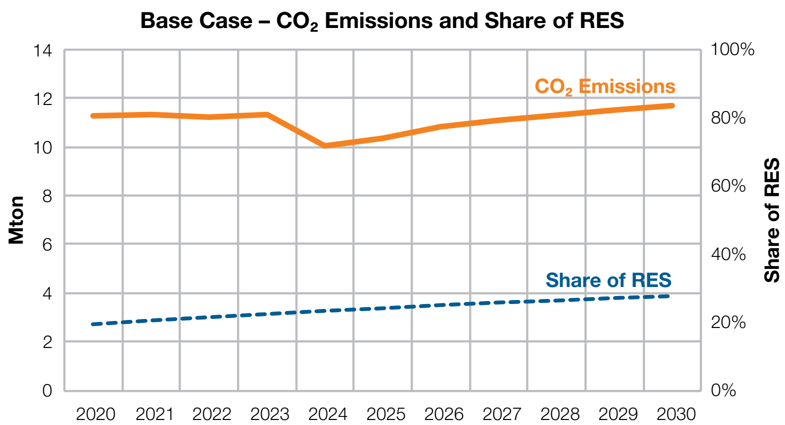


Figure 8. Renewable energy share (dotted) and the annual CO_2 emissions in tons (solid) from 2020 to 2030 for the Base Case

Base Case Scenario is a representation of the current DR expansion plan of adding a large relatively inflexible 600 MW generation asset in 2024 while also reaching the countries 27% renewable energy target by 2030. The new efficient CCGT, as expected, has the highest capacity factor of all units in the system. This new capacity operates on base load, taking up a large portion of the dispatch stack. As seen above, there is no reduction in CO_2 emissions over the decade as the new renewable capacity is mainly covering the load growth with the fossil fuel plants operating as before to cover the base load.

Going forward the Base Case scenario will be used as the point of reference for the other scenarios.

Base Case – Engines

Base Case-Engines is a sensitivity scenario that measures how system dispatch and dynamics would change if instead of building the 600 MW CCGT, the DR would add 600 MW of flexible capacity (gas engines) by 2024. The RES penetration target (27% of energy by 2030) is the same as Base Case and would meet the country's clean energy targets.

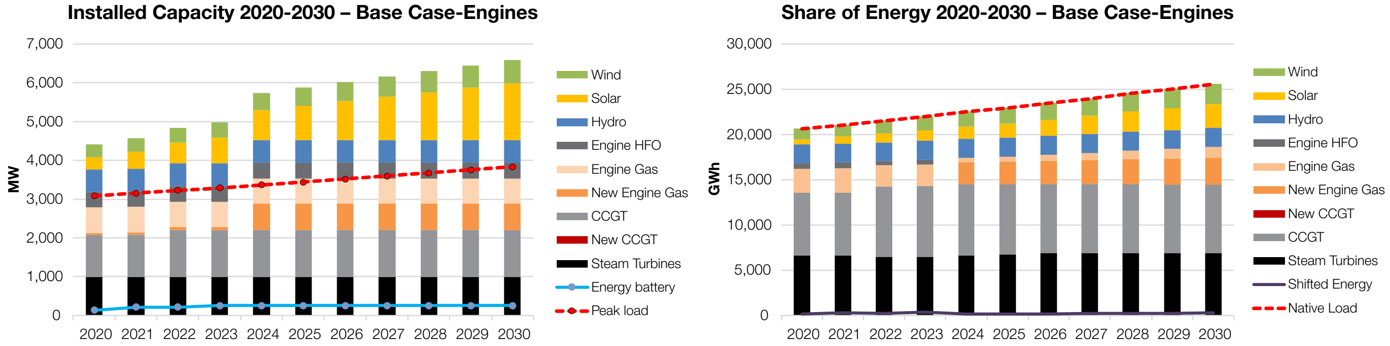


Figure 9. Base Case-Engines installed capacity by technology (left) and share of energy by technology (right) from 2020-2030.

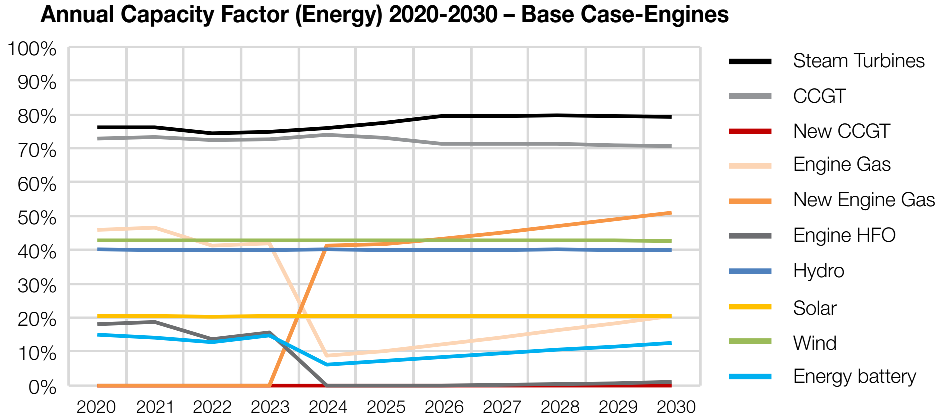


Figure 10. Base Case – Engines scenario annual capacity factors for each technology from 2020-2030.

Capacity factors show that adding the new Gas Engine technology allows all other power plants to run on a higher average load, and thereby more efficiently. In other words, the flexibility provided by the engine technology capacity allows existing base load capacity to operate closer to their optimum operation point, using less fuel. This results in an overall reduction in system operating costs. The flexibility of the new Gas Engine technology allows multiple starts and stops per day. Figure 11 below compares the average annual starts per year for all technologies.

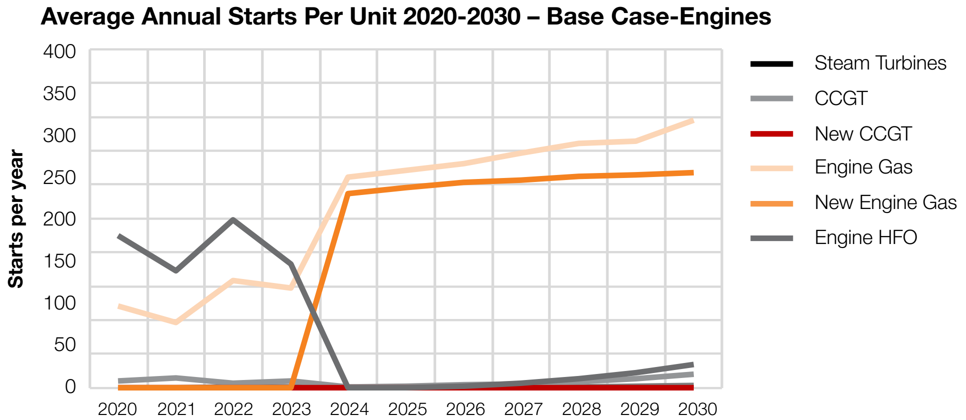


Figure 11. Base Case – Engines scenario average annual starts per year for all technologies from 2020-2030.

Below is a dispatch comparison between Base Case and Base Case – Engines. In Base Case the new CCGT pushes existing fleet "up" in the merit, meaning the existing inflexible power plants must operate less and at variable loads. The addition of engines in Base Case – Engines optimises the fleets other generating technologies to operate at more stable higher loads where the efficiency is maximized for each plant. Flexible engine capacity balances the dispatch and starts and stops when necessary to balance the system and to optimise system costs.

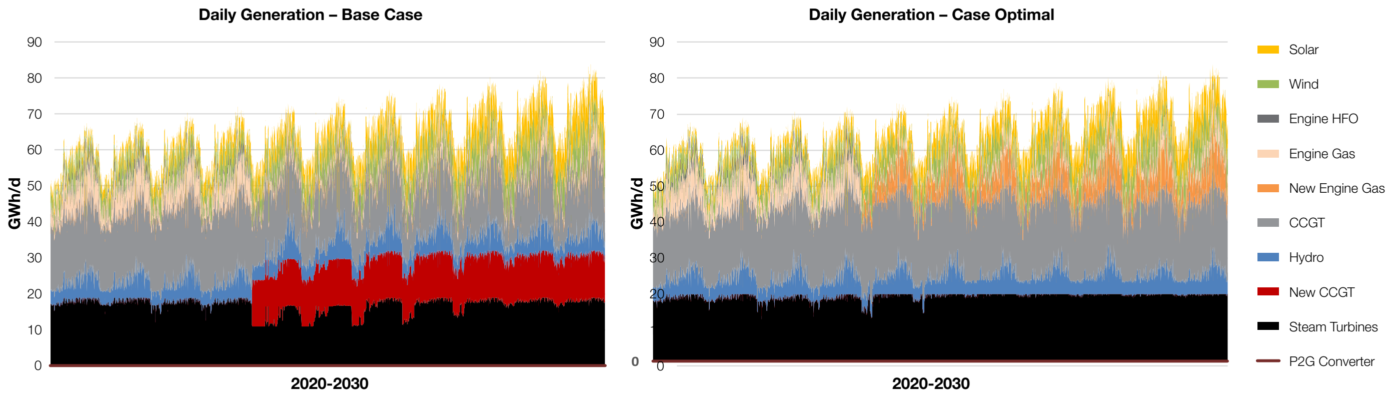


Figure 12. Daily generation comparison between Base Case (left) and Base Case- Engines (right)

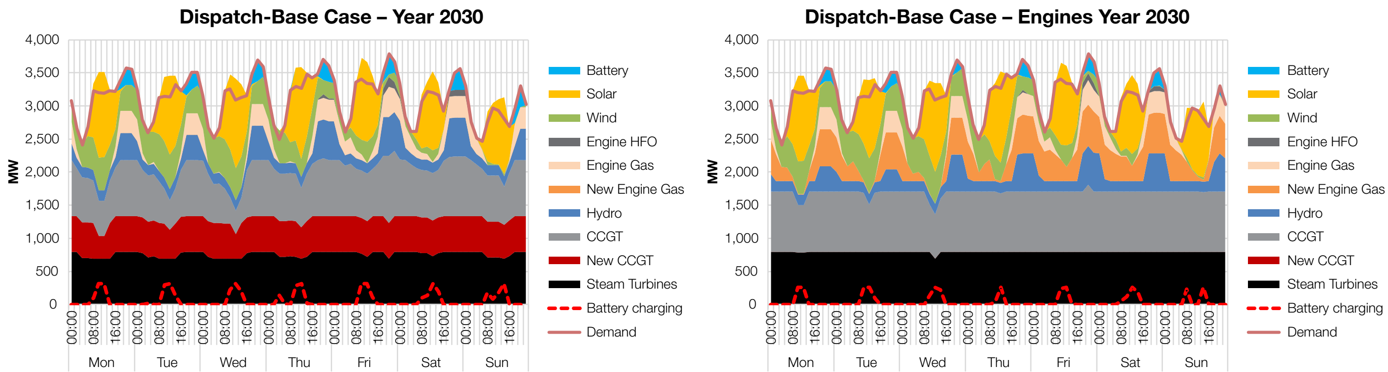


Figure 13. A weekly dispatch comparison in 2030 between Base Case (left) and Base Case- Engines (right)

In both the daily generation and weekly dispatch graphs for Base Case-Engines it is evident that the addition of the engine technology optimizes the operation of the systems existing inflexible base load assets (CCGT, coal). The engines capability to shut off and on as well as ramp up and down quickly, displayed in Figure 13 (right), is what allows the other assets to start and stop less thus reducing overall system costs.

Table 3 below displays the key results comparing Base Case to Base Case – Engines.

	Base Case	Base Case – Engines
Cumulative Savings by 2030 compared to Base Case (MUSD)	-	90 MUSD
RES Level by 2030	27%	27%
Cumulative Fuel Cost Savings by 2030 compared to Base Case (MUSD)	-	43 MUSD
Batteries installed by 2030 (MW)	317 MW/ 4hr batteries	159 MW/ 4hr batteries
Thermal Capacity added by 2030 (MW)	600 MW CCGTs	600 MW engines
Wind Capacity installed by 2030 (MW)	600 MW	600 MW
Solar Capacity installed by 2030 (MW)	1465 MW	1465 MW

Table 3. Compares results between Base Case to Base Case – Engines

Comparing the results side by side shows that despite adding the more efficient CCGT in the Base Case the total systems costs are lower with gas engines. The flexibility of the Engines enables a more efficient system operation and better utilization of RES. The cumulative savings are mainly fuel, and reduced maintenance costs of the fleet.

Case Optimal

Case Optimal displays the optimal capacity mix for the Dominican Republic for the years 2020-2030. In this scenario, Plexos optimises new thermal and RES capacity additions, technology and schedules until 2030. All in order to provide the lowest total cost and emissions for the system 2020-2030. The time line to construct all new capacity by 2030 might be too tight, but nevertheless this scenario demonstrates what would be the optimum power system to build.

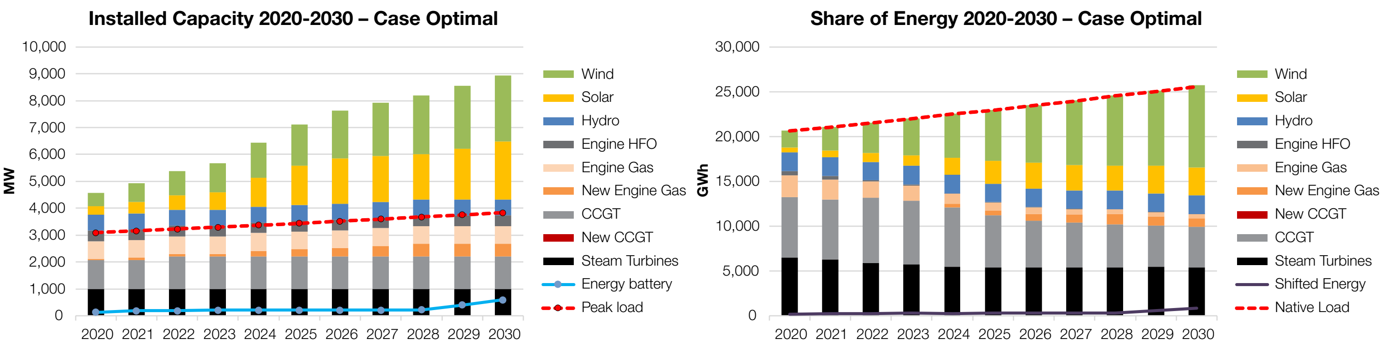


Figure 14. Case Optimal installed capacity by technology (left) and share of dispatched energy by technology (right) from 2020-2030

Compared to both previous cases, the renewable penetration has increased considerably with over 5,000 MW of RES installed. This is due to renewable generation being the cheapest form of new generating capacity. It is also important to note that new thermal capacity additions are Gas Engines – instead of CCGT´s – which provides lower costs when balancing the daily variations of the rapidly increasing wind and solar power.

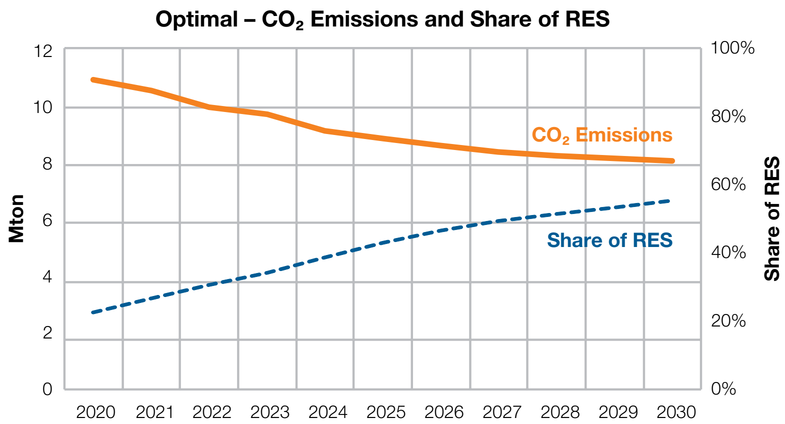


Figure 15. Renewable energy share (dotted) and the annual CO_2 emissions by tons (solid) from 2020 to 2030 for Case Optimal

It should be noted that the amount of wind capacity continues to grow at a higher rate than solar generation. Although the costs of solar may seem cheaper, from a system operating point of view wind capacity is easier to integrate and requires less storage for shifting. Wind production occurs often 24 hours a day whereas solar is only available during the day. Later, when storage becomes more affordable, Plexos starts to build more solar, typically coupled with battery storage to shift the daily over-generation to the night. Due to the increase in RES this scenario sees a clear reduction in thermal production and CO_2 emissions due to lower fossil fuel use.

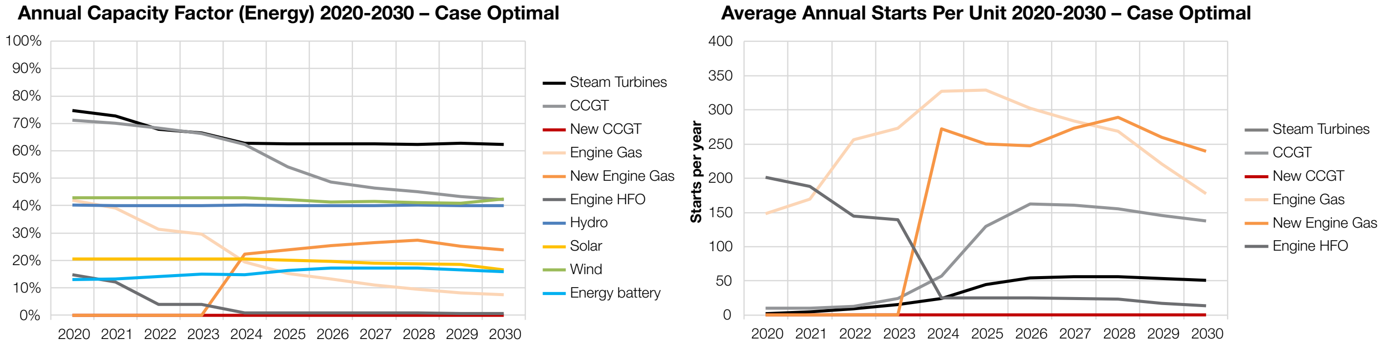


Figure 16. Case Optimal annual capacity factor by technology (left), and average annual starts per year for all technologies (right) from 2020-2030.

As seen in Figure 16, the capacity factors and number of generating asset start-ups are impacted greatly when large amounts of RES are introduced. The addition of the New Gas Engine capacity is important for allowing the other technologies in the system to run efficiently. The ability to start and stop rapidly, at no extra cost, makes engines an excellent resource for balancing the large renewable additions. These assets create greater system flexibility which will enable a smoother and faster integration of renewable energy. Note that the already existing engine plants in DR should not operate on base load mode but participate in system balancing similar to the new engines, with frequent starts and stops.

In contrast to Base Case, the New Gas Engine technology opens the doors for increasing the amount of RES in the Dominican Republic. Adding a new inflexible asset, like the large CCGT in Base Case, would limit the introduction of more renewable energy going forward. Also, a large central generating unit in an Island system is a reliability risk as every time it trips out of the system due to technical issue, the risk for black out is imminent. The flexibility added in this case is vital for optimizing the current generation fleet as variable resources are added to the power system.

Compare – Optimal vs Base Case

Figure 17 allows us to compare the daily generation during 2020-2030 for both the Base Case and Case Optimal. Most of the generation in Case Optimal (right) is made up of RES (green and yellow) with the already existing coal fired Steam Turbine units providing the base load. The addition of the flexible New Gas Engine units allows the other generation technologies on the system to run more efficiently and burn less fuel, while also balancing the increased amounts of renewables and ensuring system reliability throughout all weather conditions. Installing inflexible CCGT in Base Case (left) results in much greater operation of thermal generation– burning imported fossil fuels and producing emissions.

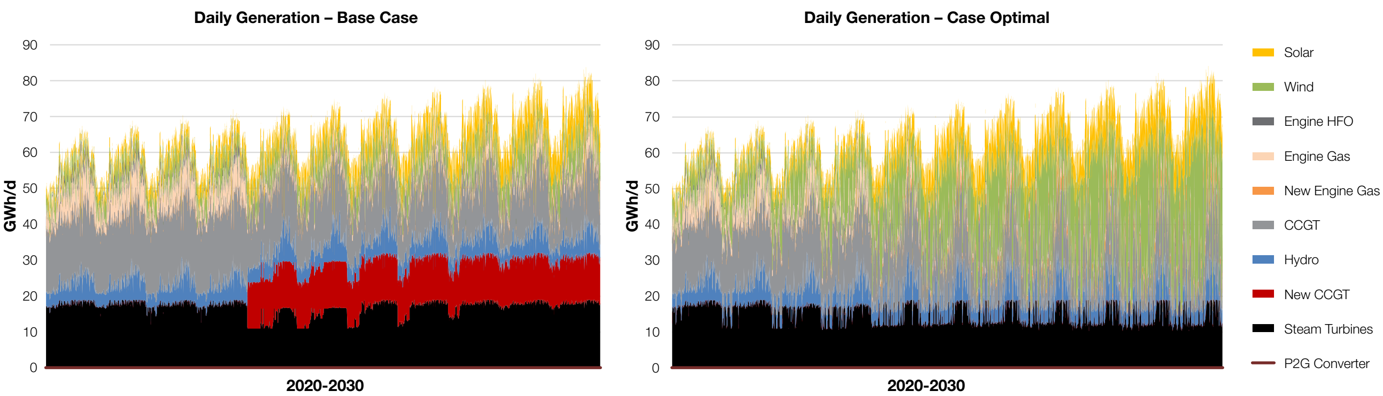


Figure 17. Daily generation comparison between Base Case (left) and Case Optimal (right) from 2020-2030. Green, blue and yellow are the emission & fuel free technologies

Table 4 below lists the findings and results when comparing Case Optimal to the previous cases.

	Base Case	Base Case – Engines	Optimal
Cumulative Savings by 2030 compared to Base Case (MUSD)	-	90 MUSD	1200 MUSD
RES Level by 2030	27%	27%	55%
Cumulative Fuel Cost Savings by 2030 compared to Base Case (MUSD)	-	43 MUSD	2350 MUSD
Batteries installed by 2030 (MW)	317 MW/ 4hr batteries	159 MW/ 4hr batteries	470 MW/ 4hr batteries
Thermal Capacity added by 2030 (MW)	600 MW CCGTs	600 MW engines	510 MW of Engines
Wind Capacity installed by 2030 (MW)	600 MW	600 MW	2,450 MW
Solar Capacity installed by 2030 (MW)	1465 MW	1465 MW	1,950 MW

Table 4. Compares the results from Case Optimal to the previous cases.

The overall take away from comparing the scenarios is that the optimal capacity mix contains more wind, solar and flexible thermal capacity than the current national plan, which is presented in the Base Case. The Optimal scenario saves 2.35 Billion US$ in fuel, reaches a renewable share of 55% by 2030, reduces carbon emissions by 31%, and provides a total generation cost saving of 1.2 Billion US$ compared to the current national plan.

100% Renewable Energy Vision

Wartsila has the vision of leading the world to the 100% renewable power systems. This case will study which steps would need to be taken in the Dominican Republic to move closer to this vision of 100% Renewable Energy, and how this system compares to the previous scenarios. This study concentrates on wind and solar resources as the new build RES options.

The Renewable energy target gradually increases in the model until 2030 where the system must be fully powered by renewable energy sources.

Seasonal variability of renewable resources will factor heavily when optimizing the 100% RES power system as renewables are responsible for generating most of the systems energy. Figure 18 displays the monthly production from variable solar and wind resources.

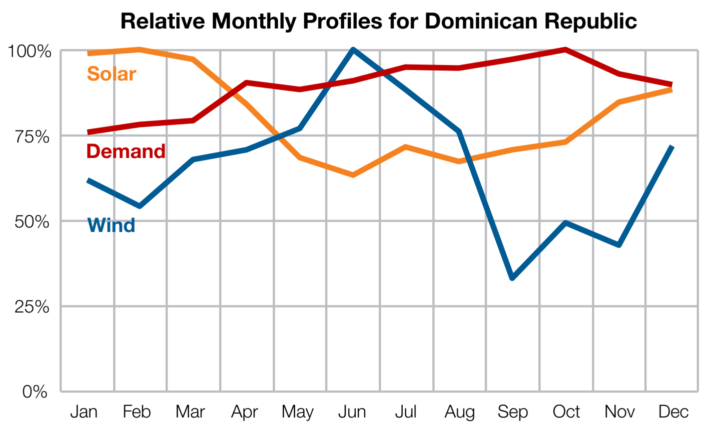


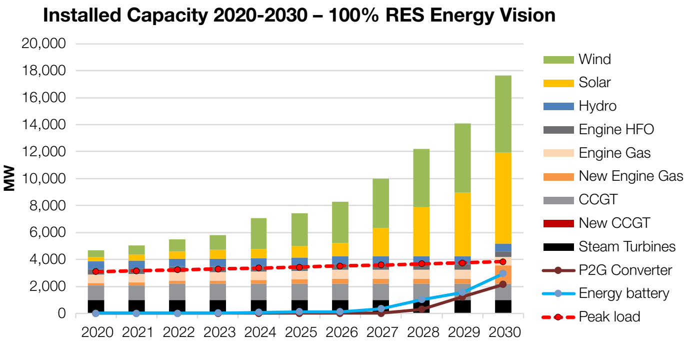
Figure 18. Monthly relative generation profiles for the 100% renewable power system in DR

Another major factor in the zero-carbon system will be the development and availability of renewable fuels. The process of producing synthetic renewable fuels is known as “Power to X” or in this case power to gas (P2G). The process requires electricity generated mainly from RES to produce Hydrogen (which is extracted from water molecules) and harnessing already existing carbon dioxide from the earth’s atmosphere. In the P2G process there are several sub-processes like hydrolysis, carbon capture, methanization, and gas storing. The ability to synthesize these renewable fuels and to store large quantities for future use will play a vital role in reaching zero carbon targets. It is important to note that renewable methane can be transported using existing LNG tankers, and distributed using existing gas networks.

Transitioning from the current power systems to 100% decarbonized systems does not mean there will be no power plants burning fuels. Synthetic Power to X fuels are carbon neutral and will be available in large quantities in the future for aviation, ship transport and other sectors that will also demand such fuels. These fuels will cost a magnitude of 3 to 5 times more than fossil fuels, but as wind and solar will produce most of the electricity, the necessary fuel quantities are relatively small.

For a system to be zero-carbon or 100% renewable, the dispatchable flexible generating assets must have the ability to use such synthetic renewable fuels. For the model’s purposes this study assumes that all the gas generating assets on the island can run on synthetic methane. Modern gas engines are already able to burn carbon neutral synthetic methane and methanol with high efficiency.

Due to the large amounts of daily and seasonal variance, energy storage will play a vital role in maintaining system reliability. Plexos utilizes energy storage technologies to balance the system on a daily and seasonal level. Lithium-ion batteries are used mainly for solar shifting from day to night, and to balance short term variations. Stored renewable synthetic fuels from the P2G process are used by fuel flexible thermal assets for balancing any large seasonal and daily variances, for instance extreme weather events where wind and solar are unavailable for extended periods. Dispatchable thermal assets are needed for these periods without normal wind and solar generation as the amount of energy stored in batteries would not suffice. The other option would be to build an extremely oversized battery storage, but to do this for only some rare weather events does not make economic sense.



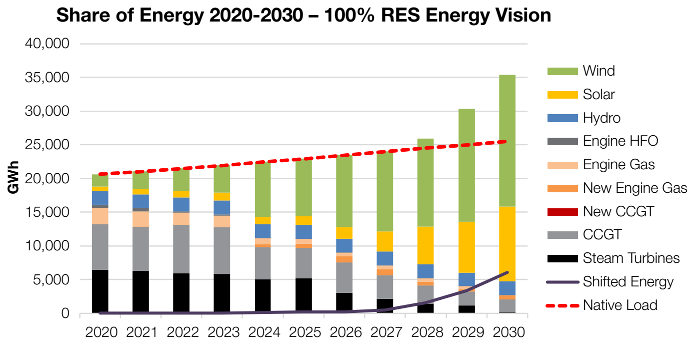


Figure 19. Installed capacity (left) and share of energy (right) by technology for the 100% RES Scenario.

Figure 19 (left) above displays the capacity build out from 2020-2030. In order to reach the 100% target overbuilding a large amount of RES is necessary with major additions each year between 2025-2030. With some thermal assets remaining online as back up for extreme weather conditions. As mentioned previously, these technologies would operate on synthetic renewable fuels from year 2030 onwards.

Figure 19 (right) represents the amount of energy being generated by technology. Renewable generation dominates the energy share by 2027 and allows for an increase in stored energy to be shifted for future use, using battery storage. Flexible gas generation, using renewable fuels, operates on low capacity factor, using small quantities of fuel, but ensures system reliability throughout all weather conditions.

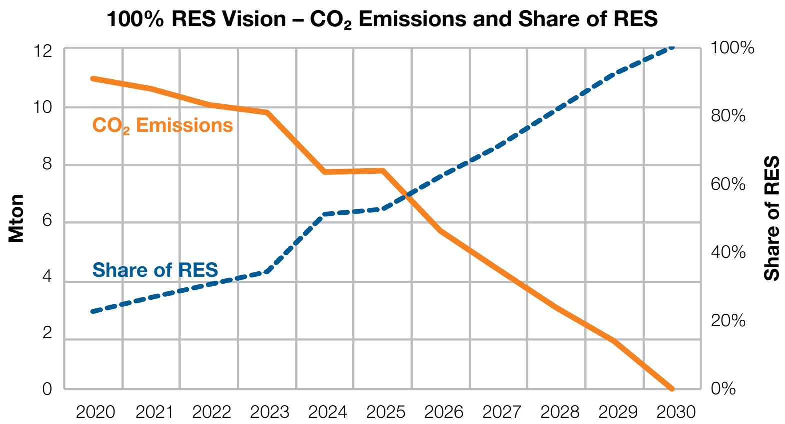


Figure 20. Renewable energy share (dotted) and the annual CO_2 emissions by tons (solid) from 2020 to 2030 for 100% Renewable Energy Vison case

For the power system to be considered 100% renewable the CO_2 emissions must be at 0 tons by 2030. Both graphs in Figure 20 display this transition over the ten-year study period. The amount of renewable energy generated, and the amount of emissions produced correlate directly and begin to change noticeably after the year 2025.

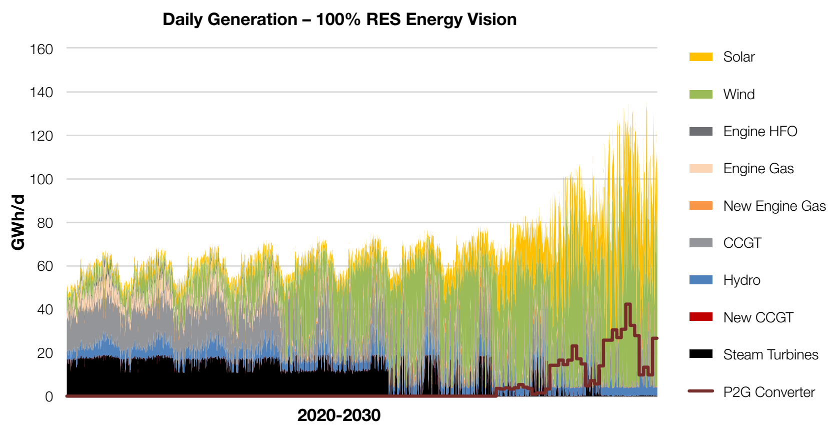


Figure 21. Daily generation by technology type from 2020- 2030 100% RES Scenario

Figure 21 shows how thermal generation is on stand-by most of the time by 2030, with RES generating most of the electricity. The excess wind and solar being generated is captured and converted to renewable fuels in the Power-to-gas process.

As mentioned, in the Power to Gas (P2G Converter) process excess wind and solar can be utilised through hydrogen electrolysis and methane synthesis to produce renewable synthetic methane (natural gas). The methane then fed to the local gas network, or liquefied to LNG, stored, and later regasified for use in flexible thermal power plants as needed. This process is indicated by the dark brown line, which rises when electricity is being consumed and converted into fuel.

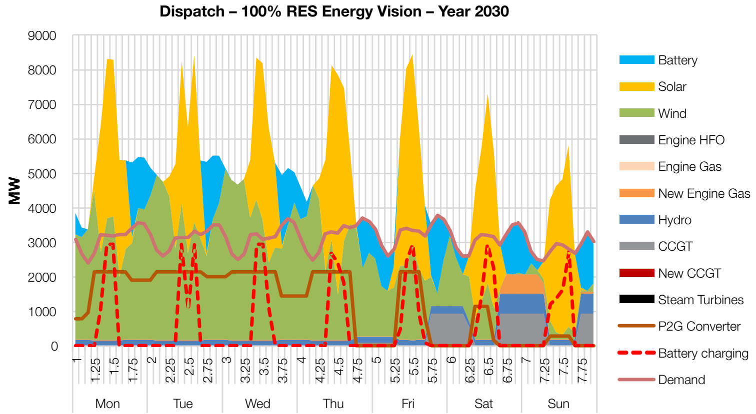


Figure 22. Weekly dispatch by technology in the year 2030 for the 100% RES Scenario

A weekly outlook on how technology is being dispatched is displayed in Figure 22. In addition to the large production of renewable energy, the batteries in the system are being used for balancing renewable variance and shifting excess solar from day to night. Power to Gas is not operating on a daily variance but instead storing fuel for longer term daily, weekly and monthly needs. The charging of batteries is indicated by dotted red line and the P2G Converter consumption is presented by the solid brown line.

Observing Saturday and Sunday on the graph gives an indication of how the system operates when not enough renewable energy is being produced to meet the load. For periods during these two days flexible thermal generation is needed to balance the system operating on renewable fuels produced by the P2G converter earlier in the week. All excess production above the demand line (solid light red line) is used to charge batteries and provide power to the P2G converters creating carbon neutral synthetic fuels, which is the only fuel for any thermal capacity at this time.

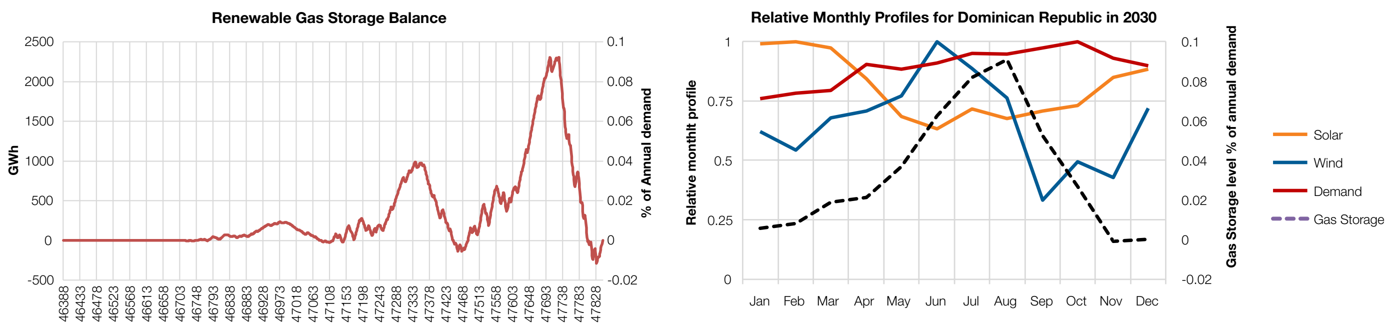


Figure 23. Renewable gas storage levels (left) and the monthly dispatch profile for 2030 (right) for the 100% RES Scenario

Figure 23 helps clarify how the Power-to-Gas process or renewable gas is helping the seasonal variance of wind and solar and demand. The model starts to utilize the Power-to-Gas technology in 2028 and by 2030 the maximum amount of renewable synthetic gas stored is equal to 10% of the demand in the Dominican Republic. The stored renewable gas is vital from August to November as wind production slows dramatically and the demand begins to increase. During this period the renewable gas is used frequently in flexible thermal assets to balance the power system.

It will be possible to import synthetic renewable fuels and the existing LNG infrastructure on the island could be utilized. Considering the Islands current LNG storage and the planned additions there is enough fuel storage available for the renewable gas by 2030. This study used the excess renewable electricity to produce the fuel locally, but the cost for importing it would be similar and would not significantly impact the results.

Table 5 below lists the findings and results when comparing the 100% Renewable Energy Vision to the previous cases.

	Base Case	Base Case – Engines	Optimal	100% Renewable Energy Vision
RES Level by 2030	27%	27%	55%	100% by 2030 – power sector is carbon neutral
Cumulative Savings by 2030 compared to Base Case	-	90MUSD	1200MUSD	-100MUSD (by 2028 and 80% RES share 900MUSD savings)
Cumulative Fuel Cost Savings by 2030 compared to Base Cas	-	43 MUSD	2350 MUSD	4,400 MUSD
Power to Gas added by 2030	-	-	-	2 GW and 2.5TWh
Batteries installed by 2030	317 MW/ 4 hr batteries	159 MW/ 4 hr batteries	470 MW/ 4 hr batteries	3 GW (12 GWh)
Thermal Capacity added by 2030	600 MW CCGTs	600 MW engines	510 MW – all Engines	1,300 MW – all Engines
Wind Capacity installed by 2030	600 MW	600 MW	2,450 MW	5,700 MW
Solar Capacity installed by 2030	1465 MW	1465 MW	1,950 MW	6,700 MW

Table 5. Compares the results from the 100% Renewable Vision Case to the previous cases.

In Table 5 above and Figure 24 below it is clear that the final push to fully de carbonize the DR power system can be costly when compared to the other scenarios

Comparing Costs and Emissions between Scenarios

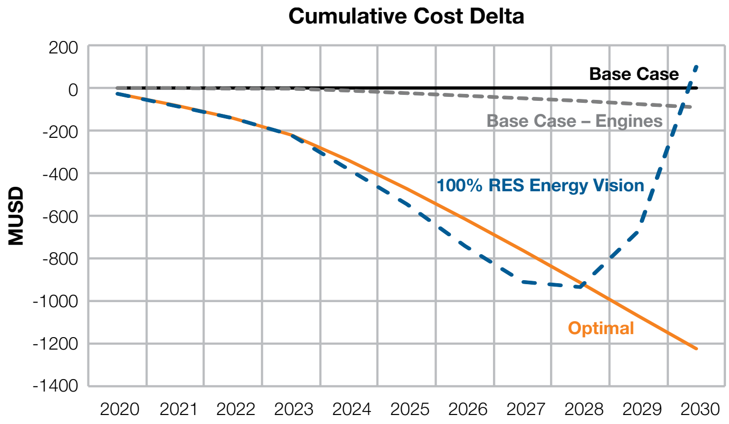


Figure 24. Cumulative Cost Delta for all the studied cases

Figure 24 compares the total cost (OpEx +FOM+ CapEx) of all three scenarios. Installing Engines instead of CCGT shows overall cost savings but adding engines and gradually increasing RES amplifies those savings significantly. Pairing a high percentage of RES with a flexible thermal portfolio decreases the reliance on fossil fuels thus decreasing costs for the island power system drastically. Flexible thermal technology balances and optimizes the power systems energy generation and allows for maximum utilization of the renewable energy.

Additionally, it's clear that the 100% RES vision is the most feasible scenario until 2028 when RES share reaches 80%. After that based on scenario settings the system rapidly pushed to 100%RES share (90% by 2029 and 100% by 2030) which is not done based on economics but other variables (e.g. political will). In these cases, costs are higher than in economically optimized scenarios. To reduce these high costs, the final year of reaching 100% decarbonization should be moved in to the 2030´s as battery storage and solar power continue becoming more competitive.

Another comparison of costs between scenarios is outlined in Figure 25. By separating the total cost into CapEx, OpEx, and FOM we can see which portions are contributing most to the total cost by 2030. The 100% RES vision sees a large decrease in operating cost due to the amount of RES in the system by 2030. However, this scenario does see a higher CapEX as in order to reach the 100% system large amounts of renewable energy sources must be installed.

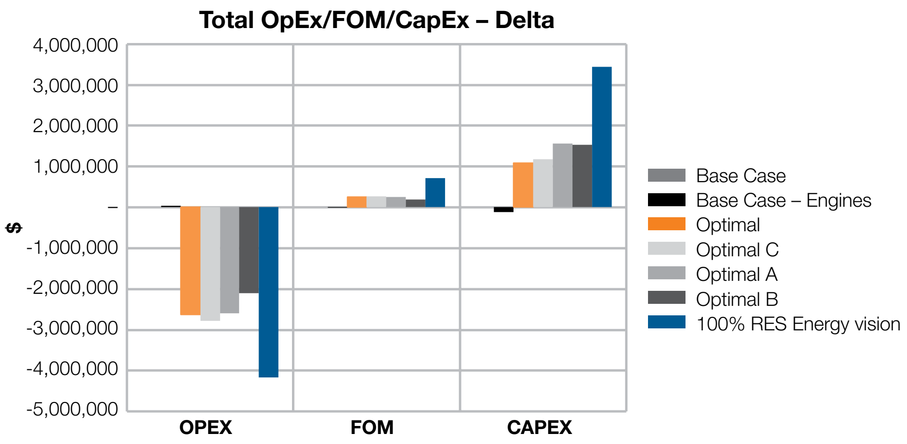
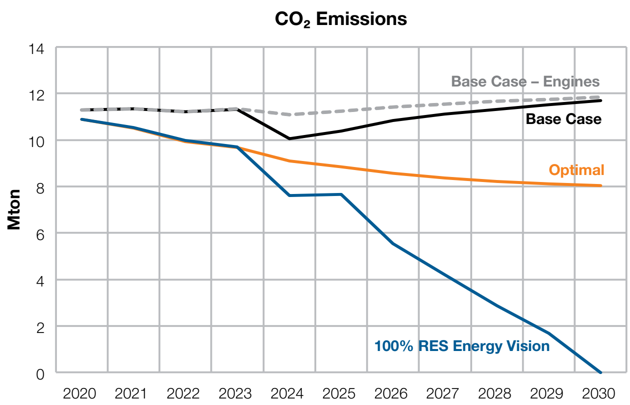


Figure 25. Cost Deltas for OpEx, FOM, and CapEx by 2030 for all the studied scenarios (sub scenarios Optimal A, B, C outlined in Appendix 1)

Based on these results it can be said that 70-80% RES share is the optimum economic renewable share at the end of the 2020´s and provides lower costs and emissions than the current power system plan. After that the steps towards carbon neutrality start to become more costly. It should be noted that while this simulation is establishing the Dominican Republic's 100% Renewable Vision by 2030, the declining cost of technologies like batteries and the improvements of the power to Gas prosses should make the 100% renewable power system more feasible after 2030.

Figure 26 below shows the CO_2 emissions from the four studied scenarios (as well as the sub scenarios outlined in Appendix 1). Along with the renewables, storage plays an important role in the emission reduction. Due to the steep cost down curve of battery costs, Plexos proposes, in most scenarios, to start installing storage closer to the year 2030.

It should be noted that emissions are not guaranteed to decrease just because more renewable capacity is added to a power system. For a system to decarbonize a combination of renewable energy and flexible thermal generation is required. This allows the portfolio to utilize the carbon free renewable energy without negatively impacting the reliability or operating costs of other assets on the system. This can be seen in the emission for Base Case with Engines.



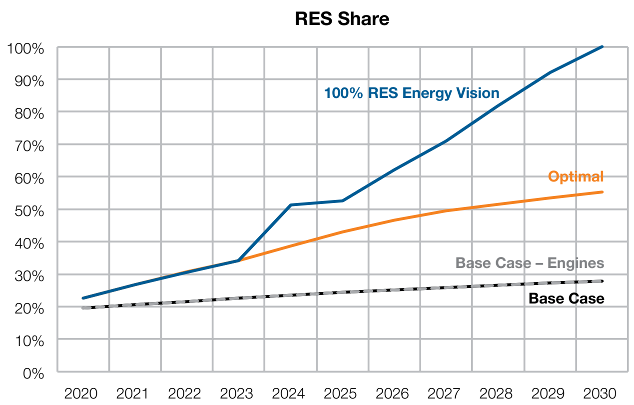


Figure 26. CO_2 Emissions (left) and the amount RES Share (right) for all the studied cases (sub scenarios Optimal A, B, C outlined in Appendix 1)

Conclusions

This study searched for the optimal path for developing the Dominican Republic power system towards 100% renewable energy, utilizing Plexos Modelling Software. Several scenarios were studied. The overall objective was to find the most efficient way forward for the DR while ensuring competitive generation costs and low emissions. The modelling inputs for expected future technology price and system data are from various reputable sources, such as Bloomberg New Energy Finance, CNE, and OC.

Solar and wind power are already today the cheapest new electricity generation source, and they will have a central role in the power system transition by generating the majority of the electricity in the future. While gradually retiring old inflexible capacity, it is important to ensure that adequate flexible gas capacity is available to efficiently balance the variability of wind and solar, keeping the system stable throughout all weather conditions. Storage will also play an important role mainly by frequency regulation and shifting solar generation from day to night. Due to the forecasted price decline of battery storage, storage installations start to increase rapidly closer to 2030.

In the early years, even after converting several asserts to operate on gas, coal and gas generation are supplying a large share of the nation's electricity while also being responsible for most of the CO_2 emissions. It should be noted that in the model there was no emissions cost or taxes for CO_2. Despite the lack off an emission cost the model sees economic value of wind and solar capacity. However, as mentioned previously, increasing the share of wind and solar generation requires flexibility from the thermal power generation, which coal power plants and CCGT cannot provide. Fortunately, Dominican Republic power fleet already includes flexible thermal capacity in form of engine power plants. It is vital for the thermal fleet to be capable of shutting down and restarting rapidly when weather conditions change as intermittency is inevitable.

For existing coal and CCGT plants, starting-up and shutting down requires a lot of time and incorporates many costs – these assets will struggle operating in a high RES power system. If these types of inflexible assets remain in the system, due to political or contractual obligations, they start to force curtailment and hinder the RES penetration and limit the chance of reaching clean energy targets. Based on the findings of this study the Dominican Republic should not, under any circumstance, add any new inflexible gas capacity (CCGT´s) to the system going forward as this will just increase costs, dependency of imported fossil fuels and limit the opportunities to add renewables.

Investing in renewable technologies will allow Dominican Republic to reduce significantly the reliance on imported fuels as well as the high cost and price risks associated with them. The funds that would have originally been used to pay for importing fuels can be used to finance the clean renewable power and in other ways to benefit the nation.

The results indicate a 70-80% RES share is the optimum economic renewable share at the end of the 2020´s and provides lower costs and emissions than the current power system plan. Reaching the economic optimum RES would more than meet the countries 2030 target of generating 27% of its energy from renewables and the 2023 target of 32% RES capacity. This optimal scenario would also meet the Latin America and Caribbean region renewable target of 70% but 2030.

The purpose of the final scenario, the 100% Renewable Energy Vision, was to demonstrate the necessary scale of wind and solar capacity, together with required balancing and shifting technologies to reach the zero-carbon power solution for the Dominican Republic. Reaching 100% by 2030 might seem unrealistic, but it is valuable to study what needs to happen in order to get there. What is for certain is that even after 2030 more renewables will be gradually added to the DR power system and the more renewable energy sources are added, the more inflexible coal and gas power plants transition from valuable base load assets to stranded assets.

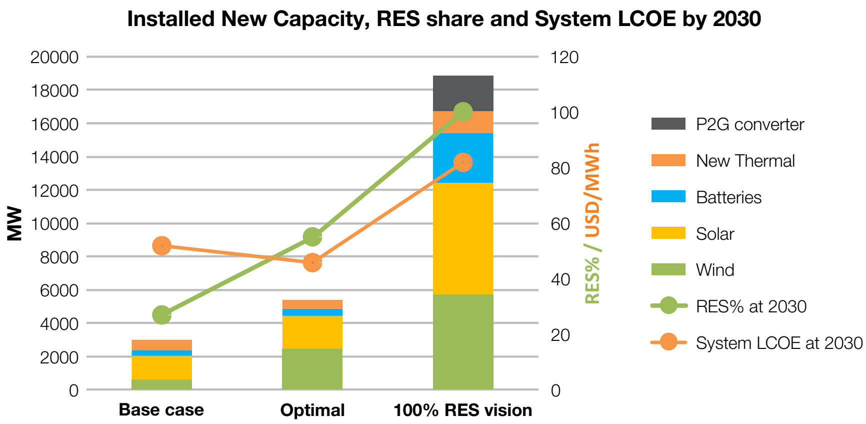


Figure 27. Installed new capacity, RES share and System LCOE by the year 2030 for all scenarios and sub scenarios

The purpose of this paper was to contribute to the conversation in the Dominican Republic and analyse the optional paths to develop the power system towards reduced fuel use and increased clean renewable energy. This study hopefully helps to understand the best ways forward, and the impacts of decisions made today on future cost of power, emissions, system reliability and the ability to reach renewable targets of the future.

Appendix 1 – Sub Scenarios

Case Optimal A & B with Wind CapEx sensitivities

In this section of scenarios, the model evaluates the difference in results with two different prices for wind generation. One with an initial price of 2,000$/ kW and another with a price of 2,500 $/ kW.

These scenarios were added to address the discussion around CapEx costs for wind power in the Dominican Republic. Recent reports have stated that prices are much higher than on other similar islands in other nations and regions of the world. The costs of all the components that make up the wind generators are the same across the world, the differences come from local customs and taxes, land transports, land, installation costs and interest rates. This study does not speculate why these costs may be much higher in the DR than in other countries.

Results from the both sub scenarios are compared to Case Optimal in Table 6 below.

	Optimal	Optimal A	Optimal B
Capital Cost of Wind Capacity	1500$/ kW	2000$/ kW	2,500$/ kW
Cumulative Savings by 2030 compared to Optimal	-	-400 MUSD	-750 MUSD
RES Level by 2030	55% RES	54% RES	49% RES
Batteries installed by 2030	470 MW/ 4 hr batteries	476 MW/ 4 hr batteries	353 MW/ 4 hr batteries
Thermal Capacity added by 2030	510 MW Engines	510 MW Engines	560 MW Engines
Wind Capacity installed by 2030	2,450 MW	2,400 MW	1,850 MW
Solar Capacity installed by 2030	1,950 MW	2,000 MW	2,200 MW

Table 6. Compares sub scenarios Optimal A and Optimal B to Case Optimal

Results for both scenarios indicate the need for the same amount of new thermal generation -approximately 500 MW of Gas Engines. Scenarios A and B both indicate that even with the higher wind CapEx the competitiveness remains almost the same for renewable energy sources in the Dominican Republic as the quantity of wind generation capacity does not change dramatically even when the wind power CapEx is increased.

Case Optimal C – without forced dispatch of Punta Catalina power plant

All previous scenarios in this study required that the Punta Catalina coal plant must be dispatched at least with a 70% capacity factor – this is a base assumption in current DR resource plans. This sub scenario, however, removes that requirement and allows the model to operate the plant optimally, and to retire the coal/steam plant when it is no longer economically and/or operationally viable. The results below in Table 7 present a comparison to Case Optimal.

	Optimal	Optimal C
Capital Cost of Wind Capacity	1500$/ kW	1500$/ kW
Cumulative Savings by 2030 compared to Optimal	-	70 MUSD
RES Level by 2030	55% RES	57% RES
CO_2 Reduction by 2030	-	14% (41% reduction when compared to Base Case)
Batteries installed by 2030	470 MW/ 4 hr batteries	425 MW/ 4 hr batteries
Thermal Capacity added by 2030	510 MW Engines	530 MW Engines
Wind Capacity installed by 2030	2,450 MW	2,450 MW
Solar Capacity installed by 2030 (MW)	1,950 MW	2,050 MW

Table 7. Compares the sub scenario Optimal C to Case Optimal

The above results indicate how the forced running of the inflexible Punta Catalina power plant in other scenarios is hindering RES penetration.

Figure 28 below displays the differences in dispatch by technologies for Case Optimal and this sub scenario of not forcing the Punta Catalina into the dispatch.

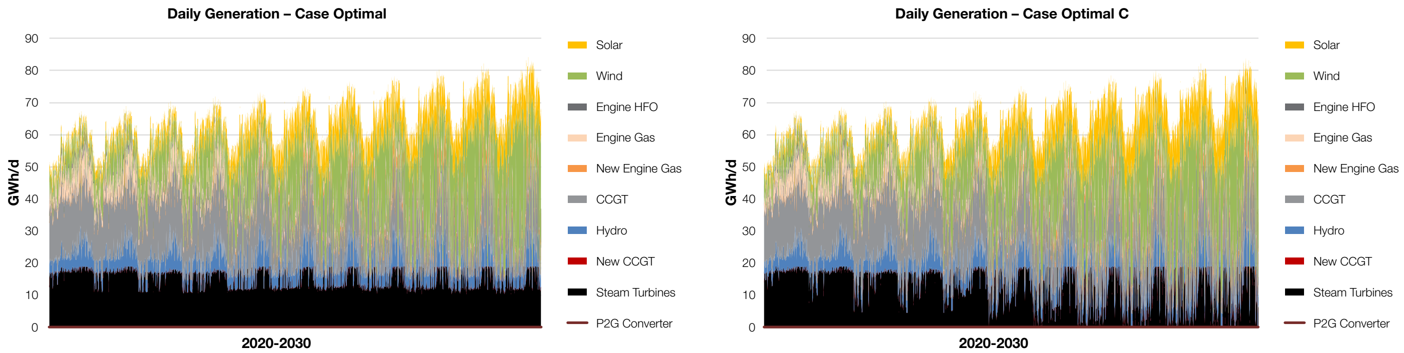


Figure 28. Dispatch between 2020-2030 for the Case Optimal (left) and Sub Scenario – Case Optimal without the Punta Catalina being forced into the system (right)

When Plexos can regulate the use of the coal plant, it gradually reduces its dispatch and adds more renewables to compensate. Not only does this reduce emissions quickly and drastically but it also makes economic sense. As there was no target set in this scenario for reaching 100% renewable energy by the end of the period, Plexos keeps the Punta Catalina coal plant in the system to provide energy during periods when there is low wind and solar output. As there is no renewable coal fuel in sight today, the plant would need to be retired, or converted to biomass, if a target of 100% renewables was set.

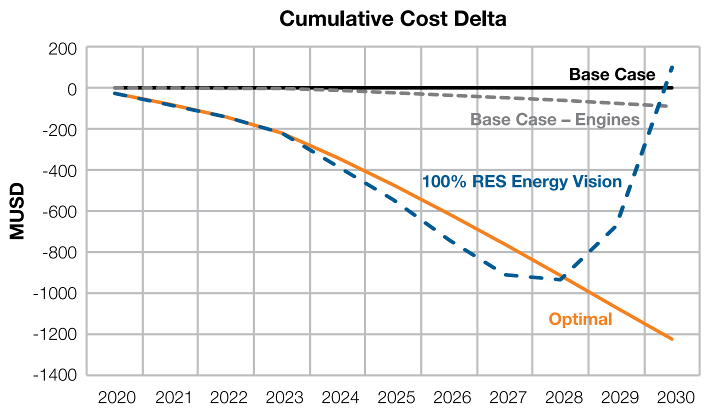


Figure 29. Differences in cost between scenarios

In Figure 29 above the cost between the cases for all scenarios are compared. The CO_2 emissions for the scenarios are shown in Figure 30 below. The sub scenario Optimal C, scenario without forced dispatch of Punta Catalina power plant, shows a minimal impact on total generation costs, compared to Case Optimal, but a drastic emission reduction. When compared to the current power system plan the impacts on total generation cost and emissions are both major.

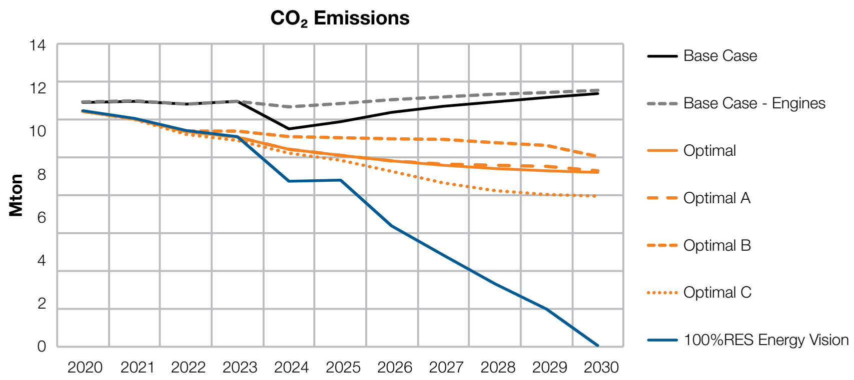


Figure 30. Differences in CO_2 emissions between scenarios

Appendix 2

Transmission Upgrades

In this study transmission upgrades were not considered. However, adding more renewables to the system would require construction of new grid lines, and this appendix evaluates the approximate grid upgrade costs, and evaluates their feasibility.

Determining which grid investments should be made in order to accommodate the grid connections for new generation capacity is a complex task. Permitting new grid lines may also be a time-consuming process. However, one can estimate the size of grid expansion necessary to incorporate all the new renewables and compare that to the system level savings available when comparing the Optimal Case to the Base case scenario.

Comparing Base Case to Case Optimal on the system level there are 1.2 Billion USD savings by 2030 and considering savings from 2030 onwards (end year effect with 10% discount rate) the amount increases to 2.5 Billion USD by 2050.

Transmission grid investments costs vary from location to location, but one main factor in grid investment cost is the voltage level. From the grid expansion plan of the Dominican Republic the following average investment costs for transmission lines can be calculated: 345 kV (0.5 Million USD/km) and 138 kV (0.225 Million USD/km). Thermal current carrying capacity for 345 kV line (three conductor) is approximately 1000 MVA and for 138 kV line (two conductor) around 300 MVA.

In the Dominican Republic the 345 kV network is the backbone of the transmission system. Considering that the DR transmission grid would need to be upgraded as per Figure 31 below, 850 km of new 345 kV line in total is proposed in this analysis. This would facilitate that projects in different site locations on the island would have access to 345 kV grid with rather short 138 kV or 69 kV lines. The upgrade would not only re-enforce the current grid but also it would enable new capacity to be connected. Investment cost for such a grid upgrade would be approximately 400-500 MUSD (based on DR cost levels for 345 kV line).

As mentioned above, a total savings of Case Optimal compared to Base Case were 2.5 billion USD. The major grid upgrade cost is approximately 500 million USD, such an investment is only 20% of the total savings. With this cost the main grid of the island could be modernized and there would still be a saving of 2 Billion USD.

It should be noted that in the IRENA report titled "Planning for the Renewable Future"[2] conducted in 2017 information on page 96 displays a value for transmission costs that is much less conservative, or much cheaper, than those used in this study, "The results indicate that about USD 50 million to USD 170 million of investment in transmission (corresponding to 520 MW to 2,050 MW of transmission capacity addition) is required to accommodate solar PV and wind at the specified levels."

Figure 31. Proposed DR grid improvement

2) https://www.irena.org/publications/2017/Jan/Planning-for-the-renewable-future-Long-term-modelling-and-tools-to-expand-variable-renewable-power

Appendix 3

The Modeling Software

Plexos is a simulation software for studying and dispatching of a power system. The modeling software uses mathematically based optimization techniques to realistically represent the operation of a real-life power system.

A Plexos model is a combination of power system data and advanced mathematical formulation, which captures the characteristics of the studied system. Figure 1 shows the power system data used in a model. This data, combined with the mathematical formulation, is a Plexos model, representing the power system with each of its techno-economic detail. The formulation basically models system features, such as the characteristics of power plants (e.g. efficiencies, dynamic features), the nodes and lines in the electrical grid, ancillary service requirements, and supply-demand balance.

The model is fed to a solver that produces the results shown in the figure. The solver optimizes the power system. In a long-term expansion model, the optimization objective is to find the optimal (lowest cost) generation capacity additions to supply the future electricity demand. In a short-term model, the objective is to minimize the power system operation cost for the study period. Due to the complex nature of the power system capacity optimization modelling some simplifications and compromises are typically needed. But it is noteworthy to mention that these simplifications should not severely impact the end results, which means that all compromises need to be carefully investigated and chosen.

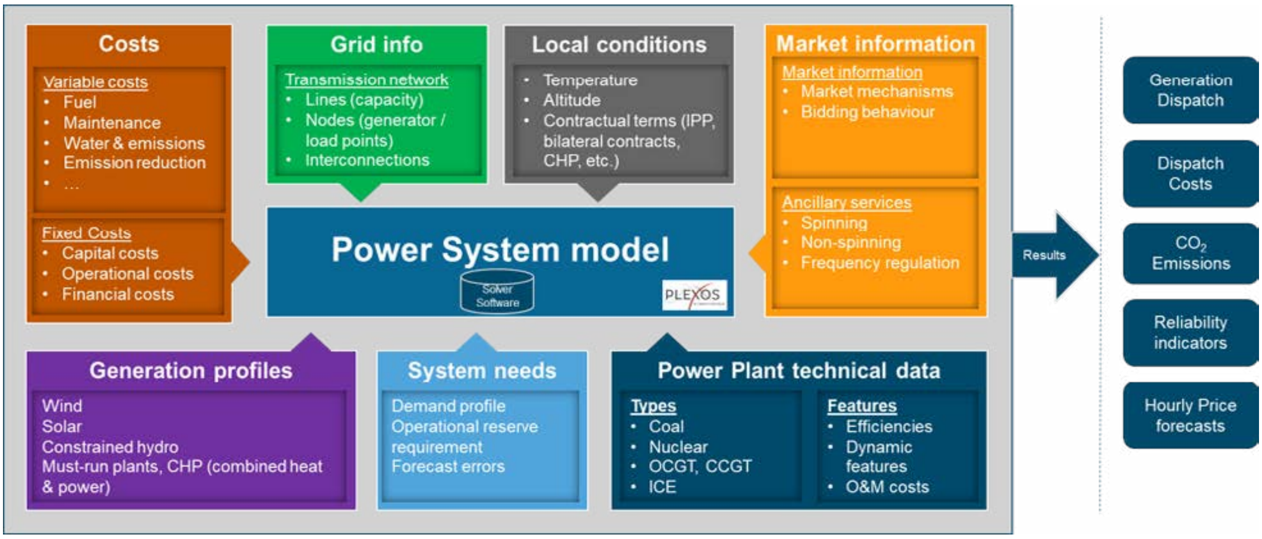


Figure 32. Plexos power system model

The inputs are provided from the sources below:

- Bloomberg New Energy Finance (BNEF)
- Organismo Coordinador (OC)
- Comisión Nacional de Energía (CNE)
- Current wind and solar PV prices stated at the International Renewable Energy Agency (IRENA)
- Future price learning curves for Renewable Energy Sources (RES) and storage technologies from Bloomberg New Energy Finance

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