COST-BENEFIT ANALYSIS FOR AIR CONDITIONER IN TUNISIA

Virginie Letschert, Shreya Agarwal, Stephane de la Rue du Can and Won Young Park

Lawrence Berkeley National Laboratory

February, 2023

USAID FROM THE AMERICAN PEOPLE

AGENCE NATIONALE POUR LA MAITRISE DE L'ÉNERGIE ANME Un engagement durable et renouvelable

BERKELEY LAB

Disclaimer

Copyright Notice

ACKNOWLEDGEMENTS

The work described in this study was funded by USAID EE4D.

The authors would like to thank Ezzedine Khalfallah, Fethi Hanchi, Abdelkader Baccouche and Souheil Ksouri of ANME for their review and contribution to this report. This report was also reviewed by Naim Darghouth, and edited by Kyra Epstein, Lawrence Berkeley National Laboratory.

Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AC	air conditioning unit
AGC	avoided generation capacity
ANME	Tunisia’s National Agency for Energy Management
BAU	business as usual
Berkeley Lab	Lawrence Berkeley National Lab
CES	CO2 emissions savings
EE4D	Energy Efficiency for Development
EES&L	energy efficiency standards and labeling
ELs	efficiency levels
FSD	fixed speed drive
GHG	greenhouse gas
HDD	heating degree days
IEA	International Energy Agency
LCC	life-cycle cost
MEPS	minimum energy performance standards
MSP	manufacturer selling price
NEC	national energy consumption
NEqC	national equipment cost
NES	national energy savings
NOC	national operating cost
NPV	net present value
PAMS	Policy Analysis Modeling System
RMI	Rocky Mountain Institute
RT	refrigeration tons
SCOP	seasonal coefficient of performance
STEG	Société Tunisienne de l'Electricité et du Gaz
UEC	unit energy consumption
VSD	variable speed drives

Executive Summary

According to the International Energy Agency (IEA), global energy use associated with air cooling tripled between 1990 and 2016, making it the fastest-growing end use in buildings (IEA 2018). This rapid growth has been influenced by conditions in developing countries, including increased urbanization and electrification, rising incomes, and falling prices for air conditioning units (ACs). In Tunisia, this growth is expected to create a significant impact on electricity generation capacity, peak load, and greenhouse gas (GHG) emissions if no policy measures are taken. Tunisia's power utility company estimated in 2013 that already 84% of Tunisia's peak power demand was due to ACs alone (STEG 2013). Since then, AC ownership has continued to grow rapidly from 34% in 2014 to reach almost 50% of households with at least one AC unit in 2019 (STEG, 2021).

This is the second report from Lawrence Berkeley National Laboratory (LBNL) in support of developing a minimum energy performance standards (MEPS) program for ACs in Tunisia. This report builds upon a market and regulatory assessment that characterized Tunisia's market and regulations for ACs (LBNL 2022). The current report is organized in the style of the technical support documents (TSDs) produced for U.S. appliance efficiency standards and comprises the following: a description of our analytical framework (Section 1) followed by several analyses of the context for and impacts of adopting a MEPS for ACs in Tunisia: an energy-use analysis (Section 2), engineering analysis (Section 3), life-cycle cost (LCC) analysis (Section 4), and national impact analysis (Section 5). The report concludes with policy recommendations (Section 6).

We analyze and compare to a baseline scenario for four potential efficiency levels that a MEPS could mandate for ACs in Tunisia. These efficiency levels are drawn from a combination of two main sources: levels identified in a LBNL study for Institute for Governance and Sustainable Development (Karali et al., 2020) and efficiency levels mandated by European Union (EU) regulation (Ecodesign 2014) (EC 2014).

The goals of this report are to (1) document the technical analyses that form the foundation for a AC MEPS in Tunisia, and (2) based on the results of our technical analyses, to recommend policies to transform the Tunisian market toward more efficient AC. The report aims to provide a basis for stakeholder discussions as part of the regulatory process to establish a MEPS for ACs in Tunisia; guide policymakers in designing a well-founded, impactful MEPS program that is consistent with international best practices; and highlight the energy, environmental and economic benefits of the MEPS on users and the nation as a whole.

Energy-Use and Engineering Analyses

The energy-use analysis (Section 2) assesses the potential energy savings from increasing the efficiency of ACs in Tunisia and forms the basis for the energy-savings values used in the LCC analysis and subsequent analyses. A key determinant in the energy-use of AC is the climate in which the AC is operated. We use data from ANME certification database (ANME, 2021) and the EU preparatory study to derive energy use for cooling and heating in Tunisia using climate data (DGTREN, 2011).

The engineering analysis (Section 3) establishes the relationship among purchase price and efficiency. This relationship is the basis for cost/benefit calculations and determination of the impacts of S&L on users of air conditioners in residential and commercial applications. This analysis is based on detailed data from Karali et al (as presented in Figure ES-1) and calibrated to the Tunisian market using the data collected as part of our market assessment.

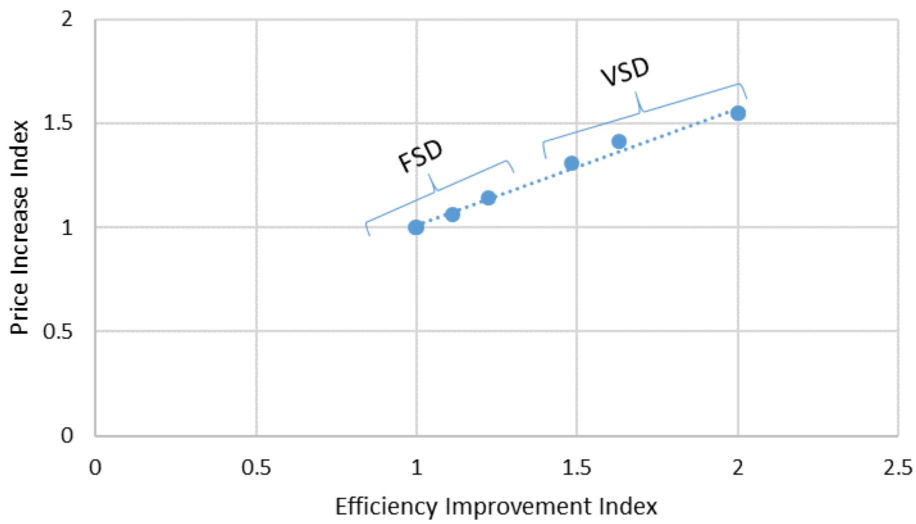

Figure ES - 1. Efficiency-Cost Relationship based on Karali et al. (2020)

Life-Cycle Cost Analysis

The LCC calculation analyzes the tradeoff between increased first costs for an efficient AC and subsequent savings in the form of lowered electricity bills during the AC's lifetime.

We find that all of the efficiency levels that we analyze are cost effective in the Tunisian context for cooling only and reversible units:

- For cooling only units, we find that the most cost-effective option is the max tech level, which is equivalent to a doubling of energy efficiency over the baseline (3.6 SEER). Payback periods vary between 2.7 and 5.4 years, to be compared to the 10-year lifetime of ACs.
- For reversible units, which can both provide cooling in the summer and heating in the winter and represent 79% of the market[1], we also find that the most cost-effective option is the max tech level. Payback periods for this product class vary between 2.8 and 4.4 years for the cost-effective MEPS options.

National Impact Analysis

In addition to financial impacts on individual consumers, standards have impacts on the nation as a

[1] LBNL. 2022. Tunisia Air Conditioner Market Assessment And Policy Review

whole. Our national impact analysis takes into account the sales and stock of air conditioners to estimate the energy, emissions and peak load impacts of the MEPS, as well as the Net Present Value of the program.

Building on STEG household surveys and inputs from ANME, the AC sales and stocks have been examined in the LBNL market assessment (2022). Figure ES-2 illustrates the sales forecast used as an input to the national impact analysis:

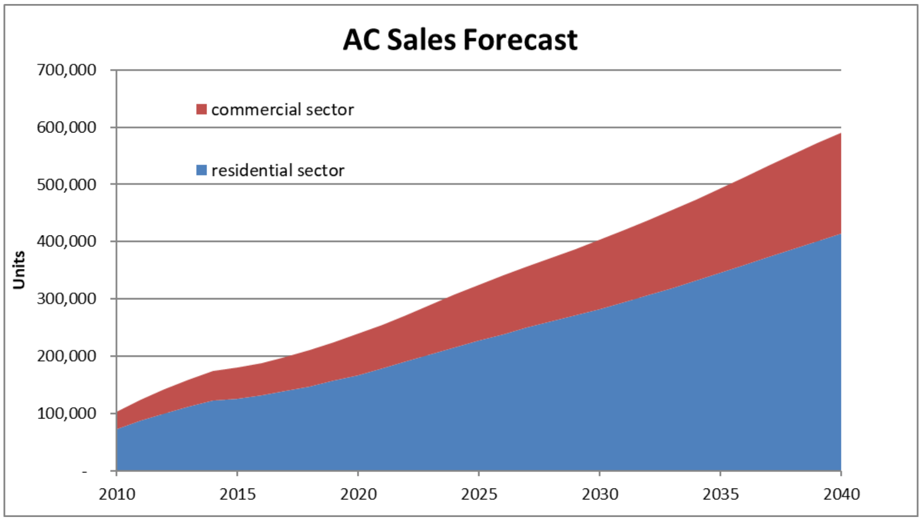

Figure ES - 2. AC Sales Forecast for Tunisia (LBNL, 2022)

Figure ES-3 shows the financial impact results in terms of additional costs and additional economic savings, comparing the BAU scenario to the higher-MEPS scenario. In the higher-MEPS scenario, more expensive units replace less-efficient ones, which results in additional costs at the time of purchase but increased savings during the AC operating lifetime. When the energy cost reduction over the AC lifetime outweighs the non-energy (first) cost increase, the standards have a positive impact on users; otherwise, the standards' impact is negative. In this case, the standard has a net positive impact only three years after taking effect.

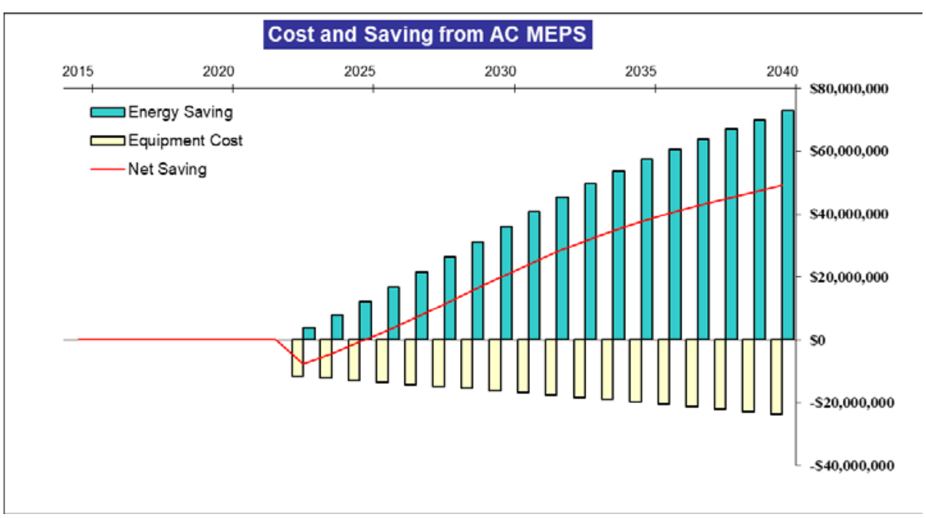

Figure ES - 3. Cost and Benefit of AC MEPS for Reversible Units (Harmonization with EU MEPS scenario)

Recommendations

Our technical analysis focuses on evaluating different efficiency levels for potential MEPS based on international best practices. The overall conclusion of the analysis is that a wide range of MEPS levels are justified technologically and economically for ACs in Tunisia.

In particular, given the history of harmonization between the EU and Tunisia, immediate adoption of a MEPS harmonized with the 2014 European Union Ecodesign regulation is recommended as a first step to transform Tunisia's market towards efficient ACs. This regulation is estimated to be highly beneficial for the following groups:

Table ES - 2. Summary of Impact Analysis Results at Recommended MEPS level

Tunisian consumers	The nation	The power sector:
Consumers will see a reduction in the cost of ownership of their AC. On average, consumers will save 15% on their electricity bill, or 50$ and 80$ over the lifetime of their cooling-only and reversible AC units, respectively.	Annual electricity consumption will be reduced by 580 GWh/yr in 2040, 5.8 TWh between 2023-2040, CO_2 emissions will be reduced by 4.0 Mt through 2040. Overall, the MEPS program is worth more than 300 Million US$.	The program will avoid the construction of new power plants by eliminating 588MW of generation capacity by 2040, equivalent to a medium-size power plant roughly valued at 1 Billion US$.

Our analysis has also underlined the importance of regulating the informal market, which represents around 50% of the market according to our estimates. Without additional enforcement, consumers will not benefit from the more efficient and highly cost-effective cooling technologies available today, and national impacts will be reduced as a consequence.

Finally, our analysis shows that complementary programs targeting higher efficiency levels will result in additional substantial national energy savings, CO_2 emission reductions, avoided generation, and national financial benefits. For this reason, design of complementary programs is recommended to accelerate high-efficiency ACs adoption and to drive down costs. For example, financial incentives and other mechanisms, such as bulk procurement programs or "cash-back" rebates, could be explored. Specific programs supporting local manufacturing upgrades to produce high efficiency ACs, in coordination with the refrigerant transition under the Kigali amendment, should be considered well. Together, these complementary programs will prepare the market for future revisions of the MEPS, mandating higher efficiency levels.

Introduction

According to the International Energy Agency (IEA), global energy use associated with air cooling tripled between 1990 and 2016, making it the fastest-growing end use in buildings (IEA 2018). This rapid growth has been influenced by conditions in developing countries, including increased urbanization and electrification, rising incomes, and falling prices for air conditioning units (ACs). The Rocky Mountain Institute (RMI) estimates that roughly 1.2 billion ACs are installed in buildings around the world. RMI projects that the number will grow to 4.5 billion ACs by 2050 (RMI 2018), with much of the growth in emerging economies, which will see a five-times increase in the number of ACs between now and 2050.. While large economies will represent much of the global AC growth over the next decades, every country with a hot climate will be challenged by the growth in its national cooling demand. This growth will create a significant impact on electricity generation capacity, peak load, and greenhouse gas (GHG) emissions if no policy measures are taken.

Tunisia’s power utility company, Société Tunisienne de l'Electricité et du Gaz (STEG), estimated in 2013 that already 84% of Tunisia’s peak power demand was due to ACs alone (STEG 2013). Since then, AC ownership has continued to grow rapidly from 34% in 2014 to reach almost 50% of households with at least one AC unit in 2019.

USAID and Lawrence Berkeley National Lab (Berkeley Lab) is working with Tunisia’s National Agency for Energy Conservation (ANME) to support the implementation of minimum energy performance standards (MEPS) for ACs. First, Berkeley Lab developed a market assessment of ACs in Tunisia, characterizing market trends, quantities of equipment sold (imports vs. locally manufactured vs. informal market), efficiencies, prices and product technology market shares (LBNL, 2022).

Because of the mandatory aspect of the MEPS, which eliminates inefficient products from the market, it is important to understand the impacts of such regulation (i.e benefits to consumers and at the national level). A cost-benefit analysis provides the basis for recommendations to adopt MEPS for AC units in Tunisia.

This report builds on the market assessment to provide the following analyses:

- **Energy-use analysis**—assessing potential energy savings from higher AC efficiency, forming the basis for energy-savings values used in the life-cycle cost (LCC) and subsequent analyses.
- **Engineering analysis**—establishing the relationship between manufacturing production cost and AC efficiency as a basis for cost-benefit calculations for individual users, manufacturers, and the nation.
- **LCC analysis**—analyzing the tradeoff between higher upfront costs and lower utility bills, including future savings scaled by a discount factor that accounts for preferences for immediate over deferred gains.
- **National impact analysis**—enabling policymakers to consider the nationwide magnitude of efficiency impacts on energy savings, emissions reductions and avoided peak demand, based on AC sales and stock.

1 Analytical Framework

1.1 Scope and Representative Units

The scope of the MEPS analyzed in this report is assumed to be the same as the European Union's Ecodesign regulation or up to 12kW.

To analyze the impacts of setting AC MEPS, this study focuses on the average AC model found in the market assessment study (LBNL, 2022) which found that the average cooling capacity is 15,000 Btu/hr or the equivalent of 1.25 refrigeration tons (RT).

1.2 Energy-Efficiency Metric

Region-specific seasonal energy-efficiency metrics have been designed to estimate AC performance under regional climatic conditions that affect the amount of time an AC operates at part or full load, and they are increasingly used as an alternative to the EER or COP to set Energy Efficiency Standards & Labeling requirements for ACs and heat pumps (Park et al. 2020). Because historically Tunisia's S&L programs have been based on the European Union's Ecodesign, we use both the EU seasonal energy efficiency ratio (EU SEER) for cooling efficiency and the EU seasonal coefficient of performance (EU SCOP) for heating efficiency in this analysis.

Because the analysis presented in this report refers to the cost-efficiency relationship developed by Karali et al. (2020), which is based on China's annual performance factor (China APF), we use the interregional conversion relationships used in Karali et al. (2020) and Park et al. (2020) to convert the APF efficiency values into EU SEER and EU SCOP..

For fixed-speed drive (FSD) units, we use the equations below:

China APF = EER × 0.707 + 0.43
ISO CSPF = EER x 1.062
ISO CSPF = 1.113 x EU SEER – 0.639

For variable-speed (VSD) units, we use the equation below, based on performance data of heat pumps available in the EU market:

EU SCOP = 0.338 EU SEER + 1.994

1.3 Efficiency Level Definition

The impact of setting MEPS depends on the current mix of equipment efficiencies sold in the business as usual (BAU) scenario and in each MEPS scenario. For this analysis, the current mix of equipment was represented by characterizing the annual sales market distributions across five efficiency levels (ELs) aligned with performance from the European Union's Ecodesign regulation, as well as intermediate efficiency levels defined by technology options (Karali et al. 2020), shown in Table 1.

Table 1. ELs Considered in the Analysis

EL	Cooling and Heating Efficiency Ratings (W/W)				Definition
	EER	COP	SEER	SCOP	
EL0	3.2	3.4	3.64	3.22	Baseline (least efficient models on the market)
EL1	4.1	4.3	4.04	3.50	Efficient fixed speed drive (FSD) (Karali et al., 2020)
EL2			4.60	3.80	EU MEPS level (2014)
EL3			5.93	3.82	High efficiency level (Karali et al., 2020)
EL4			7.28	4.45	Best available technology (Karali et al., 2020)

1.4 Analysis Period

The model used to perform the analysis evaluates impacts over a period starting at the implementation of the MEPS and ending approximately 20 years after the MEPS effective date. This analysis shows the impacts of a MEPS that would take effect in 2023, with results in 2030, and 2040.

2 Energy Use Analysis

The energy use analysis assesses potential energy savings from increasing AC cooling and heating efficiency. It forms the basis for the energy-savings values used in the subsequent analyses. The goal of the analysis is to generate a range of energy use values reflecting actual equipment used in the field.

2.1 Baseline Energy Use

The energy use of AC is highly dependent on climate conditions. There is no field survey of ACs available for Tunisia, so other sources were used to estimate the energy use of cooling only and reversible ACs units, in both residential and commercial sectors. The sources are:

- ANME's certification database (ANME 2021): this certification database provides an estimate of unit energy consumption (UEC) for cooling units. These UECs are calculated based on the capacity, efficiency, and hours of use. Based on the values provided in the database, hours of use are calculated to be equivalent to 5.5 hours/day during 3 months of the year.
- Ecodesign Preparatory Study (DGTREN 2009): this study provides energy consumption for heating and cooling in every European Union member country, adjusted for climate.

2.1.1 Cooling consumption

Using ANME's certification database, an average of 650kWh/year was calculated for all units meeting the Tunisian MEPS, with an average efficiency of 3.27 EER or 3.64 SEER, defined as our baseline.

2.1.2 Heating consumption

The Ecodesign Preparatory study (DGTREN 2009) is used to determine the energy consumption for heating in Tunisia. Energy data taken from Greece, a country with similar climate than Tunisia, is used as a proxy to determine the energy use of AC in Tunisia. Heating degree days (HDD) represent the magnitude of heating needs to scale energy consumption of heating between Tunisia and Greece. To take into account differences in economic development between the two countries[2], the reference temperature for heating is lowered to 15℃ for Tunisia. It is expected that heating consumption will go up in the future, as standards of living continue to improve in Tunisia. HDD for both countries are presented in Table 2.

Table 2. Energy Use Scaling Factors Based on HDD between Greece and Tunisia

HDD for Greece (*calculated at 18.3°C)*	1009
HDD for Tunisia *(calculated at 15°C)*	550
HDD scaling factor (HDD Tunisia/HDD Greece)	0.55

Source: (DGTREN 2009)*(Atalla, Gualdi, and Lanza 2015)*

Table 3 shows the energy consumption defined for different building types: offices, shops and residences, for cooling only and reversible type ACs, in Greece from the EU Ecodesign study along with the scaled energy consumption estimated for Tunisia using the HDD conversion factor calculated from Table 2.

Table 3. Unit Energy Heating Consumption

Heating UEC			
		Greece (1009 HDD) (kWh/yr)	Tunisia (550 HDD) (kWh/yr)
3.5kW reversible single split	Residence	400	220
3.5kW reversible single split	Office	1050	577
3.5kW reversible single split	Retail	500	275

As estimated in the market assessment, 70% of AC units are used in residential applications, while 30% are found in commercial applications. The calculation of the weighted average UEC assumes additionally that there is an equal split between offices and retails applications (15% in each subsector).

Another key element in estimating energy consumption is to estimate the efficiency level of the units considered in the baseline. The baseline efficiency used for reversible units in the 2009 European Union study has a seasonal coefficient of performance (SCOP) of 2.55. For Tunisia, a baseline SCOP of 3.22 is estimated based on the efficiency of the models collected in the market assessment study.

[2] In 2021, GDP/capita is estimated at 20.2k US$ in Greece vs 3.9k in Tunisia according to https://countryeconomy.com/countries/compare/tunisia/greece

The following formula summarizes the adjustments that take into account climate and baseline efficiency differences:

$$\mathrm{UEC_{TuHeating}} = \frac{\mathrm{SCOP_{EU}}}{\mathrm{SCOP_{Tu}}} \times \frac{HDD_{Tu}}{HDD_{EU}} \times UEC_{EUHeating}$$

Where

$UEC_{TuHeating}$ = UEC of AC in Tunisia (heating)

$UEC_{EUHeating}$ = UEC of AC in the Ecodesign reference (Heating portion)

$SCOP_{EU}$ = SCOP in the Ecodesign reference (heating efficiency)

$SCOP_{Tu}$ = SCOP in Tunisia (heating efficiency)

HDD_{Tu} = HDD Tunisia

HDD_{EU} = HDD in the Ecodesign reference (Greece)

2.2 Energy Use at Different ELs

The estimated energy use results are presented below in Table 4 and Table 5, respectively, for cooling only and reversible ACs.

Table 4. Estimated Annual UEC by EL for Cooling Only ACs

EL	Definition	SEER	Cooling UEC
		W/W	kWh/yr
EL0	Baseline	3.64	650
EL1	Efficient FSD	4.04	585
EL2	European Union MEPS level (2014)	4.60	514
EL3	High efficiency level	5.93	399
EL4	Best available technology	7.28	325

Table 5. Estimated Annual UEC by EL for Reversible ACs

EL	Definition	SEER	SCOP	Cooling UEC	Heating UEC	Total UEC
		W/W	W/W	kWh/yr	kWh/yr	kWh/yr
EL0	Baseline	3.64	3.22	650	299	949
EL1	Efficient FSD	4.04	3.50	585	276	807
EL2	European Union MEPS level (2014)	4.60	3.80	514	254	768
EL3	High efficiency level	5.93	3.82	399	253	691
EL4	Best available technology	7.28	4.45	325	216	541

3 Engineering Analysis

The engineering analysis establishes the relationship between AC manufacturing cost and efficiency, which is used to calculate costs and benefits at the consumer and national levels. The relationship between the efficiency of a product and its cost is based on the cost to manufacturers to implement a particular energy-saving design. An engineering analysis estimates the costs of efficiency improvement by assessing the energy performance of various higher-efficiency AC configurations and their associated incremental costs. This relationship is also referred to as the "cost vs. efficiency curve" or "cost curve."

3.1 Methods and Data Inputs

In order to assess the potential savings from a particular appliance, detailed engineering data is used to relate the efficiency improvement afforded by particular design options to the additional manufacturing cost in the form of materials and labor.

The analysis assumes that these incremental costs will be passed on through the distribution chain to the consumer, who will pay a higher retail price for the product. An implicit assumption is that manufacturer and retail markup factors are not dependent on product design. Therefore, retail price scales, in percentage terms, as the manufacturer's incremental cost scales (i.e., mark ups are constant at every efficiency level). This assumption allows for the estimation of retail prices at different efficiency levels by using an estimate of price of current baseline models in Tunisia in combination with relative manufacturer selling price increases.

Data from a recent cost curve analysis for ACs in China are used to characterize the relationship between cost and efficiency (Karali, et al. 2020). Because China manufactures more than 70% of room ACs in the global market (Shah, et al. 2017), Chinese cost data provide a reasonable proxy for incremental manufacturer costs. Scaled to the local market baseline prices, they provide a solid basis for projecting prices and efficiency savings to Tunisian households and businesses at a national level.

Karali, et al. (2020) considered various combinations of efficient technologies used in higher efficiency room ACs to estimate the total incremental cost and financial benefits of efficiency improvement to consumers using room AC units in China. Their methodology is similar to those used in the United States and the European Union MEPS rulemaking process to estimate the incremental cost of appliance efficiency improvements. The method shows the economic costs and efficiency ratings of different combinations of efficient technologies on a cost curve. Four categories of technologies, in the market and under development, can be used to improve mini-split AC efficiencies: compressors, variable-speed drives (VSDs), heat exchangers, and expansion valves.

The following figure illustrates the relative increase in price vs efficiency from Karali, et al. (2020)

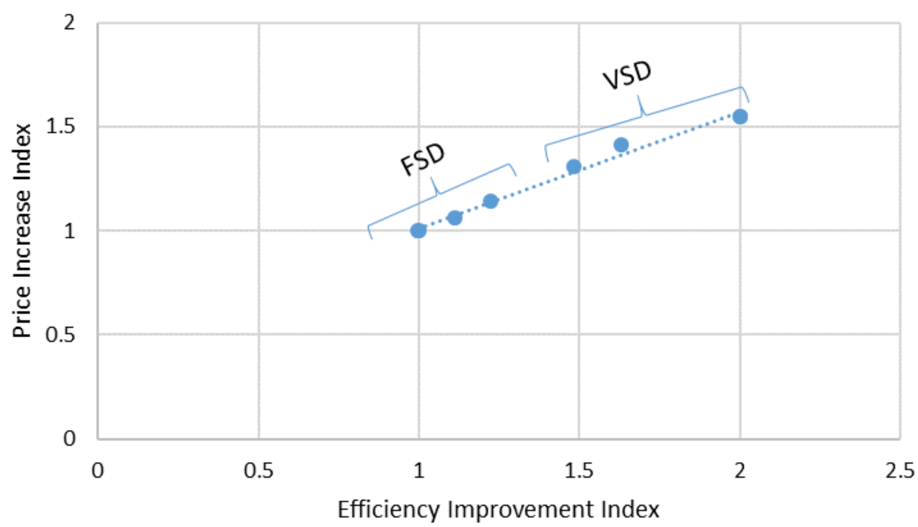

Figure 1. Efficiency-Cost Relationship based on Karali et al. (2020)

Table 6 and Table 7 present the cost vs. efficiency relationship derived from Karali, et al. (2020).

Table 6. Cost vs. Efficiency Relationship for Cooling-Only AC Unit (Karali, et al. 2020)

APF	EER	SEER	% Price ratio
2.7	3.2	3.64	1
3	3.6	4.04	1.06
4.4		5.93	1.41
5.4		7.28	1.55

Table 7. Cost vs. Efficiency Relationship for Reversible AC Unit (Karali, et al. 2020)

APF	EER	COP	SEER	SCOP	% Price ratio
2.7	3.2	3.4	3.64	3.22	1
3.3	4.1	4.3	4.45	3.50	1.14
4			5.39	3.82	1.31
5.4			7.28	4.45	1.55

In addition, purchase prices of ACs in the local market are based on local retail price data collected as part of the market assessment, which are obtained through an online retailer survey and manufacturer websites. These prices are used to calibrate the curve to reflect local baseline consumer prices. The representative 1-RT mini-split AC used in this study is an FSD room AC with a 3.2 W/W EER rating and a retail price of US$ 445 (~1,200 TND) for cooling-only units and a heating efficiency of 3.4 W/W COP and a retail price of US$460 (~1240 TND) for reversible units.[3]

Table 8 lists the key data inputs for the engineering analysis.

Table 8. Key Data Inputs for Engineering Analysis

Input	Description	Value	Source
MSP at different ELs	Cost curve	Table 5 and Table 6	Karali, et al, 2020
Retail price	Baseline price used to scale the cost curve to reflect Tunisian market	Baseline Cooling only: US$ 445 Reversible: US$ 460	Market assessment

Note: Installation costs are assumed to be the same for baseline and more efficient units - so the incremental installation cost is 0.

3.2 Results

The retail price of ACs for each Els is estimated based on the price vs. efficiency curve. The resulting prices are presented in Table 9 and Table 10 below:

Table 9. Purchase Price at the ELs Considered for Cooling-Only ACs

	EL0	EL1	EL2 (EU MEPS)	EL3	EL4
Price (US$)	$445	$471	$517	$627	$689
SEER (W/W)	3.64	4.04	4.60	5.93	7.28

Table 10. Purchase Price at the ELs Considered for Reversible ACs

	EL0	EL1	EL2 (EU MEPS)	EL3	EL4
Price (US$)	$460	$524	$537	$603	$713
SEER (W/W)	3.64	4.45	4.60	5.39	7.28
SCOP (W/W)	3.22	3.50	3.80	3.82	4.45

Note that some models that are sold currently on the Tunisian market are more efficient than the baseline units. In particular, this analysis assumes that the VSD ACs collected in this market assessment meet the EU MEPS (EL2). Therefore, we created a Business as Usual scenario (BAU) representing the weighted market average efficiency, UEC, and price of ACs sold on the market today by applying the market shares taken from the market study as described in Table 11 and Table 12 for cooling only ACs and reversible units respectively. In the BAU scenario, current market shares of ELs are assumed to remain constant. In each higher-MEPS scenario, all models that do not comply with the MEPS "roll up" to the MEPS level.

[3] Tunisian Dinar (TND) = 0.37 US$ (as of October 2021)

Table 11. Market-Average Efficiency, Price, and UEC under BAU and Higher-MEPS Scenarios for Cooling-Only ACs

		Scenario				
	EL	BAU	MEPS at EL1	MEPS at EL2 (EU MEPS level)	MEPS at EL3	MEPS at EL4
Percentage of All Market ACs at Given EL	EL0	66%				
	EL1	0%	66%			
	EL2	34%	34%	100%		
	EL3	0%	0%	0%	100%	
	EL4	0%	0%	0%	0%	100%
Market-Average Cooling Efficiency SEER (W/W)		3.96	4.23	4.60	5.93	7.28
Average Price (US$)		$469	$487	$517	$627	$689
Average UEC (kWh/year)		604	561	514	399	325

Table 12. Market-Average Efficiency, Price, and UEC under BAU and Higher-MEPS Scenarios for Reversible ACs

		Scenario				
	EL	BAU	MEPS at EL1	MEPS at EL2 (EU MEPS level)	MEPS at EL3	MEPS at EL4
Percentage of All Market ACs at Given EL	EL0	66%				
	EL1	0%	66%			
	EL2	34%	34%	100%		
	EL3	0%	0%	0%	100%	
	EL4	0%	0%	0%	0%	100%
Market-Average Cooling Efficiency SEER (W/W)		3.96	4.50	4.60	5.39	7.28
Market-Average Heating Efficiency SCOP (W/W)		3.42	3.60	3.80	3.82	4.45
Average Price (US$)		$486	$529	$537	$603	$713
Average UEC (kWh/year)		887	794	768	691	541

4. Life-Cycle Cost Analysis

Implementation of efficient technologies generally increases production costs, which are passed on to the user in the form of higher retail prices. The LCC calculation analyzes the tradeoff between these increased first costs and subsequent savings in the form of lower utility bills. This LCC analysis scales future energy cost savings by an appropriate discount factor to account for user preference for immediate over deferred gains. The analysis is implemented using the Policy Analysis Modeling System (PAMS), a tool developed by Berkeley Lab to analyze costs and benefits of AC MEPS under different efficiency scenarios (McNeil, Letschert, and Buskirk 2007a, 2007b). The tool allows for continual refinement of the analysis as more data become available.

4.1 Methods and Data Inputs

The LCC of any appliance or other energy-consuming equipment accounts for all expenditures associated with the equipment's purchase and use. From the user perspective, the two main components of the LCC are the equipment cost (first cost) and the operating cost. Equipment cost is the retail price paid by the user purchasing the appliance. Operating cost is the cost of energy, in the form of utility bills, for using the equipment. LCC is given by:

$$LCC = PP + \sum_{n=1}^{L} \frac{OC}{(1 + DR)^n}$$

Where:

PP = purchase price.
n = year since purchase.
OC = annual operating cost.

Operating cost is summed over each year of the lifetime of the appliance, L. Operating cost is calculated by multiplying the UEC (in kWh, from Table 4) by the price of electricity (P, in dollars per kWh) as follows:

$$OC = UEC \times P$$

The price of electricity (P) is taken from the tariff structure issued by STEG (STEG 2021a). The tariff categories are divided by class of consumers. Split ACs are found in both residential and light commercial applications. The marginal price of electricity used in this analysis reflects the higher tariff blocks for the residential and light commercial customers with a price of 0.414 TND/kWh (0.153 US$/kWh) and 0.391 TND/kWh (0.145 US$/kWh)[4], respectively. A weighted average tariff of 15 cts US$/kWh for the analysis is determined based on the assumption that 70% of the customers are

[4] 1 Tunisian Dinar (TND) = 0.37 US$ (as of October 2021)

residential and 30% are commercial.

The fact that future costs are less important to users than near-term costs is taken into account by dividing future operating costs by a discount factor $(1+DR)^n$, where DR is the discount rate. Discount rates for the LCC analysis are derived from estimates of the finance cost for purchasing the products studied. Following financial theory, the finance cost of raising funds to purchase equipment can be interpreted as: (1) the financial cost of any debt incurred to purchase equipment, or (2) the opportunity cost of any equity used to purchase equipment. The discount rate is defined as the average Tunisian rate of lending, equal to 6.3% as estimated by the Central Bank of Tunisia (Central Bank of Tunisia 2022).

Table 13 summarizes key data inputs for the LCC analysis.

Table 13. Key Data Inputs for LCC Analysis

Input	Description	Value	Source
UEC	Representative unit's average annual energy consumption for different ELs	Table 4 and 5	Energy-use analysis
Purchase price (PP)	Representative unit's average purchase price for different ELs	Table 12	Engineering analysis
Lifetime (L)	Average lifetime	10.5 years	Lutz, et al. 2011
Discount rate (DR)	Average lending rate	6.3%	Central Bank of Tunisia 2022
Electricity price (P)	Marginal price of electricity	15.1 cts/kWh	STEG tariff (as calculated above)

4.2 Results

Table 14 and Table 15 present the results for the representative AC unit under different efficiency scenarios. Given the large amount of energy consumed by ACs, operating costs represent a very large portion of overall LCC.

LCC savings and payback periods of 2.7 - 5.2 years (relative to a 10-year lifetime) are summarized in Table 14 and Table 15. All scenarios have a positive impact on consumers, so the technical potential afforded by best available technologies is also the cost-effective potential.

Maximum consumer benefits are found with MEPS at SEER = 7.28 (EL 4) with LCC savings of $86 for cooling-only category and a payback period of 5.2 years. For the reversible category (representing 79% of the market), maximum savings for consumers are also encountered for EL 4 with LCC savings of $152 and a payback period of 4.4 years.

Table 14. LCC and Payback Period Results for a Representative Cooling-Only AC Unit

Scenario	Market-Weighted SEER	LCC				LCC Savings	Payback Period
		Average Purchase Price	UEC	Average Annual Electricity Bill	Average LCC		
	W/W	$	kWh/year	$	$	$	years
BAU	3.96	$469	604	$91	$1,131		
MEPS at EL1	4.23	$487	561	$84	$1,101	$29	2.7
MEPS at EL2	4.60	$517	514	$77	$1,080	$50	3.5
MEPS at EL3	5.93	$627	399	$60	$1,064	$67	5.1
MEPS at EL4	7.28	$689	325	$49	$1,045	$86	5.2

For cooling-only types, all of the MEPS scenario (i.e., policy cases) LCCs are lower than the base LCC of $1,131. This implies that all efficiency levels above the baseline level are found to be cost effective for consumers. The largest cost benefits are found at EL3 and EL4, with respective savings of $67 and $86 over the lifetime of the AC (discounted at 6.3%).

Table 15. LCC and Payback Period Results for a Representative Reversible AC Unit

Scenario	Market-Weighted SEER	Market-Weighted SCOP	LCC				LCC Savings	Payback Period
			Average Purchase Price	UEC	Average Annual Electricity Bill	Average LCC		
	W/W	W/W	$	kWh/year	$	$	$	years
BAU	3.96	3.42	$486	887	$134	$1,458		
MEPS at EL1	4.50	3.60	$529	794	$120	$1,398	$60	3.0
MEPS at EL2	4.60	3.80	$537	768	$116	$1,378	$80	2.8
MEPS at EL3	5.39	3.82	$603	691	$104	$1,360	$99	3.9
MEPS at EL4	7.28	4.45	$713	541	$82	$1,306	$152	4.4

In the reversible category, the LCC in the MEPS scenarios are lower than the base LCC of $1,458. In other words, all efficiency levels are found to be cost effective for consumers. The largest benefits are found at EL3 and EL4, with respective savings of $99 and $152 over the lifetime of the reversible AC (discounted at 6.3%).

5. National Impact Analysis

Policymakers consider not only financial impacts on individual users, but also the magnitude of efficiency impacts on the nation as a whole, which is where the sales and stock of ACs are taken into account. National impacts are calculated in this analysis using PAMS.

5.1. Methods and Data Inputs

There are two main calculations for MEPS impact at the national level: national energy savings (NES) and net present value (NPV). NES is the total primary (input) fossil-fuel energy saved in the policy scenario versus the BAU scenario over the 2023–2040 forecast period. NPV is the discounted net benefit of financial savings to the entire market of users.

In some sense, national impacts are a scaling up of unit-level impacts to cover the whole market. National impacts also introduce an important time component to the evaluation of program impacts. MEPS generally affect new products only, and they usually do not affect products installed before the MEPS implementation date. Therefore, in the first year after standards are implemented, savings are usually small, because the standard only affects products purchased in that year. As time goes on, more and more of the stock is made up of products purchased after standards took effect, reflecting the MEPS level. The national impacts calculations describe the evolution of the stock and provide a profile of costs and benefits over time.

5.1.1. Stock and sales forecast

To determine the national-level impacts of MEPS, the total number of products operating in Tunisia in each year—and the rate at which old, inefficient products are replaced with new, efficient ones—is calculated. Therefore, product sales (shipments) and stock forecasting are major components of the national impacts model. The stock and sales forecast calculations are explained in detail in the market assessment report (LBNL, 2022).

5.1.2. National energy savings calculation

NES is defined as the difference in energy consumption between the BAU scenario and the policy scenario. In the BAU scenario, all products are assumed to be operating at the baseline efficiency. In the policy scenario, products purchased after the standards program implementation date (a user-adjustable parameter) are assumed to operate at the efficiency determined by a specific design option combination chosen by the model user.

PAMS calculates NES in each year by comparing the national energy consumption (NEC) of the product under study in the BAU scenario and the policy scenario, according to:

$$NES = NEC_{BAU} - NEC_{Policy}$$

In turn, the NEC of the national stock of products in year y is given by:

$$\mathrm{NEC_{BAU}} = \sum_{\mathrm{age}} \mathrm{Stock\ (y)} \times \mathrm{UEC_{BAU}(y - age)}$$

Where the UEC is determined according to the year of purchase (y-age). The UEC differs between the BAU and policy scenario for years after the MEPS implementation date because of the improvement in efficiency resulting from the standards, according to the following relationship:

$$UEC = UEC_{BAU} \; X \; \frac{Efficiency_{BAU}}{Efficiency_{Policy}}$$

Finally, CO_2 emissions savings (CES) are calculated from energy savings by applying carbon factors to site energy savings according to:

$$CES = \frac{NES}{1 - TD} \times CaF$$

Where:

TD = the fraction of energy lost in electricity transmission and distribution.
CaF = the carbon factor derived from the fraction of fossil-fuel generation.

5.1.3. Peak load reduction calculation

As depicted in Figure 1, installed capacity and peak demand ("pointe" - red line) have been increasing rapidly in the last decade. An additional 2,150 MW of capacity has been added to the grid between 2012 and 2019 to meet a peak demand increasing from 2,600 MW to 4,300 MW during the same period (STEG 2019).

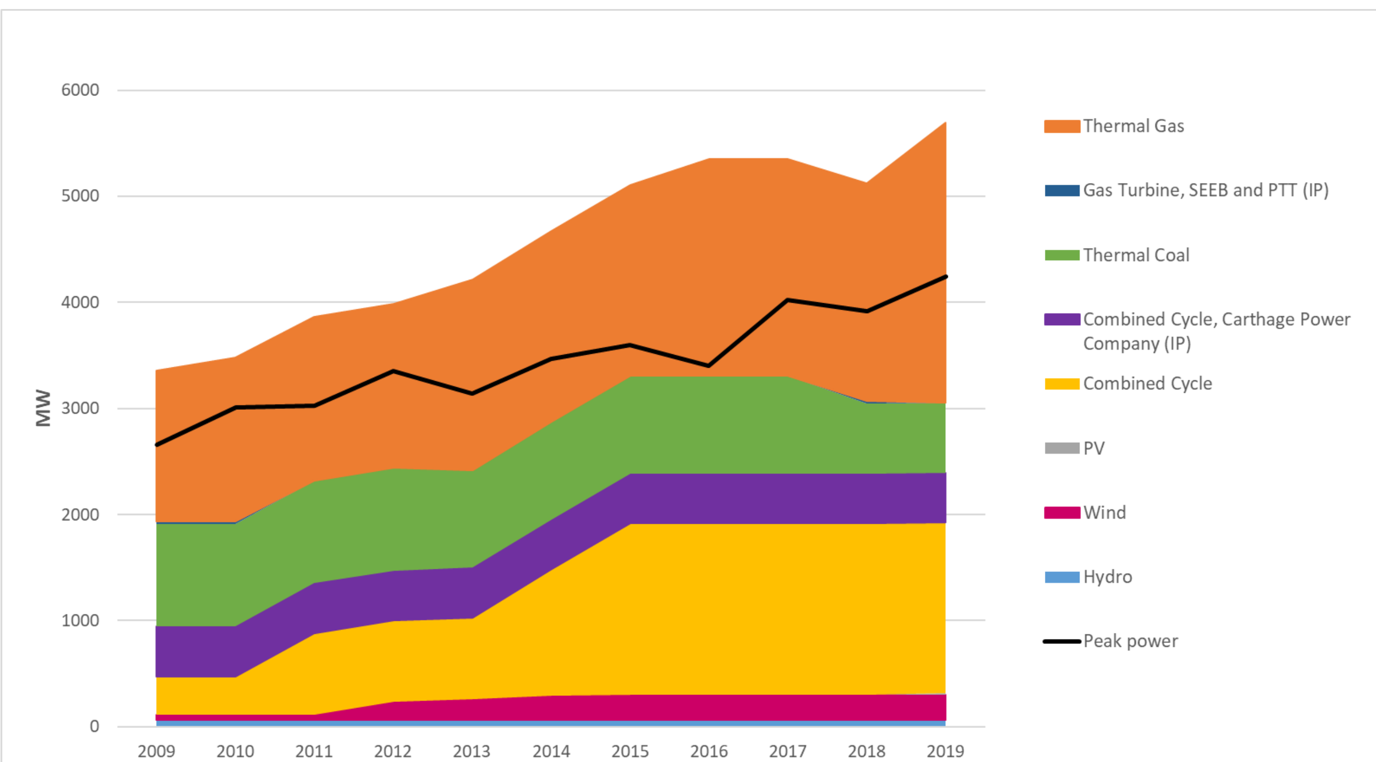

Figure 2. Installed Capacity and Peak Demand (2009-2019)

Figure 3 illustrates the daily load curve on a typical day in summer and winter in Tunisia, in 2020 (STEG 2020). The peak occurs during summer time, when temperatures are high and AC cooling is used to maintain thermal comfort in residential and commercial buildings.

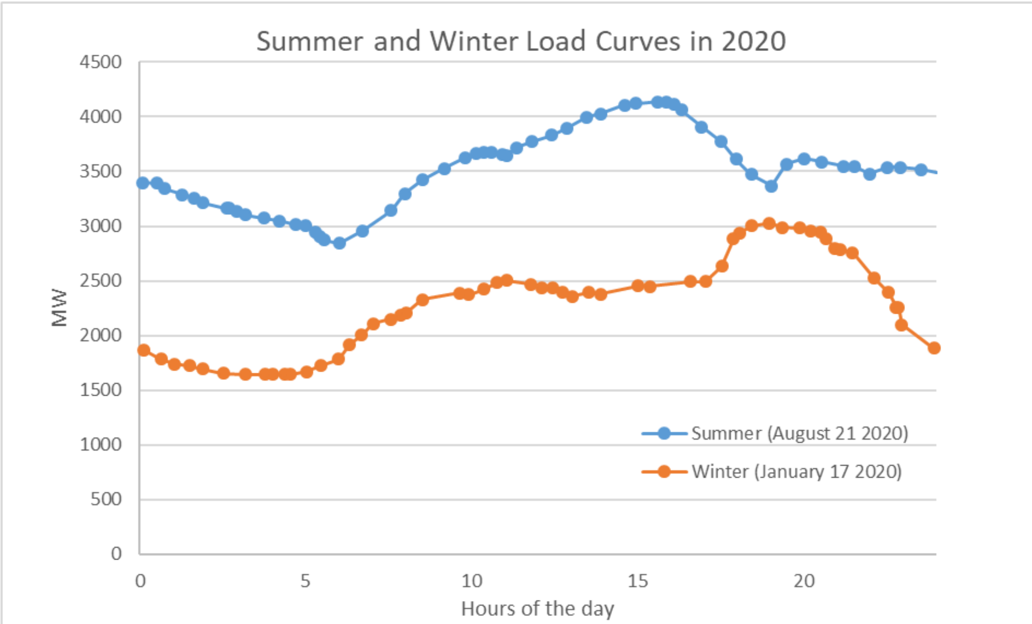

Figure 3. Sample Summer and Winter Load Curves in 2020

Any energy savings from a MEPS for ACs will translate into reduced load demand. Some of this reduced demand will occur during peak hours in the summer and some will occur during peak demand in the winter. Peak demand reduction in the summer will translate in avoided construction of new generation capacity in the near future. Figure 1 shows that peak demand occurs between 10 am and 6 pm, roughly the hottest hours of the day. The energy use analysis shows that ACs are used 5.5 hours a day during summer time. No time-of-use data are available, but it is assumed that ACs are primarily used for cooling during the warm hours of the day, with some use in the evening or at night. Because these peak hours coincide with business hours, it is assumed that all ACs in the commercial sector (40% of ACs) coincide with the peak load. In the residential sector (60% of ACs), it is assumed that 50% of AC use occurs during the day with 50% in the evening and at night. Accordingly, a 70% coincidence factor is calculated between AC use and peak demand. Finally, because of thermostat effects, ACs are cycling on and off and are not all running simultaneously. During peak, it is assumed that 60% of ACs are running simultaneously.

The avoided generation capacity (AGC) is then given by:

$$AGC = \frac{NES\ (summer)}{1 - TD} \times \frac{1}{8760} \times \frac{PCF \times SF}{U \times K}$$

Where:

NES (summer) = annual national energy savings from cooling energy efficiency (respectively 100% and 48% of NES for cooling-only and reversible ACs)

TD = the fraction of energy lost in electricity transmission and distribution.

8760 is the number of hours in a year,
PCF is the peak coincidence factor, that is the percentage of AC energy use that occurs during peak hours (70% as explained above)
SF = simultaneity factor, the percentage of ACs running at the same time.
The use factor U is the percentage of time the AC is used during the year, which is 5.5 hours over 3 months or 6% of the year.
K is the capacity factor of the power plants at peak.

K is given by:

$$K = \frac{Electricity\ Generated\ (MW)}{Installed\ capacity\ (MW)}$$

For the purpose of the analysis, we use the data for year 2019 from Figure 1 to calculate this factor (STEG, 2020).

$$K = \frac{4247}{5698} = 74.5\%$$

5.1.4. Net present value calculation

The NPV of a policy measures the policy's net financial benefit to the nation as a whole. As in the case of NES, the NPV calculation is somewhat parallel to the unit LCC calculation. National financial impacts in year y are the sum of equipment (first) costs and user operating costs. National equipment cost (NEqC) is equal to the retail price times the total number of sales:

$$NEqC = EC \times S(y)$$

Where:

EC = equipment cost (retail price).
S(y) = sales in a given year.

Likewise, national operating cost (NOC) is simply the total (site) energy consumption times the energy price:

$$NOC = NEC(y) \times P$$

The net savings in each year arise from the difference in first and operating costs in the MEPS scenarios versus the BAU scenario, ΔNEqC and ΔNOC. The NPV of the policy option is then defined as the sum over a particular forecast period of the net national savings in each year, multiplied by the appropriate national policy discount rate:

$$NPV = \sum_{y} (\Delta NOC(y) + \Delta NEC(y)) * (1 + DR_N)^{-(y-y_0)}$$

Where the subscript N indicates that, in general, the national policy discount rate will not be identical to the discount rate used in calculating LCC. For calculating NPV, y_0 is the current year, which may differ from the policy implementation year.

Table 16 lists the key data inputs for the national impact analysis.

Table 16. Key Data Inputs for National Impact Analysis

Input	Description	Value	Source
Sales data	Includes all sales of ACs <12kW	240,000 units in 2020	LBNL, 2022
UEC at different ELs	Includes cooling and heating modes	Table 4 Table 5	Energy-use and LCC analyses
Costs at different ELs	Retail price estimates	Table 6 Table 7	Engineering and LCC analyses
National policy discount rate	Based on the social discount rate applied to government projects	6.3%	Central Bank of Tunisia 2022
CO_2 emission factor	Electricity-specific emission factors	0.56 kg/kWh	de la Rue du Can, Price, and Zwickel 2015
Transmission and distribution factor	Includes losses in transmission and distribution	18%	STEG 2021b
Peak coincidence factor	Percentage of AC energy use that occurs during peak hours	70%	Berkeley Lab assumption
Simultaneity factor	Percentage of ACs running at the same time	60%	Berkeley Lab assumption
Use factor	Percentage of time the AC is used during the year, which is 5.5 hours over 3 months or 6% of the year	6%	Energy use analysis
Capacity factor K	Capacity factor of the power plants at peak (peak demand vs installed capacity)	74.5%	Calculated from STEG 2020

5.2. Results

Figure 3 shows the NEC of the representative cooling-only and reversible AC unit in the stock. These are calculated using PAMS' stock turnover analysis and UECs.

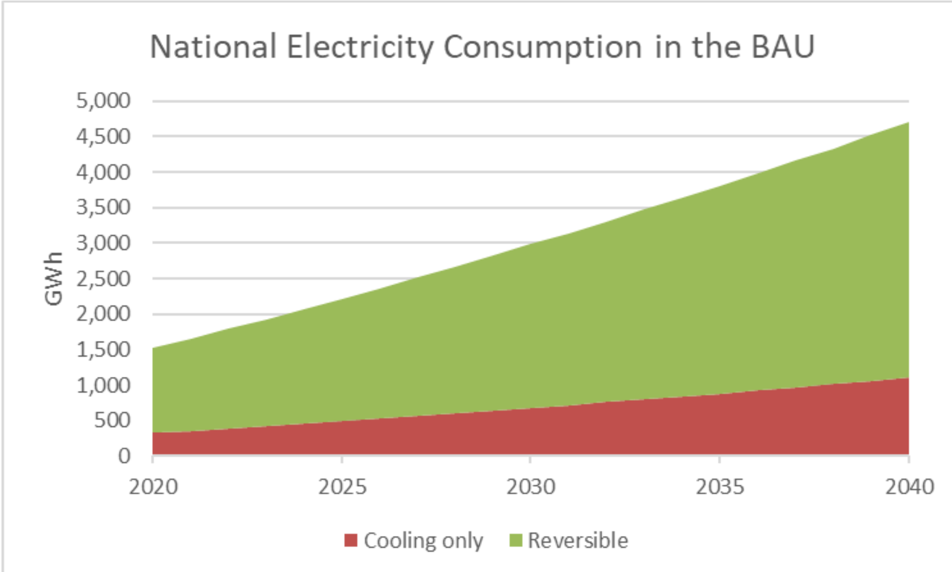

Figure 4. Tunisia National AC Electricity Consumption Forecast in BAU Scenario

Note: National estimates are higher than STEG's own estimates (500GWh in 2014) because heating consumption from reversible units and AC units used in the commercial sector are included.

Table 17 through Table 21 present national results in the years 2030 and 2040 in terms of projected annual and cumulative energy savings, cumulative CO_2 emissions reductions, avoided capacity, and NPV.

Table 17. Annual NES for ACs under Different MEPS Scenarios in 2030 and 2040

	Annual Energy Savings (GWh/year)					
	Cooling Only		Reversible		Both AC types	
	2030	**2040**	**2030**	**2040**	**2030**	**2040**
MEPS at EL1	23	46	187	379	210	425
MEPS at EL2	48	97	239	484	287	581
MEPS at EL3	109	220	393	794	502	1,014
MEPS at EL4	148	300	692	1,400	841	1,700

Table 18. Cumulative NES for ACs under Different MEPS Scenarios through 2030 and 2040

	Energy Savings through (GWh)					
	Cooling Only		Reversible		Both AC types	
	2030	**2040**	**2030**	**2040**	**2030**	**2040**
MEPS at EL1	99	467	809	3,828	908	4,295
MEPS at EL2	206	976	1,035	4,897	1,242	5,873
MEPS at EL3	471	2,229	1,697	8,026	2,168	10,256
MEPS at EL4	641	3,033	2,994	14,159	3,635	17,192

Table 19. Cumulative CO_2 Emissions Mitigation for ACs under Different MEPS Scenarios through 2030 and 2040

	CO2 Emissions Mitigation (MT)					
	Cooling Only		Reversible		Both AC types	
	2030	**2040**	**2030**	**2040**	**2030**	**2040**

MEPS at EL1	0.1	0.3	0.6	2.6	0.6	2.9
MEPS at EL2	0.1	0.7	0.7	3.4	0.9	4.0
MEPS at EL3	0.3	1.5	1.2	5.5	1.5	7.0
MEPS at EL4	0.4	2.1	2.0	9.7	2.5	11.8

Table 20. Avoided Generation Capacity for ACs under Different MEPS Scenarios in 2030 and 2040

	Avoided Generation Capacity (MW)					
	Cooling Only		Reversible		Both AC types	
	2030	2040	2030	2040	2030	2040
MEPS at EL1	31	63	176	356	207	419
MEPS at EL2	66	133	225	455	291	588
MEPS at EL3	150	303	369	747	519	1,049
MEPS at EL4	204	412	651	1,317	855	1,729

Table 21. NPV of AC MEPS under Different Scenarios (2023-2040)

		MEPS at EL1	MEPS at EL2	MEPS at EL3	MEPS at EL4
Cooling Only	Total Elec. Cost Savings	43	89	203	276
	Total Incr. Equip. Cost Savings	16	43	143	199
	Net Present Value	27	45	60	77
Reversible	Total Elec. Cost Savings	348	446	731	1,289
	Total Incr. Equip. Cost Savings	145	173	397	773
	Net Present Value	204	272	334	516
Both AC types	Total Elec. Cost Savings	391	535	934	1,565
	Total Incr. Equip. Cost Savings	161	217	540	973
	Net Present Value	230	318	394	592

These preliminary results show that, in the MEPS at EL2 scenario (harmonization with the European Union Ecodesign MEPS), the NES would amount to 5.8 terawatt-hours (TWh) (site electricity) with a positive NPV of US$318 million over the analysis period (2023–2040). At this EL, the cumulative CO_2 savings are 4.0 million metric tons through 2040, and the avoided capacity is 588 MW in 2040.

The technical potential (which is also the economic potential here) that could be achieved from the most efficient technology, represented by the results for MEPS at EL4, shows that cumulative NES would amount to 17 TWh (site electricity) with a positive NPV of US$590 million over the analysis period (2023–2040). At this EL, the cumulative CO_2 savings are 11.8 million metric tons through 2040, and the avoided capacity is 1,729MW in 2040.

Figure 5 and Figure 6 present the national cost and benefits between 2023 and 2040 from the scenario with MEPS at SEER = 4.6. The results are shown in terms of additional costs and additional economic savings, comparing the BAU scenario to the higher-MEPS scenario. In the higher-MEPS scenario, more expensive units replace less-efficient ones, which results in additional costs at the time of purchase but increased savings during the AC operating lifetime. When the energy cost reduction over the AC lifetime outweighs the non-energy (first) cost increase, the standards have a positive impact on users; otherwise, the standards' impact is negative.

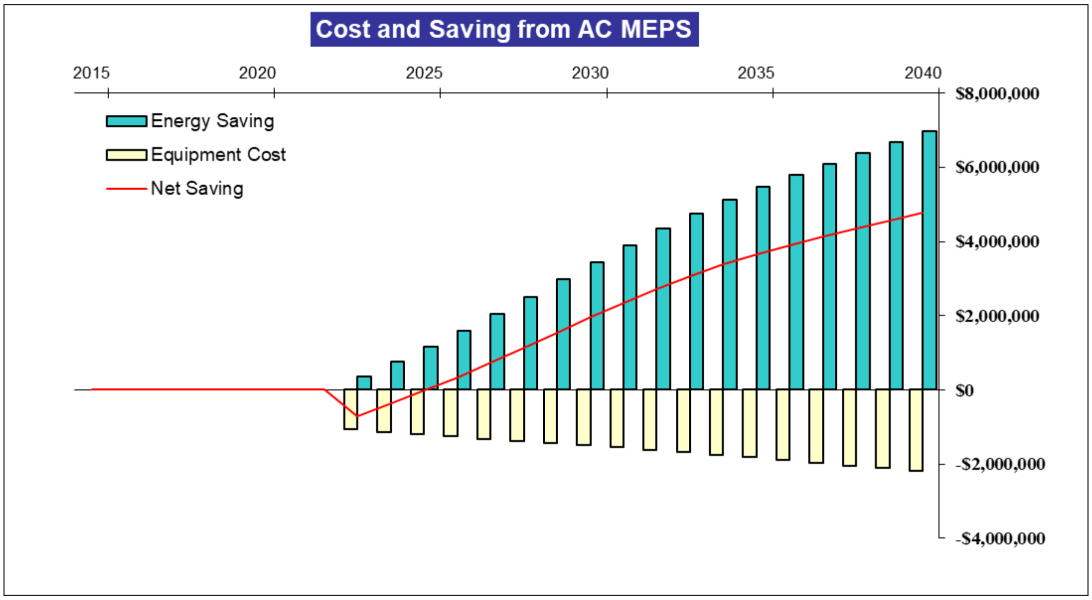

Figure 5. Cost and Benefit of AC MEPS at EL2 for Cooling-Only Units (Harmonization with European Union MEPS)

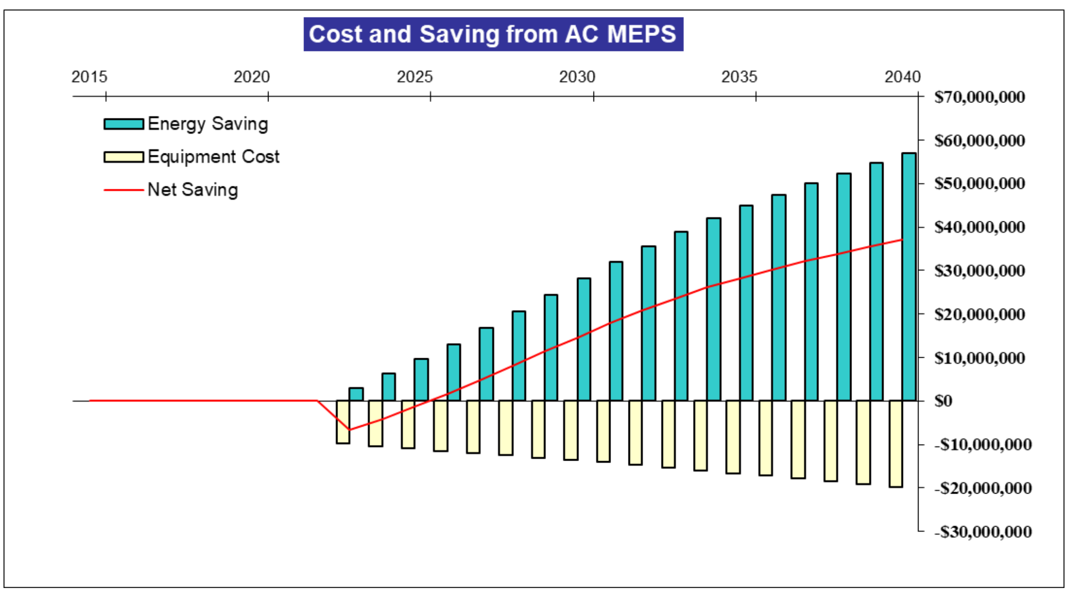

Figure 6. Cost and Benefit of AC MEPS at EL2 for Reversible Units (Harmonization with European Union MEPS)

Figure 5 and 6 show that the MEPS has a positive impact after 3 years of implementation, which is consistent with the payback period savings presented earlier in the report.

6. Recommendations

Our technical analysis focuses on evaluating different efficiency levels for potential MEPS based on international best practices. The overall conclusion of the analysis is that a wide range of MEPS levels are justified technologically and economically for ACs in Tunisia.

In particular, given the history of harmonization between the EU and Tunisia, immediate adoption of a MEPS harmonized with the 2014 European Union Ecodesign regulation is recommended as a first step to transform Tunisia's market towards efficient ACs. This regulation is estimated to be highly beneficial for the following groups:

Tunisian consumers: consumers will see a reduction in the cost of ownership of their AC. On average, consumers will save 50$ and 80$ over the lifetime of their cooling-only and reversible AC units, respectively. Overall, the MEPS program is worth more than 300 Million US$.

The nation: the annual electricity consumption will be reduced by 580 GWh/yr in 2040, 5.8 TWh between 2023-2040, CO_2 emissions will be reduced by 4.0 Mt through 2040.

The power sector: The program will avoid the construction of new power plants by eliminating 588MW of generation capacity by 2040, equivalent to a medium-size power plant roughly valued at 1 Billion US$.

Our analysis has also underlined the importance of regulating the informal market, which represents around 50% of the market according to our estimates. Without additional enforcement, consumers will not benefit from the more efficient and highly cost-effective cooling technologies available today, and national impacts will be reduced as a consequence.

Finally, our analysis shows that complementary programs targeting higher efficiency levels (EL3 and EL4) will result in additional substantial national energy savings, CO_2 emission reductions, avoided generation, and national financial benefits. For this reason, design of complementary programs is recommended to accelerate high-efficiency ACs adoption and to drive down costs. For example, financial incentives and other mechanisms, such as bulk procurement programs or "cash-back" rebates, could be explored. Specific programs supporting local manufacturing upgrades to produce high efficiency ACs, in coordination with the refrigerant transition under the Kigali amendment, should be considered well. Together, these complementary programs will prepare the market for future revisions of the MEPS, mandating higher efficiency levels.

7. References

Agarwal, Shreya; Stephane de la Rue du Can; and Virginie E. Letschert. 2022. Tunisia Air Conditioner Market Assessment And Policy Review.

ANME (National Agency for Energy Conservation). 2021. Certifcation Database.

Atalla, Tarek; Silvio Gualdi; and Alessandro Lanza. 2015. “A Global Degree Days Database for Energy-Related Applications.” doi: http://dx.doi.org/10.2139/ssrn.2586960.

Central Bank of Tunisia. 2022. Consumer Discount Rate.

de la Rue du Can, Stephane; Lynn Price; and Timm Zwickel. 2015. Understanding the Full Climate Change Impact of Energy Consumption and Mitigation at the End-Use Level: A Proposed Methodology for Allocating Indirect Carbon Dioxide Emissions. Energy Policy 159; Berkeley CA: Lawrence Berkeley National Laboratory report LBNL-1004487.

DGTREN (European Union's Directorate General for Transport and Energy). 2009. ECODESIGN Lot 10 Task 4: Preparatory Study on the Environmental Performance of Residential Room Conditioning Appliances (Airco and Ventilation).

IEA. 2018. The Future of Cooling Opportunities for Energy-Efficient Air Conditioning Together Secure Sustainable.

Karali, Nihan; Nihar Shah; Won Young Park; Nina Khanna; Chao Ding; Jiang Lin; and Nan Zhou. 2020. “Improving the Energy Efficiency of Room Air Conditioners in China: Costs and Benefits.” Applied Energy 258. doi: https://doi.org/10.1016/j.apenergy.2019.114023.

Lutz, James D.; Asa Hopkins; Virginie Letschert; Victor H. Franco; and Andy Sturges. 2011. Using National Survey Data to Estimate Lifetimes of Residential Appliances.

McNeil, Michael A.; Virginie Letschert; and Robert D. Van Buskirk. 2007a. Methodology for the Policy Analysis Modeling System (PAMS).

McNeil, Michael A.; Virginie Letschert; and Robert D. Van Buskirk. 2007b. User Instructions for the Policy Analysis Modeling System (PAMS).

Park, Won Young; Nihar Shah; Jun Young Choi; Hee Jeong Kang; Dae Hoon Kim; and Amol Phadke. 2020. “Lost in Translation: Overcoming Divergent Seasonal Performance Metrics to Strengthen Air Conditioner Energy-Efficiency Policies.” Energy for Sustainable Development 55:56–68. doi: 10.1016/J.ESD.2020.01.003.

RMI (Rocky Mountain Institute). 2018. Solving the Global Cooling Challenge How to Counter the Climate Threat from Room Air Conditioners. https://rmi.org/wp-content/uploads/2018/11/Global_Cooling_Challenge_Report_2018.pdf

Shah, Nihar; Max Wei; Virginie Letschert; and Amol Phadke. 2015. Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning. Berkeley, California: Lawrence Berkeley National Laboratory report LBNL- 1003671.

Shah, N.; N. Khanna; N. Karali; W. Y. Park; Y. Qu; and N. Zhou. 2017. Opportunities for Simultaneous Efficiency Improvement and Refrigerant Transition in Air Conditioning. Berkeley, California: Lawrence Berkeley National Laboratory report LBNL- 2001021.

STEG (Société Tunisienne de l'Electricité et du Gaz). 2013. ENQUETE CLIMATISATION 2013. DIRECTION DES ETUDES ET DE LA PLANIFICATION

STEG. 2019. Statistiques retrospectives d'electricite (2009-2019)

STEG. 2020. Rapport Annuel 2020.

STEG. 2021a. "Electricity Tariffs." Retrieved October 28, 2021 (https://www.steg.com.tn/fr/clients_res/tarif_electricite.html?tknfv=678B2868OPQRSTUVWXYZABCDEFGH298F).

STEG. 2021b. Electrical Energy Losses on the Distribution Network. Note for USAID. Central Directorate of Electricity and Gas Distribution (DCDI), Directorate of Recovery and Energy Loss Reduction, Energy Loss Reduction Department