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Energy Master Planning: Identifying Framing Constraints that Scope Your Technology Options

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ABSTRACT

This paper addresses the framing constraints for building and community energy projects that must be considered when energy master planning (EMP) is conducted. The constraints cover emissions, sustainability, resilience, regulations and directives, and regional and local limitations such as available energy types, local conditions, and project requirements.

The paper reflects development results from participants in an International Energy Agency project on energy master planning and in a U.S. Department of Defense project on technology integration to achieve resilient, low-energy use military installations.

It identifies a comprehensive list of framing constraints categorized into locational threats, locational resources, energy and water distribution and storage systems, building and facility, indoor environmental, and equipment in buildings and district systems constraints. In addition, it identifies limits for these constraints that exist in seven participating countries. Some framing constraints can profoundly impact technology selection while others impact the installation of technologies (as in hardening) and have little to no impact on technology selection. Framing constraints can be assessed in different ways and there are resources available to help EMP stakeholders evaluate them. Finally, a case is made that identifying and applying framing constraints early in EMP can bring efficiencies and better focus to the EMP process.

Conclusions include 1) for holistic energy planning, it is essential to identify and assess the framing constraints that bound an optimized EMP solution, 2) framing constraints limits should be evaluated as either hard or soft or promising technologies may fall out of an EMP analysis, 3) to maintain consistent quality in the EMP process, the identification of framing constraints and their limits, and perhaps their evaluation, should be standardized, 4) a standardized approach could establish a baseline that can be used, built upon, and improved, 5) as automated EMP tools are improved or developed, the resources in this paper could possibly contribute to their interworkings relative to technology screening, and 6) continued climate change and resulting aggressive goal setting will likely drive a continued and strong emphasis on EMP.

INTRODUCTION

As more and more countries push to improve the efficiency, environmental impact, and more recently, the resilience of their buildings and communities, the need for early and more comprehensive energy master planning continues to increase. The best energy master planning is highly dependent on a thorough consideration of project framing goals and constraints, both local and regional, and their associated limitations that will frame (set the boundaries) of an optimum master planning design.

After stakeholders complete the key initial EMP step of establishing the overarching goals and objectives of their project, at some point they must identify the rigid constraints (requirements) that limit their energy-related design choices. When, and if, goals or objectives change into requirements or result in the creation of requirements (such as an EU directive resulting in a requirement established by a member country), these requirements become constraints on EMP design choices. This paper will touch upon EMP framing goals and then focus on the identification of design constraints and their limitations in the U.S., Norway, Denmark, Finland, Germany, the UK (United Kingdom), and Australia.

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Design constraints may be obvious (e.g., those set by stakeholders) or far less obvious (e.g., inadequate local biomass resources to support a new biomass-based energy plant). The keys are 1) to do a thorough job of identifying all design constraints and 2) applying them early to gain efficiencies in the EMP process.

The constraints and limitations in this paper were developed by countries participating in the International Energy Agency's "Energy in Buildings and Communities Program Annex 73" as well as research performed under the U.S. Department of Defense Environmental Security Technology Certification Program (ESTCP) project EW18-D1-5281, "Technologies Integration to Achieve Resilient, Low-Energy Military Installations" (IEA EBC Annex 73, DOD ESTCP).

The design constraints cover topics such as emissions, sustainability, resilience, regulations and directives, and regional and local limitations such as available energy types, local conditions, and project requirements. Lastly, the paper proposes a comprehensive table of framing constraints and associated limits for each country that the master planner can use to help them narrow the numerous energy-related technology options down early in the EMP process to those that will lead to an optimum solution to local conditions and project requirements. While developed specifically to support technology down-selection in an automated energy master planning scenario analysis tool under development in a collaborative project (IEA ECB Annex 73, DOD ESTCP), the framing constraints assembled and the strategies suggested for assessing and applying them can be used by anyone as a starting point for technology down-selection when undertaking an EMP effort.

BACKGROUND

The status quo in planning and execution of energy-related projects will not support attainment of current energy and emissions goals. This is evident via the continuing push by regulators and other stakeholders for more aggressive actions related to energy use and climate change (EPBD 2018, EC 2016, U.S. 10CFR-433 2013, ASHRAE Std. 90.1-2016, ASHRAE Std. 100-2018). Most national and international energy policies, energy codes, and energy and sustainability assessment tools for the built environment have traditionally focused on renewable energy sources and energy efficiency in single buildings (U.S. 10CFR-433 2013, ASHRAE Std. 90.1-2016, ASHRAE Std. 100-2018, BREEAM, LEED, Energy Star).

Building-centric planning falls short of delivering community-level sustainability and resilience. The frequency of regional power disruptions have increased due weather, outdated and aging distribution infrastructure, man-made events, and the lack of energy resilience. Utility disruptions have "degraded critical mission capabilities and caused significant economic impacts at military installations" (Zhivov et al. 2017).

Significant additional energy savings, reduced emissions, and increased energy security can be realized by considering holistic solutions for the heating, cooling and power needs of communities – comprising collections of buildings. As a result, considerable literature has become available including both guidance and assessment tools aimed at energy master planning at the community/campus level (U.S. DOE 2013, Huang et al. 2015, NZP Tool, EnergyPlan, CASBEE, BREEAM, LEED). But the existing guidance and tools do not seem to be fully solving the challenges. Schiefelbein et al. (2017) concluded in their investigation of case studies and energy guidelines for energy-efficient communities that "the primary challenges result from inefficient organizational processes and unsupportive framework for implementation."

In order to be able to apply principles of a holistic approach to community energy planning and to provide the necessary methods and instruments to master planners, decision makers, and stakeholders, it is essential to identify and frame the constraints that bound the options towards an optimized energy master planning solution. There is a plethora of master planning guidance available that indicates that identifying and establishing project goals is a critical first step. In the specific area of "energy" master planning, similar but less abundant guidance supports this (NASEO 2018, Stromann-Andersen 2012, Fox 2016, Zhivov et al. 2014b, and U.S. DOE 2013). Far less common in EMP guidance and related literature is information on the identification of constraints that limit energy technology options. Literature in this area mentions options analysis or prioritization, or optimization analysis (Fox 2016, Zhivov et al. 2014b, U.S. DOE 2013, Robinson et al. 2009), but few mention constraint identification related to energy technologies. Yet options analysis or optimization is certainly influenced, perhaps very strongly, by project energy-related constraints.

While developed specifically to support technology down-selection in an automated energy master planning scenario analysis tool under development in a collaborative project (IEA ECB Annex 73, DOD ESTCP), the framing constraints and constraint limits identified, and the ideas suggested for assessing and applying them in this paper can be used by anyone as a starting point for technology down-selection when undertaking an EMP effort. The results in this paper are intended to broaden the planners or other stakeholders thinking in terms of project constraints, give them a head start on the identification of constraints, and perhaps help them add more effectiveness and efficiency to their EMP process.

FRAMING GOALS FOR ENERGY MASTER PLANNING

Framing goals are typically higher-level objectives your country, community, designer, or building owner want to achieve. Goals may be diverse, long-term or short-term, and may only be goals, not requirements.

Invoked at the European Union (EU) and U.S. national levels, the framing goals in Table 1 provide direction to plan-

Table 1. European Union (EU) and U.S. Federal Government Energy-Related Goals and Directives

Policy or Directive	Goal, Law, or Regulation	
EU-EPBD*	Goal	EU reduce GHG emissions 20% below 1990 levels (Dir. 2010/31/EU)
		20% of EU energy use from renewable sources by 2020 (Dir. 2010/31/EU)
		New buildings nearly zero-energy by 2020; public buildings by 2018 (Dir. 2018/884/EU)
		Countries do national plans to increase number of NZEBs (Dir. 2018/884/EU)
EU-EC**		Energy efficiency target for the EU
		Renewable energy target for the EU
U.S.-EPACT 2005*	Law	Federal facilities be designed a minimum of 30% better than IECC or ASHRAE codes
		Renewable energy use by federal government be at least 7.5% of total by 2013
U.S.-EISA 2007*		Federal government eliminate fossil fuel use in new and renovated facilities by 2030
		Federal government reduce energy use of facilities by 30% by 2015
		New and renovated federal government buildings reduce use of fossil-fuel-generated energy by 55% (2010), 80% (2020), and 100% (2030).
		At least 30% of hot water demand in federal buildings to be met by solar heating.
U.S.-10CFR433*	Regulation	Federal facilities be designed to meet ASHRAE 90.1-2013
		Federal facilities designed a minimum of 30% below ASHRAE Baseline Building 2013.

*See references (EPBD 2018, EPACT 2005, EISA 2007, U.S. 10CFR-433 2013).

**EC-European Commission, see reference (EC 2016).

ners, building owners/stewards, and building designers across the EU member countries and for the U.S. federal government. The European Building Performance Directive (EPBD 2018) sets goals for the EU and then each member country prepares a country-specific implementation plan with goals and restrictive requirements for their country to help put the EU on track to meet the goals in the EPBD. In this way, EU goals (which are targets) roll down to each country that may translate these goals into specific requirements (constraints) for the design and renovation of buildings. Constraints are rigid requirements which shall be met in either the design or actual performance of the building, or both. In this way, framing goals can translate into design constraints and shape the design of local buildings and communities.

In the U.S., the Energy Independence and Security Act of 2007 (EISA 2007) built upon the goals established in the Energy Policy Act of 2005 by adding government energy use reduction targets and fossil-fuel reduction targets. These targets are not community- or building-level design constraints. The U.S. government has, however, taken some of these goals and translated them into facility- and building-level requirements (design constraints) via the Code of Federal Regulations, Part 433 (U.S. 10CFR-433 2013). Along the same lines, a U.S. federal agency may translate these goals into design constraints that apply to their specific agency facilities. As an example, the U.S. General Services Administration (GSA) requires its buildings to be designed to achieve the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Gold certification (GSA-LEED).

IDENTIFYING FRAMING CONSTRAINTS

Project constraints (requirements) may be set at the community or building level as well. An example constraint is the LEED certification required by GSA mentioned previously. Aggressive constraints may also be set. Examples are the community or building owner may want to be 100% renewable energy, meet a stringent energy target, use no fossil-fuel-based energy, be net-zero or energy neutral, have 100% backup on critical facilities, or achieve a percentage reduction in emissions or zero emissions. One should be careful to distinguish between goals and constraints.

Framing constraints are identified in EMP to define the boundaries of your design possibilities. Existing guidance and literature speaks little about the timing of constraint identification in EMP.

Identification of framing constraints early in the EMP process allows them to be used to reduce the possible technology solution sets for buildings or campuses/communities. The can reduce design options up front and thus avoid the evaluation of non-compatible technologies during the optimization/ prioritization phase of EMP. Doing this can bring additional cost and labor efficiencies to the EMP process.

This paper proposes a methodology for classifying project framing constraints in Table 2. Energy-related framing constraints are divided into two subgroups: natural (naturally occurring) and imposed (man-made). Natural constraints are further classified into two constraint categories, locational threats and locational resources. Locational threats deal with natural threats that may influence the choice of technologies or solutions (e.g., regional or local air quality, or high winds). Locational resources deal with the availability of energy or space including space to site renewable energy systems.

Imposed (man-made) constraints cover the capabilities of existing infrastructure (e.g., energy distribution systems), building and facility-level constraints (e.g, building energy use), indoor environment constraints (e.g, fresh air), and building equipment and district system level constraints (e.g., equipment efficiencies). Limits for these constraints can be imposed by policy makers, regulators, administrators, standards, planners, building owners, designers, and others.

Table 2 shows the list of typical framing constraints identified and categorized by the Annex 73/ESTCP project team that is relevant to any EMP effort. While the list could potentially be expanded, it can serve as a comprehensive starting point for assessing the energy-related constraints in any EMP project.

Constraints regarding locational threats, indoor environment, and equipment in buildings and district systems are a bit different than the others. When applied, these constraints typically do not eliminate candidate technologies. Threats usually just influence the way a technology is installed (threat-hardened) while limitations for equipment in buildings and district systems usually just impact the efficiency of selected equipment. Indoor environment constraints typically influence the capacity (or size of equipment) and not technology type. These constraints typically do not affect the holistic energy master planning solution, as such, but merely influence requirements to individual parts in the scheme. Therefore, these constraints belong on a lower level of the planning process and are only touched upon beyond this point.

FRAMING CONSTRAINT LIMITS AND THEIR APPLICATION

Table 3 is an expansion of Table 2 and provides the limits and/or references for limits that apply to each framing constraint identified in the seven countries. These limits can easily impact technology selection during EMP. Some of the limits, of course, vary across countries as a result of ?differing natural and imposed constraints, regulations, and the political challenges and actions taken in each country.

Some of the design constraints (e.g. ?extreme temperature) might be significant for one country/region and not relevant for another. All ?countries have sets of regulations and guidelines for new building constructions, and the majority of them ?have extended the boundary to neighborhoods and district. Even though the overall aim of design ?constraints in all countries is to promote responsible use of natural resources and limit energy waste and emissions, there is considerable differences in the limits and implementation strategies by country. For example, while some countries are ?promoting zero energy buildings, others have lower mandatory requirements.

In the subsections that follow, the constraint limits in Table 3 will be discussed in terms of their application, i.e., their potential to impact technology selections, along with examples.

Natural Constraints: Locational Threats

As mentioned previously, locational threats usually do not influence technology selections. Threats such a flooding, high winds, lightning, storms, and earthquakes typically influence the way a technology is installed (e.g., hardened), and not the down selection of technology options. Some locational threats do have the potential to affect technology selection and should, therefore, be evaluated to narrow solution options. Local air quality conditions and their limits may eliminate the use of combustion-based heating or power generation systems especially in more urban areas. Other examples are extreme cold temperatures which can eliminate the use of air-to-air heat pumps and areas with significant humidity which can constrain or eliminate evaporative-type cooling systems.

Natural Constraints: Locational Resources

Resource limits can profoundly affect technology selection. Low solar insolation, wind, biomass, and space resources can quickly eliminate many renewable technologies from consideration. If certain fuels are not available or limited, some fuel-fired technologies may get eliminated and this may be even more pronounced if there is a dual-fuel capability desired for resilience. The lack of district chilled, hot water, or steam resources may limit you to building-level energy systems unless there is an option to increase the scope of your project.

Energy and Water Distribution and Storage System Constraints

Limitations in existing distribution and energy storage systems will certainly influence technology selection. Electric feeders, and local transformers and conductors limit the capacity to distribute electricity. And there may be limitations on connecting renewable energy sources to existing distribution lines. Local gas lines, if they exist, have fixed sizes and distribution pressures that limit the amount of gas that can be

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Table 2. Energy Master Planning Framing Constraints

Natural Constraints		Imposed Constraints				
Constraint Category	**Constraint***	**Constraint Category**		**Constraint***	**Constraint Category**	**Constraint***
1. Locational Threats	Regional or local air quality	**3. Energy and Water Distribution and Storage Systems**		Natural Gas	**5. Indoor Environment**	Space temperature
	Low-lying area (flooding)			Electricity		Humidity[1]
	Extreme temperatures			Fuel Oil		Illumination levels
	Extreme humidities			Chilled water		Radon
	High winds			Hot water/steam		Ventilation
	Fire			Water		
	Lightning					
	Ground threats (volcano, mud, sinkhole, earthquake)	**4. Building and Facility**	**4a. Energy Use**	Energy use (site)	**6. Equipment in Buildings and District Systems**	Space heating
				Energy use (primary)		Space cooling
2. Locational Resources	Solar insolation			Energy efficiency		Ventilation
	Wind		**4b. Environmental**	Renewables		Humidity control
	Biomass			Emissions		Water heating
	Land area		**4c. Operational**	Resilience		Food preparation
	Roof area			Financial/Cost		Waste handling
	Natural Gas			Maintenance limits (e.g., simple, low cost)		Control systems
	Electricity					Electric generation
	Liquid fuels (oil, LPG, etc.)			Work force limitations		District steam
	Chilled water			Critical facility		District hot water
	Hot water/steam			Other planner/building owner limiting factor		District chilled water
	Water					

* Constraint that could limit technology selection

Table 3. Framing Constraints and Limits that Affect Technology Selection by Country*

Constraint Category	Constraint (that could limit technology selection)	Country-Specific Limits						
		U.S.	Norway	Australia	Denmark	Finland	Germany	U.K.
1. Locational Threats	Regional/local air quality	Assess (US-NAAQS)						
	Low-lying area (flooding)	Constraint typically impacts the way technologies are installed (bermed, raised, etc.), not technology selection.						
	Extreme temperatures							
	Extreme/high humidities							
	High winds, Fire, Lightning	Constraint typically impacts the way technologies are installed (isolated, hardened, etc.), not technology selection.						
	Ground threats (volcano, earthquake, etc.)							
2. Locational Resources	Solar insolation; Wind; Biomass; Land & Roof area;	Limit is local amount available						
	Electricity; Natural Gas; Liquid fuels (oil, LPG, etc.)							
	District chilled or hot water; District steam; Water							
3. Energy & Water Distribution & Storage Systems	Electricity; Natural gas; Fuel oil; District chilled or hot water; District steam	Limits are local distribution and storage capacities.						
	Water (domestic/potable)							

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Table 3. Framing Constraints and Limits that Affect Technology Selection by Country* ***(continued)***

Constraint Category		Constraint (that could limit technology selection)	Country-Specific Limits						
			U.S.	Norway	Australia	Denmark	Finland	Germany	U.K.
4. Building and Facility Constraints	4a. Energy use and efficiency	Energy use (site)	Military (Army): Maximum annual energy use limits by building type (US1). Commercial: Maximum annual energy use limits by building type if standard adopted (Std100). Outperform simulated reference building or prescriptive requirements if standard or code adopted (Std90.1,IECC)	Natl code has max kWh/m2 values by building type (net demand, i.e. without efficiency of technical systems). (NO15, 16, 17, 18). (BREEAM-Nor, NS3700, NS3701)				Outperform simulated reference building. EnEV- Energy Saving Ordinance (DE1)	
		Energy use (primary/source)	Maximum annual energy use limits by building type if adopted by local code (Std100)	Requirements (BREEAM-Nor, NS3700, NS3701)	Maximum annual hourly average kJ/ m2-hr by building type. (NCC Sec. JP1). Class 6 building, 80 kJ/ m2.hr; Class 5, 7b, 8 or 9a building or Class 9b school, 43 kJ/m^2.hr; Other classes (with limits): 15 kJ/m^2.hr.	Maximum annual kWh/m^2 by building type (DK1).	Maximum annual kWh/m2 by building type. (F1)	EnEV (DE1) regulates primary energy demand for newly built buildings as well of existent buildings. There are no explicit limits.	
		Energy efficiency	Commercial and Military: Minimum thermal requirements of building components (walls, roofs, etc.) Minimum air tightness. (Std90.1,IECC)	Requirements on U-values for the envelope, SFP, air tightness, and cold bridges (National Building Code) (NO15-18, BREEAM-Nor, NS3700, NS3701)	National limits (NCC, Sec. J). State limits. (c) solar radiation being utilized for heating;				1. Building Regulations and Government Buying Standard Minimum (UK4, UK5) 2. Defense Related Environmental Assessment Methodology, DREAM (UK6)

Table 3. Framing Constraints and Limits that Affect Technology Selection by Country* ***(continued)***

Constraint Category		Constraint (that could limit technology selection)	Country-Specific Limits						
			U.S.	**Norway**	**Australia**	**Denmark**	**Finland**	**Germany**	**U.K.**
4. Building and Facility Constraints (cont'd)	4b. Environ mental	Renewables		Heating systems using fossil fuels are not allowed. (NO 17, NO 20)	No obligation to include renewables.	Must use renewables. District heating assumed (DK1)		Fixed quotas for heating and cooling.	No obligation to include renewables.
		Emissions	None at building level.	Requirements. (BREEAM-Nor, NS3700, NS3701)	None at building level.				Must achieve Target CO_2 Emissions Rate (Building Regulations) (UK4)
	4c. Operational	Resilience	Military: 14-day, grid-independent operation for critical facilities. (US2)	Buildings heating over 1,000 m^2 shall: a) have energy flexible heating systems, b) be adaptable to low-temperature heating solutions. (NO19)					No set standard, assessed on individual basis to meet resilience requirements.
		Financial /Cost		Requirements (NO18)					Government: DREAM or equivalent (e.g. CEEQUAL6, BREEAM7 etc.) assessment required. New projects require 'excellent' and major refurbishments require 'very good' rating (Regulations/ Govt Buying Std). (CEEQual, BREEAM, UK4, UK5, UK6)
		Maintenance (simple, low cost)							Different Regulation Documents for home based UK Countries
		Work force							
		Critical facility							

Table 3. Framing Constraints and Limits that Affect Technology Selection by Country* *(continued)*

Constraint Category	Constraint (that could limit technology selection)	Country-Specific Limits						
		U.S.	**Norway**	**Australia**	**Denmark**	**Finland**	**Germany**	**U.K.**
5. Indoor Environment Constraints	Indoor temperature (DB-dry bulb/WB-wet bulb)[1]	U.S. Army: Occupied: min DB: 70F, max. DB: 75F Unoccupied (short term) min DB: 55F,max DB: 85F Unoccupied (long term) min DB: 40F, max DB: none Critical equipment min DB: Equip min Critical equipment max DB: Equip max Commercial: Comfort zones limits vary by occupant conditions if standard adopted (Std55)		Maximum contaminant limits	Requirements exist (DK1). Occupied min: 20 C Occupied max: 26 C (cooling penalty). Dwellings: Max 100 hrs above 27 C and 25 hrs over 28 C; Offices/buildings with similar usage pattern: Max 100 hrs above 26 C and 25 hrs over 27 C. Recommendations for minimum workplace temperatures.	Requirements exist (F1). Heating season: 20–26 °C Other time: 20–32°C (30°C old people's house)		As per CIBSE Guide A - Environmental Design (UK2). MOD Estate - Joint Service Publication 315 - Building Performance Standards Estate Wide Standards and Guidance (UK3).
	Humidity[1]	U.S. Army: Occupied maximun: 50% Unoccupied (short term) max: 50% Unoccupied (long term) max: 50% Critical equipment max: 50% or equipment max Commercial: Limits vary by occupant conditions if standard adopted (Std55)	Requirements (NO8-NO12)	Refer to NABERS Energy for Offices (NABERS)	Recommendations exist (DK1).			As per CIBSE Guide A - Environmental Design (UK2). MOD Estate - Joint Service Publication 315 - Building Performance Standards Estate Wide Standards and Guidance (UK3).
	Lighting levels	Level requirements if code adopted (US3).	Requirements (NO6)		Lighting levels and daylighting requirements.			Regulated (UK2, UK3)
	Radon	Mitigation in states of NJ,WA,MI,MN,MD,OR,IL ,MA, CT	Requirements (NO5)					
	Ventilation	Requirements per person and area per space occupancy category when code adopted (Std62)	Requirements per unit area.	Required per person and area based on occupancy category	Requirements per person and area by building type (daycares, schools, etc.) (DK1)	Requirements per person and area by building type		Regulated (UK2, UK3)

Table 3. Framing Constraints and Limits that Affect Technology Selection by Country* ***(continued)***

Constraint Category	Constraint (that could limit technology selection)	Country-Specific Limits						
		U.S.	Norway	Australia	Denmark	Finland	Germany	U.K.
6. Equipment in Buildings and District Systems Constraints	Space heating	Min efficiencies by equipment type (Std90.1, IECC)		Minimum efficiencies by equipment type (AU1) per Equipment Energy Efficiency Program (E3) Performance rating of water-chilling and heat pump water heating packages using vapor compression (AHRI 551/ 591). Gas fired water heaters for hot water supply & central heating (AS 4552)	Minimum efficiencies by equipment type.			Equipment energy efficiency requirements (Building Regulations and Government Buying Standard Minimum) (UK4, UK5)
	Space cooling							
	Ventilation equipment	Numerous control requirements (US-Std 90.1/US-IECC)	Energy efficiency requirements (NO1,NO2,NO3)		Minimum efficiency and maximum power use			
	Humidity control equipment	Equipment requirements (Std 90.1)	Requirements. (NO8, NO9, NO12)					
	Water heating equipment	Service water heating requirements (Std90.1, IECC)	Requirements. (NO19, NO21)		Minimum efficiencies by equipment type. (DK1)	Min/max hot water temp. 50 °C, 65 °C		
	Cooking equipment							
	Waste handling equipment		Requirements. (NO45,NO46,NO47,NO48,NO49)					
	Control systems	Specific controls requirements (Std90.1, US-IECC)			Minimum efficiency			
	Combustion-type electric generation systems	Emission and noise limits (NSPS, NESHAP, US4). Local noise/nuisance ordinances.					Regulated emissions & noise.	
	District steam/hot water, chilled water	Minimum efficiencies by equipment type.(Std 90.1, IECC)						

*Note references for this table are identified in brackets "()" and are provided at the end of the paper.

distributed. And on-site fuel storage systems have limited capacities. While all of these can limit technology selection, most of these are soft constraints (they can be overcome, either by adding larger or additional distribution components or more storage). So, one should be careful not to eliminate technologies before a hard/soft constraint limit analysis, discussed later is this paper, is performed.

Building and Facility Constraints

A common building level constraint is an energy use limit. More common in EU countries, these limits are usually based on a maximum energy use per unit of floor area (energy use intensity or EUI) by building type. While robust energy use targets have been recently developed for climate zones in the U.S., they have not been adopted on a significant scale to date in local energy codes to turn them into constraints.

Generally, energy use limits push you to select more efficient versions of a technology and do not eliminate technologies. But if the limit is based on building site energy use (the energy use as measured at the building as opposed to a source or primary energy use basis which takes into account the energy consumed in energy generation and distribution), an energy use limit can much more profoundly affect technology selection. For example, if energy use is measured on a site-energy basis, a heat pump can deliver 2 to 4 units of energy for every unit they consume in contrast to a gas furnace which will deliver approximately 1 unit for every unit consumed. As a result, the heat pump will use far less energy on a site energy basis than the furnace. But the cost per unit of energy for electricity may be 3-8 times that for natural gas on a site energy basis (partly because of power generation and distribution losses). On this basis, the heat pump may reduce your energy use but will likely push up your annual energy bill.

Another example is a fossil-fueled combined heat and power plant. While these can provide major electricity cost savings, they dramatically boost total energy use as measured on a site-energy-use basis (additional discussion on this can be found in Zhivov et. al. 2014b). In both cases, site-energy-use-based constraints without consideration of energy costs may push the planner to a significantly lower EUI but at a higher annual operational energy cost. A primary or source energy use basis for measurement does not have this extreme energy use variance relative to technology selection and thus does not tend to eliminate technologies as an energy limit. Planners/designers should pay considerable attention to this if an energy use constraint is specified since competing technologies could be eliminated just because of the basis of the energy use measurement.

Building energy efficiency requirements usually do not exist at the whole building or facility level. They usually exist at the system (attics or windows for example) or equipment (chiller or heating system) which would be covered under Building Equipment and District Systems Constraints in Table 3. Some energy codes require a new building to be a specific percentage better that a standard or baseline design. If that percentage is based on an EUI change and the EUIs are measured on a site-energy-use basis, technology selection could be impacted simply from the chosen basis for the EUI as discussed in the previous paragraph.

Environmental-related, building-level constraints could easily impact technology selection. A renewable energy use requirement would definitely affect technology selection if the renewable energy is generated on-site. An emissions-related constraint at the building level is rare but could affect technology selection if they exist. Primarily, it is local air quality threat or building equipment constraints on emissions that affect technology selection.

The other type of building and facility level constraints in Table 3 are operational constraints. Resilience and critical facility constraints are usually related and may affect technology selection. Examples would be a requirement for local (at the building) backup electrical power or full islanding capability. Either case could drive you toward fuel-fired generator sets, renewable technologies, and/or energy storage systems. Other operational constraints are financial and work-force related. Fixed construction or tight annual operating budgets may mandate technology trade offs. Work-force limitations (either man-power or expertise or both) may exist and influence technology selection.

Indoor Environment Constraints

Comparing with other constraints in Table 3, indoor environment constraints mainly address the thermal comfort of building occupants from the aspect of personal needs. It aims at providing more comfortable indoor conditions to improve health benefits and work productivity. Indoor environment is a complex concept and involves a variety of factors that can influence environmental quality and energy use. Based on the national conditions, each country sets its own requirement and constraints on the indoor temperature, humidity, lighting illumination levels, radon and ventilation. Thereby, energy use can vary due to the different demand.

Equipment in Buildings and District Systems Constraints

Per Table 3, most existing limits for building equipment and district system constraints are minimum equipment efficiencies by system type. Minimum equipment efficiencies exist to ensure that efficient equipment is installed and by themselves, do not eliminate competing technologies. Equipment efficiency when combined with fuel cost, emissions, or other factor considerations may eliminate a technology but generally not equipment efficiency alone. At least two building-equipment-related constraints limits in Table 3, equipment emissions and noise, could limit technology selection and should be considered when reducing candidate technologies early in master planning.

Comparison of Constraint Limits Across Countries

Table 3 offers an interesting look at some similarities and significant differences between framing constraints that exist in different countries. Natural locational threat and resource constraints are handled very similarly across countries as we would expect. Installs are hardened in the face of locational threats and while locational resources may vary from location to location, they are assessed in similar fashions and have similar effects on technology selections.

One of the first significant differences in Table 3 is with building-level, energy use constraints. Some countries use a site-energy-use basis for building energy use limits while some use a source-energy-use (primary-energy-use) basis. In addition, some EU countries in heating-dominated climates use heated floor area as the divisor in the EUI. Except in the military, the U.S. has not adopted building energy use limits by building type except on a very limited scale (Seattle 2018; Washington State 2019).

A second significant difference is a renewable energy use requirement at the building level. While a goal at the U.S. federal government level, renewable energy use requirements have not rolled down to the building level. This contrasts with EU countries where requirements exist to use renewables (Denmark and Germany) or push you to use renewables (Norway; no fossil-fuel-based heating systems allowed).

Resilience is an emerging constraint and also differs. Beyond the U.S. military and perhaps for hospitals, only Norway was identified as having a resilience requirement at the building level.

All of these differences can affect technology selection, so the selection of technologies at the building or community level will differ somewhat between countries based on differences in their framing constraints. While there are other differences in Table 3 in Indoor Environment and Equipment in Building and District Systems constraints, these, in most cases will affect the efficiency or the control features of a technology, and not eliminate specific technologies for heating, cooling, or other systems.

Assessing THE LIMITS OF NATURAL LOCATIONAL CONSTRAINTS

Per Table 2, natural locational constraints can typically be categorized into resources and threats. Locational resources enable you to use different technologies while locational threats primarily influence how an individual technology is installed, not technology selection as discussed previously under Natural Constraints: Locational Threats.

Assessing the Limits for Locational Threats

As mentioned earlier, some locational threats may affect technology selection and should be evaluated to narrow solution options. Local air quality conditions and their limits may eliminate the use of combustion-based heating or power generation systems especially in more urban areas. And extreme cold temperatures may eliminate the use of air-to-air heat pumps while areas with significant humidity may constrain the use of evaporative-type cooling systems.

Assessing the Limits for Resource Constraints

Identifying and assessing the limits for some natural resource constraints can be challenging but there are many resources available to help the master planner. Assessing the availability and amounts of energy available to the building or community is a logical first step. This may not be a significant concern for a building or community that exists if the master planning effort reduces current energy use. But if the demand on an existing energy resource increases, especially substantially like in the case of adding a combined heat and power plant, energy demand could significantly increase and strain the current energy resource and/or distribution capability.

Electricity availability and distribution limitations can be identified through your local provider. The availability of electricity is usually not an issue, but the existing distribution capacity for electricity can definitely be a limitation.

Fuel and water resource limits can also be identified via local utility providers. These are likely available in quantities needed, but distribution systems could be a constraint. These could also be soft constraint limits, as options for overcoming constrained distribution systems could be increasing distribution pressure (to increase volume), adding new piping, or increasing pipe size to eliminate the constraint.

Chilled water, hot water, and steam resource limits can be identified via the capacity of the local central plants that supply them. Note these resource limits must be considered in light of the resource demand from any users currently on the district system outside the building or campus under consideration.

The availability of insolation, wind, and biomass resources can be challenging but there are often tools available that will help in this evaluation. Before the availability of these resources is evaluated, however, it is sometimes worthwhile to look at the availability of land and roof areas to support these systems. If there is insufficient area for technology installation, resource availability does not matter. Constraints associated with available land and roof areas to support the installation of energy generation systems such as solar or wind can of course be quantified via campus maps, building drawings, or simple measurements.

Solar insolation maps like that shown in Fig. 1 can be used to quantify the local insolation resource. Unless solar insolation is quite low year-round, the annual quantities alone are not sufficient to eliminate solar-based technologies. Higher energy prices in areas of low insolation or low energy prices in areas of high insolation can change the economics of solar-energy-based renewable energy systems. An economic evaluation comparing the cost of grid energy displaced relative to the first and operational cost of the solar-based system is required to screen technologies.

The U.S. National Renewable Energy Laboratory (NREL) developed the Renewable Energy Optimization Tool

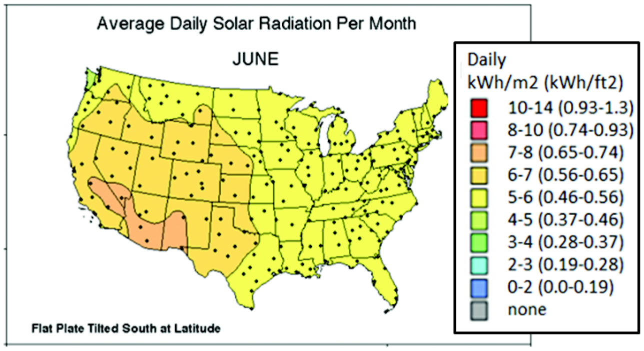

Figure 1 *Solar Radiation Intensity Map of the United States (source: National Energy Renewable Laboratory, Golden, CO).*

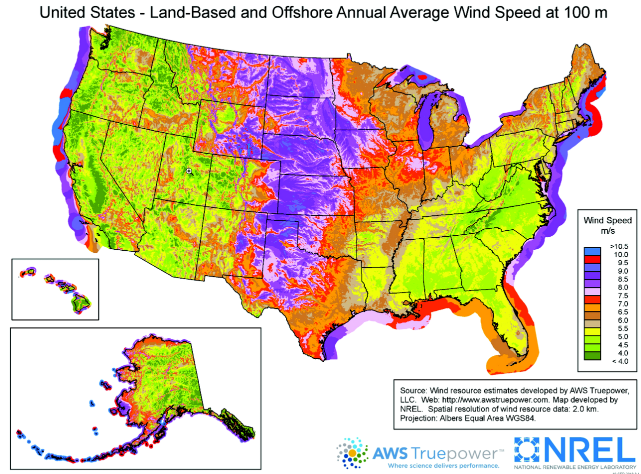

Figure 2 *Average Wind Speed Map of the United States (source: National Renewable Energy Laboratory, Golden, CO).*

(REopt) (https://reopt.nrel.gov/) to perform the economic analysis of renewable energy options based on local site conditions and system costs. This tool is publicly available and can be used by novices to make a go/no-go decision on renewable energy technologies. If a go decision is made, NREL recommends a skilled REopt user to perform the analysis to produce the final, more accurate economic analysis results. In Europe, the Photovoltaic Geographical Information System (PVGIS) provides solar radiation maps and the ability to evaluate the performance of grid-connected photovoltaic (PV) systems (https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html).

Wind resource maps like that shown in Fig. 2 are often available and can be used to quantify wind availability. In cases, quantifying the wind resource may be sufficient to inform the user of the viability of wind-based technologies without an economic analysis. A wind resource normally has to be quite abundant for wind-based energy systems to be economic. Like for insolation, local energy prices and distribution infrastructure costs (if located remotely) can influence the viability of wind-based technologies. NREL's REopt tool can also assist in the go/no-go decision for wind technologies.

Biomass resource maps showing tons/year like that in Fig. 3 can be used to estimate your local biomass resource. In addition to ample local availability, material quality (material type and moisture content) can be significant influences on the practicality of a biomass-based system. The REopt tool can again be used for analyzing the go/no-go economic analysis for biomass-based systems. Unlike solar and wind technologies, biomass-based systems can be material handling equipment, biomass storage, and labor intensive. Costs associated with these factors should not be overlooked in the economic analysis. Another very important factor that drives biomass-based system economics is the long-term cost stability of the biomass fuel. If local demand for biomass changes rapidly, costs can increase rapidly which can be a major impact on the economic viability of a biomass-based system. These many important factors, which are easy to miss in a simple economic analysis, should be considered very carefully if a system of this type is considered.

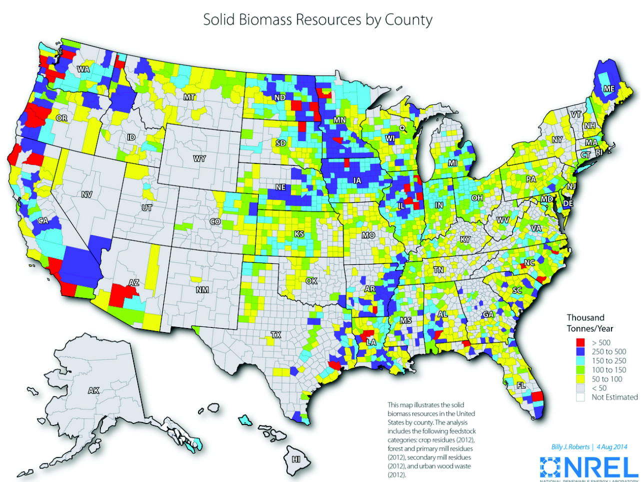

Figure 3 *Biomass Resource Map of the United States (source: National Renewable Energy Laboratory, Golden, CO).*

If sufficient renewable energy resources are available, the evaluation of roof or land areas to support a renewable energy system is also needed. Solar, wind, and biomass-based systems require space. Urban settings or the lack of control over land or roof space can take on-site renewable energy options out of consideration. Approximately 100 m^2 (1076 ft^2) are needed for every 20 kw of solar panel capacity (note efficiencies are improving which reduces the area need). Wind turbines and biomass plants can have much larger footprints. All of these resource constraints can affect technology

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selection, so their area requirements are worth evaluating early to down select the options you evaluate.

APPLYING FRAMING CONSTRAINT LIMITS

The energy master planning process is carried out in at least three stages starting with the concept phase, the first planning stage, and iterations. Interactions between EMP and other construction planning have to be set up from day one to avoid costly iterations.

Decision Making to Reach Design Options

In the first stage of EMP (concept phase), more holistic and even generic constraints resulting from mission-related framing goals and spatial planning have to be considered. These may affect technology selections. The second stage adds the assessment of constraints and their limits on both technology selection and component levels.

The Hierarchy of Applying Constraints

The process of applying and evaluating constraint limits is illustrated in Fig. 4. Once a comprehensive list of constraints is identified (as in Table 2) and their limits quantified for the first step of Fig. 4, the next step is to perform an analysis of the rigidity of each constraint limit (Step 2, the hard/soft limit analysis). The EMP planner/evaluator needs to assure that any constraint limit used in the final scoping down of technology options is a hard limit. Hard limits go directly to Step 4. In many cases, identified limits will be soft limits where there is flexibility to overcome them (see related discussion in next section). The planner/evaluator needs to assure they do not eliminate technologies based on soft limits. Soft limits move to Step 3, where options for overcoming each soft limit are evaluated to identify the real, hard limit for the constraint in question. These move to Step 4 with the others to produce the complete set of hard limits. With these in hand, the EMP planner/evaluator can begin the orderly application of constrain limits to neck down the many technology options to those that will satisfy their final project objectives.

Identifying Soft and Hard Constraint Limits

The characterization as a "soft" limit means that an existing constraint limit can be overcome by a less restrictive limit. As illustrated in Fig. 4, after the comprehensive list of constraint limits is assembled, the EMP team should assess if any of the limits are "soft" and if so, identify the hard limits related to them to arrive at the final list of hard constraint limits. The characterization as a "hard" limit means the opposite, that a constraint limit is not flexible, negotiable, and the limit cannot be overcome by a less restrictive limit. Some examples of soft limits and ideas for their less-restrictive hard limits are presented below to illustrate these concepts to the planner/evaluator.

a. Soft locational resource constraint limit - lack of local roof and land area. Lack of local mounting area for PV systems does not necessarily eliminate this technology. PV systems can be located in space remote to a building or main campus, tied to the local grid, and supplied to feed the building or campus. This is a common practice with the U.S. military but note that tying into a local grid may not be easy or without significant cost.

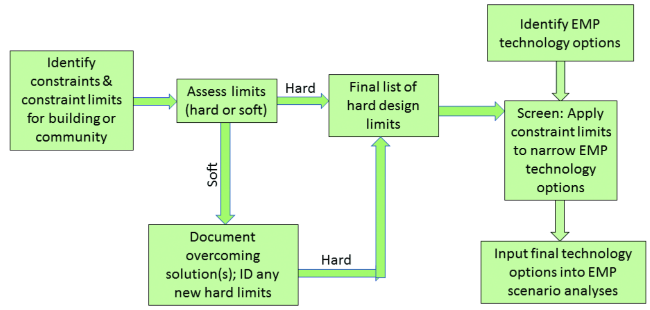

Figure 4 *Workflow for Scoping Down Technology Options to Optimize EMP Scenario Analysis.*

b. Soft locational resource constraint limit – district chilled water is unavailable because existing system is at capacity. Options that may relax or eliminate this limit could be adding a new chiller to the central plant or perhaps building a new district chiller plant if the project scope is large.

c. Soft distribution system & storage constraint limit – gas is not piped to the campus or building, or local lines are at capacity. Because they typically do not account for a major percentage increase in project cost, new gas lines are commonly installed in both large- and small-scale projects. If current lines are at capacity, some more flexible possibilities are to increase gas line pressures (increasing flow volume) and installing additional or larger lines.

d. Soft building constraint limit – limited manpower or skill set of in-house maintenance. This limitation may affect larger, more complex technologies such as combined heat and power systems or other energy generation technologies. Outsourcing operations and maintenance is perhaps an option and for highly, cost- effective technologies, the additional cost may easily be covered by cost savings resulting from the technology.

While all of these soft constraint limits have the potential to eliminate candidate technologies, in most cases, they would be considered soft constraints that can be overcome in whole or in part and in doing so, avoid the elimination of what could be desirable technologies for an EMP solution. As a result, the planner/evaluator should be careful about assuming a limit is hard and using it to eliminate technologies before the hard or soft, constraint limit analysis is performed.

Examples of hard constraint limits are more easily understood and are such things as rigid local air quality limits, other laws and imposed constraint limits that are inflexible, and low amounts of local solar radiation or wind.

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Applying the Constraint Limits to Reach EMP Solution Options

The first step in preparing to apply constraints is to identify the optimum hierarchy for applying them. Applying constraints should normally flow as they are presented in Table 2, beginning with the application of natural constraints, either locational threats or resources. Assessing locational threats relative to eliminating technologies is usually easier and faster as they are easy to assess and few of them are significant enough to rule out technologies. Three that may quickly eliminate some technologies are extreme cold temperatures and high humidities (their potential technology impacts are discussed under Natural Constraints: Locational Threats), and air quality threats. Air quality threats are often present in or near population-dense cities. In the U.S., this could mean a campus or city in a non-attainment area where air quality is worse than current air quality standards or in an area with air quality near non-attainment status. This scenario can easily constrain or eliminate combustion-based technologies from consideration.

The assessment of natural resource constraints is recommended next as many are relatively easy to assess and for those that are more difficult, there are data and tools available that can help the evaluator in their assessment (see Assessing the Limits for Resource Constraints for this discussion and some available tools).

Moving closer to and within the boundary of the community or facility, energy distribution systems and energy storage constraints are the next logical constraints to apply. Design specifications and capabilities of these systems are typically available. If district chilled or hot water, or steam plants are unavailable, this quickly narrows the planner to building-specific heating and cooling technologies unless there is sufficient budget and project scope that a district plant could be constructed.

Once within the community or facility, building and facility constraints are recommended as the next area for the evaluation of constraint limits. At this point, several technologies may have already been taken off the EMP evaluation plate as a result of other applied constraints. Constraint limits may eliminate additional technologies but also may push you toward specific technologies. As examples, a limitation requiring the use of renewable energy will force you to renewable energy systems and one requiring the continuous operation of critical facilities would push you to backup generation or energy storage systems, or both).

Limits for indoor environment and equipment in building and district systems constraints should have the lowest evaluation priority since they typically do not impact technology selection. If this is the case, then the application of constraint limitations to scope down the plethora of technology options for EMP may end with the application of building and facility constraints.

SUMMARY AND CONCLUSIONS

This paper identifies, classifies, and summarizes the framing constraints that should be considered when EMP is conducted for buildings or communities. In addition, it summarizes the existing limits or references to them for each framing constraint for seven countries. The constraints cover energy use, emissions, sustainability, resilience, regulations and directives, and regional and local constraints such as available energy types, renewable energy resources, operational, and threats to energy infrastructure.

The paper also discusses how the integration of framing constraints can benefit the EMP process. The table of framing constraints can serve as a comprehensive starting point for assessing local constraints that can scope down the technology options for any EMP project. Once characterized, the master planner can use the limits identified for each framing constraint to narrow the numerous design options down to those that offer an optimized fit to the local conditions and requirements for the building or community being developed or improved. If applied early and in a systematic way, their application should add effectiveness and efficiency (including computational efficiency if automated) to the EMP process. This occurs by eliminating the consideration and evaluation of technologies that consume planning resources and may otherwise be discovered to be incompatible with project constraints way downstream in the EMP process.

In the countries where the existing limits for the constraints have been identified, the master planner can use these to get a head start on the constraint limits that will scope their final EMP design. Additional thoughts and conclusions derived from this work are:

- To apply the principles of a holistic approach to community energy planning, it is essential to identify and assess the framing constraints that bound an optimized energy master planning solution.
- Early screening of technologies using framing constraints should better focus EMP team efforts.

EMP framing constraints can be classified into natural and imposed constraints and then be further classified into these categories: locational threats, locational resources, energy and water distribution and storage systems, building and facility, indoor environment, and equipment in buildings and district systems.

While locational threats usually do not influence technology selections, locational resource limits as well as the limits of existing distribution and energy storage systems can profoundly affect technology selection.

Identified framing constraints should be evaluated as either hard or soft. If not, constraints that can be overcome may be missed and promising technologies inadvertently stripped out of a final EMP solution.

To maintain consistent quality in the EMP process, it is recommended that the identification of framing constraints and their limits, and perhaps their evaluation, be standardized (perhaps starting in checklist form).

If identifying constraints and applying their limits were standardized, the results here could perhaps help establish a baseline that can be used by others, built upon, and improved.

As existing automated EMP tools are improved or new ones come available, the resources in this paper could possibly contribute to their interworkings relative to technology screening (e.g., in the EMP optimization phase but preferable much earlier).

Climate change and the aggressive goals regulators have or are considering putting in place will likely initiate more and more aggressive building and community energy-related requirements that will drive continued and strong emphasis on EMP if they are to be achieved.

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