Lemos, June

From: noreply@granicusideas.com
Sent: Monday, October 12, 2020 11:04 AM
To: Lemos, June
Subject: New eComment for City Council - Via Video Conference

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New eComment for City Council - Via Video Conference

Jacob Patterson submitted a new eComment.

Meeting: City Council - Via Video Conference

Item: 8A. 20-871 Receive Report and Community Development Committee Recommendations and Provide Direction to Staff Regarding the Scope of Work in a Request for Proposals for Professional Services to Prepare a Commercial Cannabis Cultivation Ordinance for the Inland Area of Fort Bragg

eComment: see attached

View and Analyze eComments

This is overkill for what can be a simple and efficient staff project, particularly when the City is adding planning staff and has a fill-time employee with a planning background charged with housing and economic development efforts. With the FAR increase as a separate project, updating the City's land use tables to require use permits for cannabis cultivation in industrial zoning districts should require a total of no more than 8-12 hours of actual work plus the public hearings. In fact, it might actually take more time to go through the process of farming this out than it would have taken to actually draft the ordinance and staff report! Considering this, we are better served by staff doing this work in-house, which will also help the General Fund because the City can fund the project using General Plan Maintenance Fee funds for what would otherwise be staff time billed to the General Fund. This fiscal benefit is lost by using those special funds to pay for an outside consultant, likely at far greater expense than the staff time equivalent. This is particularly true considering the City is proposing to apply a CEQA exemption and subject all future projects to a site-specific CEQA analysis thus significantly shortening the amount of time necessary to prepare the draft ordinance and staff report called for under the scope of work. This proposal is fiscally irresponsible and brings into question the actual value brought to the City by retaining staff resources who then proceed to farm out the substantive work and serve as little more than glorified project managers coordinating consultants. We can and should do better with the City’s limited resources.

From:	Evan Mills
To:	Lemos, June
Subject:	Can you show me where to post some comments?
Date:	Tuesday, October 13, 2020 3:23:08 PM
Attachments:	Energy-use-by-the-indoor-cannabis-industry.pdf cannabis-carbon-footprint.pdf

Hi June,

I noticed that there is a City Council meeting tonight about cannabis cultivation. There are big concerns about the carbon footprint of energy used that most policymakers aren't very aware of. I've done a couple of major studies on this that I'd like to share.

I went to the link marked for comments
https://cityfortbragg.granicusideas.com/meetings/1031-special-city-council-closed-session-via-video-conference/agenda_items/5f84e02424439894fa021dc8-1-public-comments-on-closed-session-items

... hoping to post there ... but there is no place to enter anything.

Please advise.

I'm attaching the two items, and I have a LinkedIN post that summarizes it here:
https://www.linkedin.com/pulse/energy-use-indoor-cannabis-industry-inconvenient-truths-evan-mills

Thanks,
~ Evan Mills

Energy Policy 46 (2012) 58–67

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

The carbon footprint of indoor *Cannabis* production

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ARTICLE INFO

Article history:
Received 7 September 2011
Accepted 10 March 2012
Available online 17 April 2012

Keywords:
Energy
Buildings
Horticulture

ABSTRACT

The emergent industry of indoor *Cannabis* production – legal in some jurisdictions and illicit in others – utilizes highly energy intensive processes to control environmental conditions during cultivation. This article estimates the energy consumption for this practice in the United States at 1% of national electricity use, or $6 billion each year. One average kilogram of final product is associated with 4600 kg of carbon dioxide emissions to the atmosphere, or that of 3 million average U.S. cars when aggregated across all national production. The practice of indoor cultivation is driven by criminalization, pursuit of security, pest and disease management, and the desire for greater process control and yields. Energy analysts and policymakers have not previously addressed this use of energy. The unchecked growth of electricity demand in this sector confounds energy forecasts and obscures savings from energy efficiency programs and policies. While criminalization has contributed to the substantial energy intensity, legalization would not change the situation materially without ancillary efforts to manage energy use, provide consumer information via labeling, and other measures. Were product prices to fall as a result of legalization, indoor production using current practices could rapidly become non-viable.

1. Introduction

On occasion, previously unrecognized spheres of energy use come to light. Important historical examples include the pervasive air leakage from ductwork in homes, the bourgeoning energy intensity of computer datacenters, and the electricity "leaking" from billions of small power supplies and other equipment. Intensive periods of investigation, technology R&D, and policy development gradually ensue in the wake of these discoveries. The emergent industry of indoor *Cannabis* production appears to have joined this list.[1]

This article presents a model of the modern-day production process – based on public-domain sources – and provides first-order national scoping estimates of the energy use, costs, and greenhouse-gas emissions associated with this activity in the United States. The practice is common in other countries but a global assessment is beyond the scope of this report.

2. Scale of activity

The large-scale industrialized and highly energy-intensive indoor cultivation of *Cannabis* is a relatively new phenomenon, driven by criminalization, pursuit of security, pest and disease management, and the desire for greater process control and yields (U.S. Department of Justice, 2011a; World Drug Report, 2009). The practice occurs across the United States (Hudson, 2003; Gettman, 2006). The 415,000 indoor plants eradicated by authorities in 2009 (and 10.3 million including outdoor plantations) (U.S. Department of Justice, 2011a, b) presumably represent only a small fraction of total production.

Cannabis cultivation is today legal in 15 states plus the District of Columbia, although it is not federally sanctioned (Peplow, 2005). It is estimated that 24.8 million Americans are eligible to receive a doctor's recommendation to purchase or cultivate *Cannabis* under existing state laws, and approximately 730,000 currently do so (See Change Strategy, 2011). In California alone, 400,000 individuals are currently authorized to cultivate *Cannabis* for personal medical use, or sale for the same purpose to 2100 dispensaries (Harvey, 2009). Approximately 28.5 million people in the United States are repeat consumers, representing 11% of the population over the age of 12 (U.S. Office of National Drug Control Policy, 2011).

Cultivation is also substantial in Canada. An estimated 17,500 "grow" operations in British Columbia (typically located in residential buildings) are equivalent to 1% of all dwelling units Province-wide, with an annual market value of $7 billion (Easton, 2004).

Official estimates of total U.S. *Cannabis* production varied from 10,000 to 24,000 metric ton per year as of 2001, making it the nation's largest crop by value at that time (Hudson, 2003; Gettman, 2006). A recent study estimated national production at far higher levels (69,000 metric ton) (HIDTA, 2010). Even at the

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[1] This article substantively updates and extends the analysis described in Mills (2011).

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http://dx.doi.org/10.1016/j.enpol.2012.03.023

lower end of this range (chosen as the basis of this analysis), the level of activity is formidable and increasing with the demand for *Cannabis*.

No systematic efforts have previously been made to estimate the aggregate energy use of these activities.

3. Methods and uncertainties

This analysis is based on a model of typical *Cannabis* production, and the associated energy use for cultivation and transportation based on market data and first-principals buildings energy end-use modeling techniques. Data sources include equipment manufacturer data, trade media, the open literature, and interviews with horticultural equipment vendors. All assumptions used in the analysis are presented in Appendix A. The resulting normalized (per-kilogram) energy intensity is driven by the effects of indoor-environmental conditions, production processes, and equipment efficiencies.

Considerable energy use is also associated with transportation, both for workers and for large numbers of small-quantities transported and then redistributed over long distances before final sale.

This analysis reflects typical practices, and is thus intended as a "central estimate". While processes that use less energy on a per-unit-yield basis are possible, much more energy-intensive scenarios also occur. Certain strategies for lowering energy inputs (e.g., reduced illumination levels) can result in lower yields, and thus not necessarily reduce the ultimate energy-intensity per unit weight. Only those strategies that improve equipment and process energy efficiency, while not correspondingly attenuating yields would reduce energy intensity.

Due to the proprietary and often illicit nature of Cannabis cultivation, data are intrinsically uncertain. Key uncertainties are total production and the indoor fraction thereof, and the corresponding scaling up of relatively well-understood intensities of energy use per unit of production to state or national levels could result in 50% higher or lower aggregate results. Greenhouse-gas emissions estimates are in turn sensitive to the assumed mix of on- and off-grid power production technologies and fuels, as off-grid production (almost universally done with diesel generators) can – depending on the prevailing fuel mix in the grid – have substantially higher emissions per kilowatt-hour than grid power. Final energy costs are a direct function of the aforementioned factors, combined with electricity tariffs, which vary widely geographically and among customer classes. The assumptions about vehicle energy use are likely conservative, given the longer-range transportation associated with interstate distribution.

Some localities (very cold and very hot climates) will see much larger shares of production indoors, and have higher space-conditioning energy demands than the typical conditions assumed here. More in-depth analyses could explore the variations introduced by geography and climate, alternate technology configurations, and production techniques.

4. Energy implications

Accelerated electricity demand growth has been observed in areas reputed to have extensive indoor *Cannabis* cultivation. For example, following the legalization of cultivation for medical purposes (Phillips, 1998; Roth, 2005; Clapper et al., 2010) in California in 1996, Humboldt County experienced a 50% rise in per-capita residential electricity use compared to other parts of the state (Lehman and Johnstone, 2010).

Aside from sporadic news reports (Anderson, 2010; Quinones, 2010), policymakers and consumers possess little information on the energy implications of this practice. A few prior studies tangentially mentioning energy use associated with *Cannabis* production used cursory methods and under-estimate energy use significantly (Plecas et al., 2010 and Caulkins, 2010).

Driving the large energy requirements of indoor production facilities are lighting levels matching those found in hospital operating rooms (500-times greater than recommended for reading) and 30 hourly air changes (6-times the rate in high-tech laboratories, and 60-times the rate in a modern home). Resulting power densities are on the order of 2000 W/m^2, which is on a par with that of modern datacenters. Indoor carbon dioxide (CO_2) levels are often raised to 4-times natural levels in order to boost plant growth. However, by shortening the growth cycle, this practice may reduce final energy intensity.

Specific energy uses include high-intensity lighting, dehumidification to remove water vapor and avoid mold formation, space heating or cooling during non-illuminated periods and drying, pre-heating of irrigation water, generation of carbon dioxide by burning fossil fuel, and ventilation and air-conditioning to remove waste heat. Substantial energy inefficiencies arise from air cleaning, noise and odor suppression, and inefficient electric generators used to avoid conspicuous utility bills. So-called "grow houses" – residential buildings converted for *Cannabis* production – can contain 50,000 to 100,000 W of installed lighting power (Brady, 2004). Much larger facilities are also used.

Based on the model developed in this article, approximately 13,000 kW/h/year of electricity is required to operate a standard production module (a $1.2 \times 1.2 \times 2.4$ m ($4 \times 4 \times 8$ ft) chamber). Each module yields approximately 0.5 kg (1 pound) of final product per cycle, with four or five production cycles conducted per year. A single grow house can contain 10 to 100 such modules.

To estimate national electricity use, these normalized values are applied to the lower end of the range of the aforementioned estimated production (10,000 t per year), with one-third of the activity takes place under indoor conditions. This indicates electricity use of about 20 TW/h/year nationally (including off-grid production). This is equivalent to that of 2 million average U.S. homes, corresponding to approximately 1% of national electricity consumption — or the output of 7 large electric power plants (Koomey et al., 2010). This energy, plus associated fuel uses (discussed below), is valued at $6 billion annually, with associated emissions of 15 million metric ton of CO_2 — equivalent to that of 3 million average American cars (Fig. 1 and Tables 1–3.)

Fuel is used for several purposes, in addition to electricity. The carbon dioxide injected into grow rooms to increase yields is produced industrially (Overcash et al., 2007) or by burning propane or natural gas within the grow room contributes about 1–2% to the carbon footprint and represents a yearly U.S. expenditure of $0.1 billion. Vehicle use associated with production and distribution contributes about 15% of total emissions, and represents a yearly expenditure of $1 billion. Off-grid diesel- and gasoline-fueled electric generators have per-kilowatt-hour emissions burdens that are 3- and 4-times those of average grid electricity in California. It requires 70 gallon of diesel fuel to produce one indoor *Cannabis* plant (or the equivalent yield per unit area), or 140 gallon with smaller, less-efficient gasoline generators.

In California, the top-producing state, indoor cultivation is responsible for about 3% of all electricity use, or 9% of household use.[2] This corresponds to the electricity use of 1 million average California homes, greenhouse-gas emissions equal to those from 1 million average cars, and energy expenditures of $3 billion per

[2] This is somewhat higher than estimates previously made for British Columbia, specifically, 2% of total Provincial electricity use or 6% of residential use (Garis, 2008; Bellett, 2010).

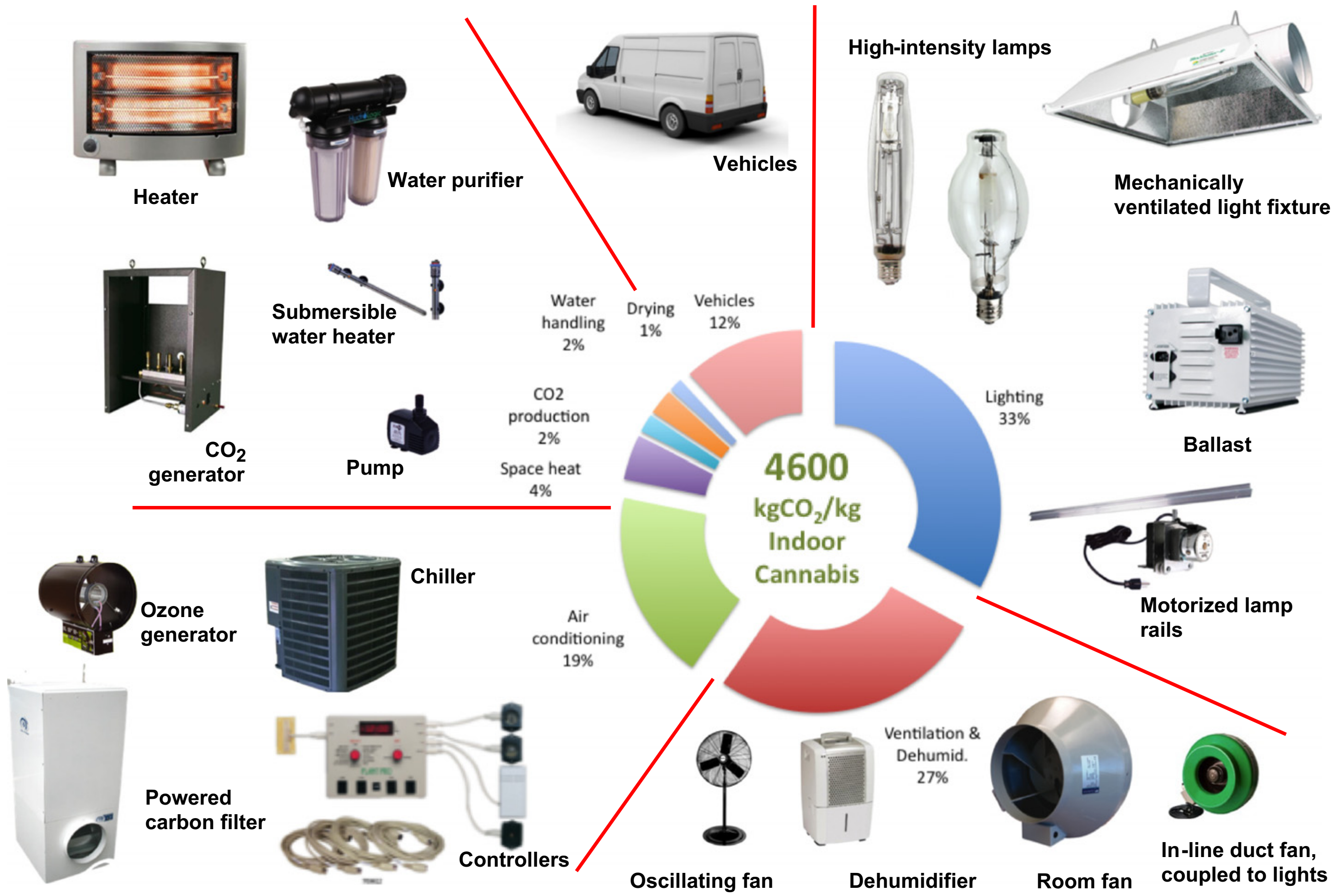

Fig. 1. Carbon footprint of indoor Cannabis production.

Table 1
Carbon footprint of indoor *Cannabis* production, by end use (average U.S conditions).

	Energy intensity (kW/h/kg yield)	Emissions factor (kgCO$_2$ emissions/kg yield)	
Lighting	2283	1520	33%
Ventilation & dehumid.	1848	1231	27%
Air conditioning	1284	855	19%
Space heat	304	202	4%
CO$_2$ injected to increase foliage	93	82	2%
Water handling	173	115	2%
Drying	90	60	1%
Vehicles		546	12%
Total	6074	4612	100%

Note: The calculations are based on U.S.-average carbon burdens of 0.666 kg/kW/h. "CO$_2$ injected to increase foliage" represents combustion fuel to make on-site CO$_2$. Assumes 15% of electricity is produced in off-grid generators.

year. Due to higher electricity prices and cleaner fuels used to make electricity, California incurs 50% of national energy costs but contributes only 25% of national CO$_2$ emissions from indoor *Cannabis* cultivation.

From the perspective of individual consumers, a single *Cannabis* cigarette represents 1.5 kg (3 pounds) of CO$_2$ emissions, an amount equal to driving a 44 mpg hybrid car 22 mile or running a 100-watt light bulb for 25 h, assuming average U.S. electricity emissions. The electricity requirement for one single production module equals that of an average U.S. home and twice that of an average California home. The added electricity use is equivalent to running about 30 refrigerators.

From the perspective of a producer, the national-average annual energy costs are approximately $5500 per module or $2500 per kilogram of finished product. This can represent half the wholesale value of the finished product (and a substantially lower portion at retail), depending on local conditions. For average U.S. conditions, producing one kilogram of processed *Cannabis* results in 4600 kg of CO$_2$ emissions to the atmosphere (and 50% more when off-grid diesel power generation is used), a very significant carbon footprint. The emissions associated with one kilogram of processed *Cannabis* are equivalent to those of driving across country 11 times in a 44-mpg car.

These results reflect typical production methods. Much more energy-intensive methods occur, e.g., rooms using 100% recirculated air with simultaneous heating and cooling, hydroponics, or energy end uses not counted here such as well-water pumps and water purification systems. Minimal information and consideration of energy use, coupled with adaptations for security and privacy (off-grid generation, no daylighting, odor and noise control) lead to particularly inefficient configurations and correspondingly elevated energy use and greenhouse-gas emissions.

The embodied energy of inputs such as soil, fertilizer, water, equipment, building materials, refinement, and retailing is not estimated here and should be considered in future assessments. The energy use for producing outdoor-grown *Cannabis* (approximately two-thirds of all production) is also not estimated here.

Table 2
Equivalencies.

Indoor Cannabis production consumes…	**3%**	of California's total electricity, and	**9%**	of California's household electricity	**1%**	of total U.S. electricity, and	2% of U.S. household electricity
U.S. Cannabis production & distribution energy costs…	**$ 6**	Billion, and results in the emissions of	**15**	Million tonnes per year of greenhouse gas emissions (CO_2)	Equal to the emissions of	**3**	million average cars
U.S. electricity use for Cannabis production is equivalent to that of…	**1.7**	Million average U.S. homes	**or**	**7**	Average U.S. power plants		
California Cannabis production and distribution energy costs...	**$ 3**	Billion, and results in the emissions of	**4**	Million tonnes per year of greenhouse gas emissions (CO_2)	Equal to the emissions of	**1**	Million average cars
California electricity use for Cannabis production is equivalent to that of…	**1**	Million average California homes					
A typical 4 × 4 × 8-ft production module, accomodating four plants at a time, consumes as much electricity as…	**1**	Average U.S. homes, or	**2**	Average California homes	or	**29**	Average new refrigerators
Every 1 kilogram of Cannabis produced using national-average grid power results in the emissions of…	**4.3**	Tonnes of CO_2	Equivalent to	**7**	Cross-country trips in a 5.3 l/100 km (44 mp g) car		
Every 1 kg of Cannabis produced using a prorated mix of grid and off-grid generators results in the emissions of…	**4.6**	Tonnes of CO_2	Equivalent to	**8**	Cross-country trips in a 5.3 l/100 km (44 mp g) car		
Every 1 kg of Cannabis produced using off-grid generators results in the emissions of…	**6.6**	Tonnes of CO_2	Equivalent to	**11**	Cross-country trips in a 5.3 l/100 km (44 mp g) car		
Transportation (wholesale + retail) consumes…	**226**	Liters of gasoline per kg	or	**$ 1**	Billion dollars annually, and	**546**	Kilograms of CO_2 per kilogram of final product
One Cannabis cigarette is like driving…	**37**	km in a 5.3 l/100 km (44 mpg) car	Emitting about	**2**	kg of CO_2, which is equivalent to operating a 100-watt light bulb for	**25**	Hours
Of the total wholesale price…	**49%**	Is for energy (at average U.S. prices)					

If improved practices applicable to commercial agricultural greenhouses are any indication, such large amounts of energy are not required for indoor *Cannabis* production.[3] The application of cost-effective, commercially-available efficiency improvements to the prototypical facility modeled in this article could reduce energy intensities by at least 75% compared to the typical-efficiency baseline. Such savings would be valued at approximately $40,000/year for a generic 10-module operation (at California energy prices and $10,000/year at U.S. average prices) (Fig. 2(a)–(b). These estimated energy use reductions reflect practices that are commonplace in other contexts such as more efficient components and controls (lights, fans, space-conditioning), use of daylight, optimized air-handling systems, and relocation of heat-producing equipment out of the cultivation room. Moreover, strain choice alone results in a factor-of-two difference in yields per unit of energy input (Arnold, 2011).

[3] See, e.g., this University of Michigan resource: http://www.hrt.msu.edu/energy/Default.htm

5. Energy intensities in context

Policymakers and other interested parties will rightfully seek to put these energy indicators in context with other activities in the economy.

One can readily identify other energy end-use activities with far greater impacts than that of *Cannabis* production. For example, automobiles are responsible for about 33% of U.S. greenhouse-gas emissions (USDOE, 2009), which is100-times as much as those produced by indoor *Cannabis* production (0.3%). The approximately 20 TW/h/year estimated for indoor *Cannabis* production is about one/third that of U.S. data centers (US EPA, 2007a, 2007b), or one-seventh that of U.S. household refrigerators (USDOE, 2008). These shares would be much higher in states where *Cannabis* cultivation is concentrated (e.g., one half that of refrigerators in California (Brown and Koomey, 2002)).

On the other hand, this level of energy use is high in comparison to that used for other indoor cultivation practices, primarily owing to the lack of daylighting. For comparison, the energy intensity of Belgian greenhouses is estimated at approximately 1000 MJ/m^2 (De Cock and Van Lierde, No date), or about 1% that estimated here for indoor *Cannabis* production.

Table 3
Energy indicators (average U.S. conditions).

	per cycle, per production module	per year, per production module	
Energy use			
Connected load		3,225	(watts/module)
Power density		2,169	(watts/m^2)
Elect	2756	12,898	(kW/h/module)
Fuel to make CO_2	0.3	1.6	(GJ)
Transportation fuel	27	127	(Gallons
On-grid results			
Energy cost	846	3,961	$/module
Energy cost		1,866	$/kg
Fraction of wholesale price		47%	
CO_2 emissions	1936	9,058	kg
CO_2 emissions		4,267	kg/kg
Off-grid results (diesel)			
Energy cost	1183	5,536	$/module
Energy cost		2,608	$/kg
Fraction of wholesale price		65%	
CO_2 emissions	2982	13,953	kg
CO_2 emissions		6,574	$kgCO_2$/kg
Blended on/off grid results			
Energy cost	897	4,197	$/module
Energy cost		1,977	$/kg
Fraction of wholesale price		49%	
CO_2 emissions	2093	9,792	kg
CO_2 emissions		4,613	$kgCO_2$/kg
Of which, indoor CO_2 production	9	42	$kgCO_2$
Of which, vehicle use			
Fuel use			
During production		79	Liters/kg
Distribution		147	Liters/kg
Cost			
During production		77	$/kg
Distribution		143	$/kg
Emissions			
During production		191	$kgCO_2$/kg
Distribution		355	$kgCO_2$/kg

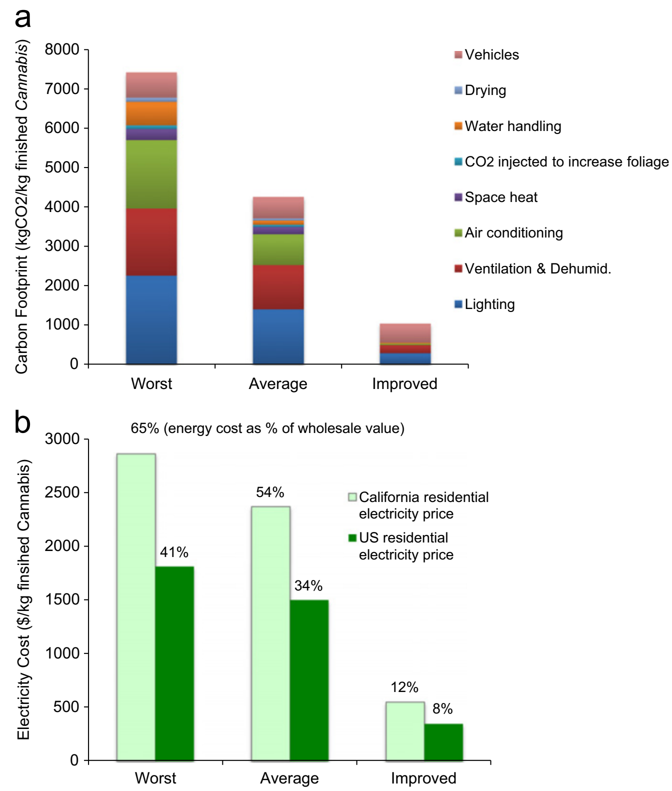

Fig. 2. Carbon footprint and energy cost for three levels of efficiency. (a) Indoor cannabis: carbon footprint. (b) Indoor cannabis: electricity cost. Assumes a wholesale price of $4400/kg. Wholesale prices are highly variable and poorly documented.

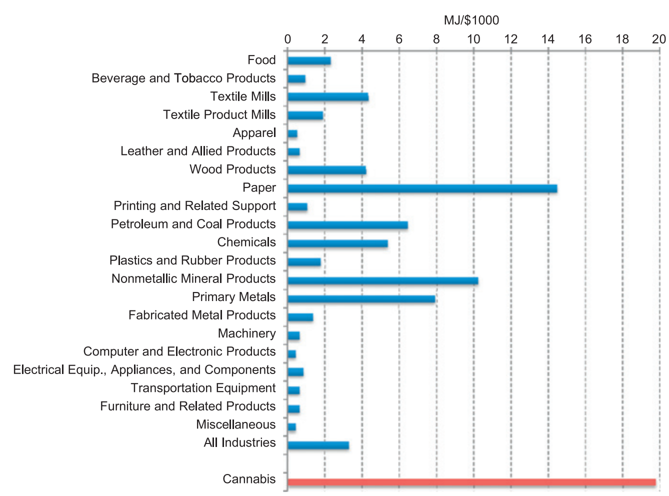

Fig. 3. Comparative energy intensities, by sector (2006).

Energy intensities can also be compared to those of other sectors and activities.

- Pharmaceuticals — Energy represents 1% of the value of U.S. pharmaceutical shipments (Galitsky et al., 2008) versus 50% of the value of Cannabis wholesale prices. The U.S. "Pharma" sector uses $1 billion/year of energy; Indoor Cannabis uses $6 billion.
- Other industries — Defining "efficiency" as how much energy is required to generate economic value, Cannabis comes out the highest of all 21 industries (measured at the three-digit SIC level). At ~20 MJ per thousand dollars of shipment value (wholesale price), Cannabis is followed next by paper (~14), nonmetallic mineral products (~10), primary metals (~8), petroleum and coal products (~6), and then chemicals (~5) (Fig. 3). However, energy intensities are on a par with *Cannabis* in various subsectors (e.g., grain milling, wood products, rubber) and exceed those of *Cannabis* in others (e.g., pulp mills).
- Alcohol — The energy used to produce one marijuana cigarette would also produce 18 pints of beer (Galitsky et al., 2003).
- Other building types — Cannabis production requires 8-times as much energy per square foot as a typical U.S. commercial building (4x that of a hospital and 20x that of a building for religious worship), and 18-times that of an average U.S. home (Fig. 4).

6. Outdoor cultivation

Shifting cultivation outdoors can nearly eliminate energy use for the cultivation process. Many such operations, however, require water pumping as well as energy-assisted drying techniques. Moreover, vehicle transport during production and distribution remains part of the process, more so than for indoor operations.

A common perception is that the potency of *Cannabis* produced indoors exceeds that of that produced outdoors, leading

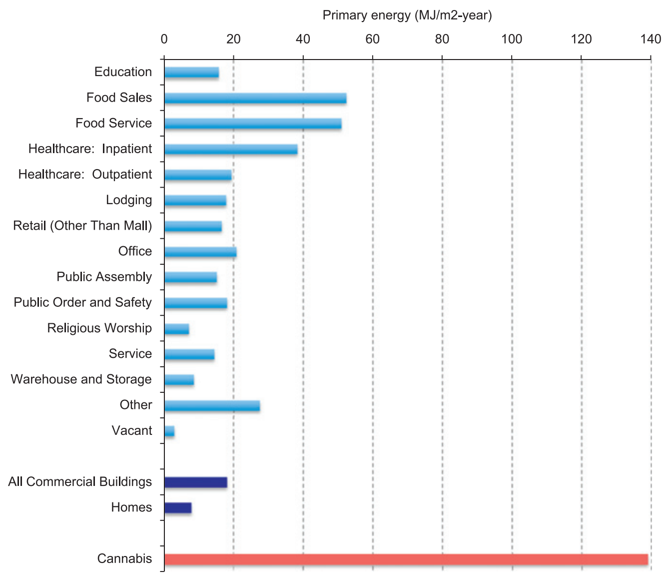

Fig. 4. Comparative energy intensities, by U.S. building type (2003).

consumers to demand *Cannabis* produced indoors. Federal sources (National Drug Intelligence Center, 2005) as well as independent testing laboratories (Kovner, 2011) actually find similar potencies when best practices are used.

Illegal clearing of land is common for multi-acre plantations, and, depending on the vegetation type, can accordingly mobilize greenhouse-gas emissions. Standing forests (a worst-case scenario) hold from 125 to 1500 t of CO_2 per hectare, depending on tree species, age, and location (National Council for Air and Soil Improvement, 2010). For biomass carbon inventories of 750 t/ha and typical yields (5000 kg/ha) (UNODC, 2009), associated biomass-related CO_2 emissions would be on the order of 150 kg CO_2/kg *Cannabis* (for only one harvest per location), or 3% of that associated with indoor production. These sites typically host on the order of 10,000 plants, although the number can go much higher (Mallery, 2011). When mismanaged, the practice of outdoor cultivation imposes multiple environmental impacts aside from energy use. These include deforestation; destruction of wetlands, runoff of soil, pesticides, insecticides, rodenticides, and human waste; abandoned solid waste; and unpermitted impounding and withdrawals of surface water (Mallery, 2011; Revelle, 2009). These practices can compromise water quality, fisheries, and other ecosystem services.

7. Policy considerations

Current indoor *Cannabis* production and distribution practices result in prodigious energy use, costs, and unchecked greenhouse-gas pollution. While various uncertainties exist in the analysis, the overarching qualitative conclusions are robust. More in-depth analysis and greater transparency of the energy impacts of this practice could improve decision-making by policymakers and consumers alike.

There is little, if any, indication that public policymakers have incorporated energy and environmental considerations into their deliberations on *Cannabis* production and use. There are additional adverse impacts of the practice that merit attention, including elevated moisture levels associated with indoor cultivation that can cause extensive damage to buildings,[4] as well as electrical fires caused by wiring out of compliance with safety codes (Garis, 2008). Power theft is common, transferring those energy costs to the general public (Plecas et al., 2010). As noted above, simply shifting production outdoors can invoke new environmental impacts if not done properly.

Energy analysts have also not previously addressed the issue. Aside from the attention that any energy use of this magnitude normally receives, the hidden growth of electricity demand in this sector confounds energy forecasts and obscures savings from energy efficiency programs and policies. For example, Auffhammer and Aroonruengsawat (2010) identified a

[4] For observations from the building inspectors community, see http://www.nachi.org/marijuana-grow-operations.htm

Table A1
Configuration, environmental conditions, set-points.

Production parameters		
Growing module	1.5	m^2 (excl. walking area)
Number of modules in a room	10	
Area of room	22	m^2
Cycle duration	78	days
Production continuous throughout the year	4.7	cycles
Illumination	Leaf phase	Flowering phase
Illuminance	25 klux	100 klux
Lamp type	Metal halide	High-pressure sodium
Watts/lamp	600	1000
Ballast losses (mix of magnetic & digital)	13%	0.13
Lamps per growing module	1	1
Hours/day	18	12
Days/cycle	18	60
Daylighting	None	none
Ventilation		
Ducted luminaires with "sealed" lighting compartment	150	CFM/1000 W of light (free flow)
Room ventilation (supply and exhaust fans)	30	ACH
Filtration	Charcoal filters on exhaust; HEPA on supply	
Oscilating fans: per module, while lights on	1	
Water		
Application	151	liters/room-day
Heating	Electric submersible heaters	
Space conditioning		
Indoor setpoint — day	28	C
Indoor setpoint — night	20	C
AC efficiency	10	SEER
Dehumidification	7x24	hours
CO_2 production — target concentration (mostly natural gas combustion in space)	1500	ppm
Electric space heating	When lights off to maintain indoor setpoint	
Target indoor humidity conditions	40–50%	
Fraction of lighting system heat production removed by luminaire ventilation	30%	
Ballast location	Inside conditioned space	
Drying		
Space conditioning, oscillating fans, maintaining 50% RH, 70–80F	7	Days
Electricity supply		
grid	85%	
grid-independent generation (mix of diesel, propane, and gasoline)	15%	

Table A2
Assumptions and conversion factors.

Service levels		
Illuminance*	25–100	1000 lux
Airchange rates*	30	Changes per hour
Operations		
Cycle duration**	78	Days
Cycles/year**	4.7	Continuous production
Airflow**	96	Cubic feet per minute, per module
Lighting		
Leafing phase		
Lighting on-time*	18	hrs/day
Duration*	18	days/cycle
Flowering phase		
Lighting on-time*	12	hrs/day
Duration*	60	days/cycle
Drying		
Hours/day*	24	hrs
Duration*	7	days/cycle
Equipment		
Average air-conditioning age	5	Years
Air conditioner efficiency [Standards increased to SEER 13 on 1/23/2006]	10	SEER
Fraction of lighting system heat production removed by luminaire ventilation	0.3	
Diesel generator efficiency*	27%	55 kW
Propane generator efficiency*	25%	27 kW
Gasoline generator efficiency*	15%	5.5 kW
Fraction of total prod'n with generators*	15%	
Transportation: Production phase (10 modules)	25	Miles roundtrip
Daily service (1 vehicle)	78	Trips/cycle. Assume 20% live on site
Biweekly service (2 vehicles)	11.1	Trips/cycle
Harvest (2 vehicles)	10	Trips/cycle
Total vehicle miles**	2089	Vehicle miles/cycle
Transportation: Distribution		
Amount transported wholesale	5	kg per trip
Mileage (roundtrip)	1208	km/cycle
Retail (0.25oz $\times$ 5 miles roundtrip)	5668	Vehicle-km/cycle
Total**	6876	Vehicle-km/cycle
Fuel economy, typical car [a]	10.7	l/100 km
Annual emissions, typical car [a]	5195	$kgCO_2$
	0	$kgCO_2$/mile
Annual emissions, 44-mpg car**	2,598	$kgCO_2$
	0.208	$kgCO_2$/mile
Cross-country U.S. mileage	4493	km
Fuels		
Propane [b]	25	MJ/liter
Diesel [b]	38	MJ/liter
Gasoline [b]	34	MJ/liter
Electric generation mix*		
Grid	85%	share
Diesel generators	8%	share
Propane generators	5%	share
Gasoline generators	2%	share
Emissions factors		
Grid electricity — U.S. [c]	0.609	$kgCO_2$/kW/h
Grid electricity — CA [c]	0.384	$kgCO_2$/kW/h
Grid electricity — non-CA U.S. [c]	0.648	$kgCO_2$/kW/h
Diesel generator**	0.922	$kgCO_2$/kW/h
Propane generator**	0.877	$kgCO_2$/kW/h
Gasoline generator**	1.533	$kgCO_2$/kW/h
Blended generator mix**	0.989	$kgCO_2$/kW/h
Blended on/off-grid generation — CA**	0.475	$kgCO_2$/kW/h
Blended on/off-grid generation — U.S.**	0.666	$kgCO_2$/kW/h
Propane combustion	63.1	$kgCO_2$/MBTU
Prices		
Electricity price — grid (California — PG&E) [d]	0.390	per kW/h (Tier 5)
Electricity price — grid (U.S.) [e]	0.247	per kW/h
Electricity price — off-grid**	0.390	per kW/h
Electricity price — blended on/off — CA**	0.390	per kW/h
Electricity price — blended on/off — U.S.**	0.268	per kW/h
Propane price [f]	0.58	$/liter
Gasoline price — U.S. average [f]	0.97	$/liter
Diesel price — U.S. average [f]	1.05	$/liter
Wholesale price of Cannabis [g]	4,000	$/kg
Production		
Plants per production module*	4	
Net production per production module [h]	0.5	kg/cycle
U.S. production (2011) [i]	10,000	metric tonnes/y
California production (2011) [i]	3,902	metric tonnes/y
Fraction produced indoors [i]	33%	
U.S. indoor production modules**	1,570,399	
Calif indoor production modules**	612,741	
Cigarettes per kg**	3,000	
Other		
Average new U.S. refrigerator	450	kW/h/year
	173	$kgCO_2$/year (U.S. average)
Electricity use of a typical U.S. home — 2009 [j]	11,646	kW/h/year
Electricity use of a typical California home — 2009 [k]	6,961	kW/h/year

Notes:
* Trade and product literature; interviews with equipment vendors.
** Calculated from other values.
Notes for Table A2.
[a]. U.S. Environmental Protection Agency., 2011.
[b]. *Energy conversion factors,* U.S. Department of Energy, http://www.eia.doe.gov/energyexplained/index.cfm?page=about_energy_units, [Accessed February 5, 2011].
[c]. United States: (USDOE 2011); California (Marnay et al., 2002).
[d]. Average prices paid in California and other states with inverted-block tariffs are very high because virtually all consumption is in the most expensive tiers. Here the PG&E residential tariff as of 1/1/11, Tier 5 is used as a proxy for California http://www.pge.com/tariffs/ResElecCurrent.xls, (Accessed February 5, 2011). In practice a wide mix of tariffs apply, and in some states no tier structure is in place, or the proportionality of price to volume is nominal.
[e]. State-level residential prices, weighted by *Cannabis* production (from Gettman. 2006) with actual tariffs and U.S. Energy Information Administration, "Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State", http://www.eia.doe.gov/electricity/epm/table5_6_a.html, (Accessed February 7, 2011)
[f]. U.S. Energy Information Administration, Gasoline and Diesel Fuel Update (as of 2/14/2011) – see http://www.eia.gov/oog/info/gdu/gasdiesel.asp Propane prices – http://www.eia.gov/dnav/pet/pet_pri_prop_a_EPLLPA_PTA_dpgal_m.htm, (Accessed April 3, 2011).
[g]. Montgomery, 2010.
[h]. Toonen et al., 2006); Plecas et al., 2010.
[i]. *Total Production*: The lower value of 10,000 t per year is conservatively retained. Were this base adjusted to 2011 values using 10.9%/year net increase in number of consumers between 2007 and 2009 per U.S. Department of Health and Human Services (2010), the result would be approximately 17 million tonnes of total production annually (indoor and outdoor). *Indoor Share of Total Production*: The three-fold changes in potency over the past two decades, reported by federal sources, are attributed at least in part to the shift towards indoor cultivation See http://www.justice.gov/ndic/pubs37/37035/national.htm and (Hudson, 2003). A weighted-average potency of 10% THC (U.S. Office of Drug Control Policy, 2010) reconciled with assumed 7.5% potency for outdoor production and 15% for indoor production implies 33.3%::67.7% indoor::outdoor production shares. For reference, as of 2008, 6% of eradicated plants were from indoor operations, which are more difficult to detect than outdoor operations. A 33% indoor share, combined with per-plant yields from Table 2, would correspond to a 4% eradication success rate for the levels reported (415,000 indoor plants eradicated in 2009) by the U.S. Drug Enforcement Agency (http://www.justice.gov/dea/programs/marijuana.htm). Assuming 400,000 members of medical Cannabis dispensaries in California (each of which is permitted to cultivate), and 50% of these producing in the generic 10-module room assumed in this analysis, output would slightly exceed this study's estimate of total statewide production. In practice, the vast majority of indoor production is no doubt conducted outside of the medical marijuana system.
[j]. Total U.S. electricity sales: U.S. energy information administration, "retail sales of electricity to ultimate customers: Total by end-use sector" http://www.eia.gov/cneaf/electricity/epm/table5_1.html, (Accessed March 5, 2011)
[k]. California Energy Commission, 2009; 2011.

statistically significant, but unexplained, increase in the growth rate for residential electricity in California during the years when indoor *Cannabis* production grew as an industry (since the mid-1990s).

Table A3
Energy model.

ELECTRICITY	Energy type	Penetration	Rating (Watts or %)	Number of 4 × 4 × 8-ft production modules served	Input energy per module	Units	Hours/day (leaf phase)	Hours/day (flower phase)	Days/cycle (leaf phase)	Days/cycle (flower phase)	kW/h/cycle	kW/h/year per production module
Light												
Lamps (HPS)	elect	100%	1,000	1	1,000	W		12		60	720	3,369
Ballasts (losses)	elect	100%	13%	1	130	W		12		60	94	438
Lamps (MH)	elect	100%	600	1	600	W	18		18		194	910
Ballast (losses)	elect	100%	0	1	78	W	18		18		25	118
Motorized rail motion	elect	5%	6	1	0.3	W	18	12	18	60	0	1
Controllers	elect	50%	10	10	1	W	24	24	18	60	2	9
Ventilation and moisture control												
Luminare fans (sealed from conditioned space)	elect	100%	454	10	45	W	18	12	18	60	47	222
Main room fans — supply	elect	100%	242	8	30	W	18	12	18	60	31	145
Main room fans — exhaust	elect	100%	242	8	30	W	18	12	18	60	31	145
Circulating fans (18")	elect	100%	130	1	130	W	24	24	18	60	242	1,134
Dehumidification	elect	100%	1,035	4	259	W	24	24	18	60	484	2,267
Controllers	elect	50%	10	10	1	W	24	24	18	60	2	9
Spaceheat or cooling												
Resistance heat or AC [when lights off]		90%	1,850	10	167	W	6	12	18	60	138	645
Carbon dioxide Injected to Increase foliage												
Parasitic electricity	elect	50%	100	10	5	W	18	12	18	60	5	24
AC (see below)	elect	100%										
In-line heater	elect	5%	115	10	0.6	W	18	12	18	60	1	3
Dehumidification (10% adder)	elect	100%	104	0	26	W	18	12	18	60	27	126
Monitor/control	elect	100%	50	10	5	W	24	24	18	60	9	44
Other												
Irrigation water temperature control	elect	50%	300	10	15	W	18	12	18	60	19	89
Recirculating carbon filter [sealed room]	elect	20%	1,438	10	29	W	24	24	18	60	54	252
UV sterilization	Elect	90%	23	10	2.1	W	24	24	18	60	4	18
Irrigation pumping	elect	100%	100	10	10	W	2	2	18	60	2	7
Fumigation	elect	25%	20	10	1	W	24	24	18	60	1	4
Drying												
Dehumidification	elect	75%	1,035	10	78	W		24		7	13	61
Circulating fans	elect	100%	130	5	26	W		24		7	4	20
Heating	elect	75%	1,850	10	139	W		24		7	23	109
Electricity subtotal	elect										2,174	10,171
Air-conditioning				10	420	W					583	2,726
Lighting loads				10		W					259	1,212
Loads that can be remoted	elect	100%	1,277	10		W					239	1,119
Loads that can't be remoted	elect	100%	452	10		W					85	396
CO2-production heat removal	elect	45%	1,118	17		W	18	12	18	60	—	—
Electricity Total	elect				3,225	W					2,756	12,898

FUEL	Units	Technology Mix	Rating (BTU/h)	Number of 4 × 4 × 8-ft production modules served	Input energy per module		Hours/day (leaf phase)	Hours/day (flower phase)	Days/cycle (leaf phase)	Days/cycle (flower phase)	GJ or $kgCO_2$/cycle	GJ or $kgCO_2$/year
On-site CO_2 production												
Energy use	propane	45%	11,176	17	707	kJ/h	18	12	18	60	0.3	1.5
CO2 production – > emissions	kg/CO_2										20	93
Externally produced Industrial CO_2		5%		1	0.003	liters CO_2/hr	18	12	18	60	0.6	2.7
Weighted-average on-site/purchased	$kgCO_2$										2	10

For *Cannabis* producers, energy-related production costs have historically been acceptable given low energy prices and high product value. As energy prices have risen and wholesale commodity prices fallen, high energy costs (now 50% on average of wholesale value) are becoming untenable. Were product prices to fall as a result of legalization, indoor production could rapidly become unviable.

For legally sanctioned operations, the application of energy performance standards, efficiency incentives and education, coupled with the enforcement of appropriate construction codes could lay a foundation for public-private partnerships to reduce undesirable impacts of indoor *Cannabis* cultivation.[5] There are early indications of efforts to address this.[6] Were such operations to receive some form of independent certification and product labeling, environmental impacts could be made visible to otherwise unaware consumers.

Acknowledgment

Two anonymous reviewers provided useful comments that improved the paper. Scott Zeramby offered particularly valuable insights into technology characteristics, equipment configurations, and market factors that influence energy utilization in this context and reviewed earlier drafts of the report.

Appendix A

See Tables A1–A3.

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Energy Use by the Indoor Cannabis Industry:
Inconvenient Truths for Producers, Consumers, and Policymakers

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June 22, 2020

Forthcoming in *The Routledge Handbook of Interdisciplinary Cannabis Research*
Dominic Corva and Joshua Meisel (eds.)

Contents

Abstract

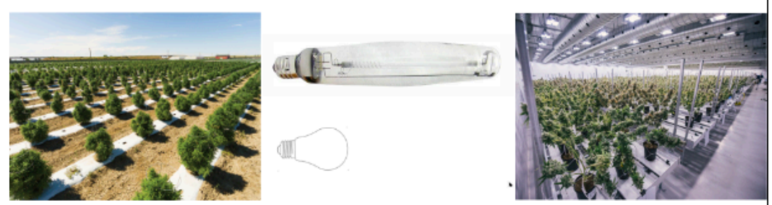
Decades spent in the shadows of the black market precluded opportunities to understand the energy use of indoor cannabis cultivation and compel the industry to keep its environmental consequences in check. Although the impacts of outdoor cultivation on ecosystems have received considerable attention, those associated with vastly more energy-intensive indoor cultivation have rarely been evaluated and integrated into policy-making, even in the post-prohibition era. Indeed, indoor cannabis cultivators continue to be passed over by most energy policy instruments developed since the energy crises of the 1970s. Moreover, some cannabis regulations are inadvertently driving energy use upwards, while "financial incentives" for energy efficiency offered to indoor growers by utility companies subsidize and legitimize polluting activities that could be performed outdoors with virtually no energy use. These anti-competitive repercussions of ill-conceived and poorly evaluated policy demonstrate that cannabis legalization is necessary but not sufficient to address environmental issues. This chapter pinpoints blindspots in regulation, outlines research and analysis needs, argues for consumer information and protections against greenwashing and industry capture of regulatory and green-certification processes, and offers recommendations for incorporating energy considerations into the broader tapestry of cannabis policy. Even at ostensibly high energy efficiencies and use of renewable energy, indoor cultivation "optimizes the suboptimal" and cannibalizes renewable energy infrastructure developed for other purposes, which is untenable in a carbon-constrained world. Outdoor cultivation—which has sufficed for millennia—is the most technologically elegant, sustainable, ethical, and economically viable approach for minimizing the rising energy and environmental burden of cannabis production.

Introduction: Cannabis legalization is necessary but not sufficient for addressing energy waste

Decades spent in the shadows of the black market created few opportunities to understand the patterns of energy use associated with indoor cannabis cultivation, let alone compel the industry to manage consumption and thus keep its environmental consequences in check.[1] Cannabis production, distribution, and sale involve a myriad of energy uses, some of which are direct and others indirect (Figure 1). Drivers of energy demand include creating the inputs and energy used during production, processing, managing waste, downstream retail activities, and transportation. Key decision-makers and stakeholders include policymakers, planners, producers, investors, industry analysts, and consumers.

[1] This chapter expands on a presentation entitled "Policymakers' Primer on Addressing the Carbon Footprint of Cannabis Production" to the Council of State Governments annual meeting in December 2017 (Mills 2017).

Direct and indirect drivers of energy use and greenhouse-gas emissions from the cannabis industry

Inputs	• Energy (on-grid and off-grid)* • Industrial CO2* • Water production and supply • Soil and amendments • Artificial growing media • Fertilizer • Pesticides, herbicides, fungicides • Plastics (bagging, mulch, greenhouse sheeting, containers, irrigation, etc.)	
Production	• Outdoor • Small structure (windowless)* • Large structure (windowless) • Greenhouse • Energy use: lighting, cooling, heating, ventilation, odor control, CO2 generator, dehumidification, water heat, pumping, IT, plug loads*	
Processing	• Flower drying* or freezing • Energy for producing extracts; solvents (butane, propane, ethanol, isopropyl alcohol) • Cooking/baking • Packaging • Testing labs	
Waste	• Failed/interdicted crops; material not passing inspection • Single-use soil or artificial growing media • Plastics • Hydroponic water effluent to waste-treatment plant • Biomass	
Retail	• Facility construction • Lighting • Heating • Cooling • Ventilation • Refrigeration	
Transport	• Materials to jobsite • Workers to jobsite* • Product to intermediaries • Product to retail* • Consumer to retail* • Delivery services • Waste disposal	

** Items accounted for in energy-use estimates by Mills (2012).*

Figure 1. Modes of energy use associated with cannabis production, distribution, and sale.

Although the impacts of outdoor cultivation on ecosystems have received considerable attention (and do not primarily involve energy), those associated with far more energy-intensive indoor cultivation have only rarely been evaluated and integrated into policy-making, even in the post-prohibition era. Indeed, cannabis cultivators continue to be passed over by almost every energy policy instrument developed since the first modern energy crisis of nearly half a century ago. Moreover, there are many instances of post-prohibition cannabis policies that are inadvertently driving energy use upwards, while the "financial incentives" for energy efficiency being offered to indoor cultivators by electric utility companies represent a counter-productive subsidy and legitimization of a polluting activity that could be done much more sustainably outdoors.

The sometimes anti-competitive repercussions of ill-conceived policy and scant evaluation of policy adequacy demonstrate that legalization is necessary—but not sufficient—to address the associated environmental issues. These considerations intersect with more prominent cannabis policy issues such as taxation, public health and safety, interstate commerce, testing and product labeling, broader agricultural policy, and solid waste management. Particularly vexing is that even the most basic analyses are impeded by lack of rigor and lingering uncertainties about the structure and drivers of energy use and how far energy-efficiency and renewable energy can realistically go towards mitigating the associated undesirable impacts. For example, stemming from fundamental data gaps, even baseline studies often omit key considerations, and unwittingly suffer from unquantified biases due to problems with data collection and verification.

This chapter pinpoints blindspots in regulation, outlines research and analysis needs, argues for consumer information and protections against greenwashing and industry capture of regulatory and green-certification processes, and offers recommendations for incorporating energy considerations into the broader tapestry of cannabis policy. The balance of evidence suggests that Even at ostensibly high energy efficiencies and intensive use of renewable energy, indoor cultivation "optimizes the suboptimal" and cannibalizes renewable resources previously developed for other purposes, which is untenable in a carbon-constrained world. Outdoor cultivation—which has sufficed for millennia—is the most technologically elegant, sustainable, ethical, and economically viable approach for minimizing the rising energy and environmental burden of cannabis production.

The cannabis conundrum: Drug policy is decoupled from environmental policy

Few public policy issues are as multifaceted as that of cannabis production and consumption. Quantifying the energy use and carbon footprint associated with producing cannabis and its derivative products is one of the primary and least explored policy-relevant questions. When confined to the black market, this sector could not readily access relevant analysis and information sharing. However, little progress has been made in the wake of legalization efforts.

Windowless cannabis factory farms constantly battle local weather conditions to maintain round-the-clock tropical temperatures and pump out acres of electric light brighter than the summer sun, day or night. Such industrialized cannabis cultivation facilities—whether in Fairbanks or Phoenix—must simulate and maintain artificially cloudless tropical environments while suppressing humidity year-round. Industrially manufactured carbon dioxide (an added energy-intensive input and greenhouse gas in its own right, increasing carbon footprint on the order of 5% -- more if and as energy efficiency improves), is often injected to artificially boost plant growth. Running the equipment[2] needed to create and maintain these artificial environments can

[2] The primary energy users are heating and cooling, dehumidification, and lighting. With conventional lighting, most of the input energy results in heat generation which needs to be immediately removed by air conditioning. Other miscellaneous energy loads

require as much energy as a similarly sized data center. Indoor cultivators cite multiple reasons for this practice: security, a more predictable product, buffering from weather and other crop hazards, maximized cash flow due to year-round production, the need for fewer employees, legislative restrictions, and multiple harvests per year.[3]

As with most other environmental issues, those associated with cannabis get "shaded out" by other seemingly more pressing concerns faced by policymakers (taxation, zoning, child safety, etc.). Together with the highly technical and complicated nature of how energy is used in the industry and how to quantify energy efficiency, few policymakers are even equipped to engage effectively. As a case-in-point, the IRS has been thwarted in pursuing tax-fraud cases since it cannot readily correlate reported sales volumes with utility bills.

Concern about the environmental footprint of cannabis production: Demonization or double standard?

Energy-intensive indoor cultivation has been conducted within the black market for decades. The original shift to the practice was, in part, a structural product of prohibition enforcement efforts that pushed growers indoors to avoid detection (Silvaggio in this Handbook). Legalization does not intrinsically address the energy issues, and can even compound them by encouraging the rapid scale-up of indoor facilities and otherwise altering patterns of energy use in unexpected ways, some of which are noted below.

Some industry advocates have complained that cannabis is singled out for scrutiny, while other sectors are left to their devices or otherwise pollute more. This argument is spurious (Mills 2016), as cannabis is in actuality one of the vanishingly few segments of the economy that has been largely overlooked in energy and environmental policy. Moreover, as is well established in the climate change mitigation field, there is no "silver-bullet" solution and a multitude of energy uses must be simultaneously addressed in order to meet society's important emissions-reduction targets. It is a false choice to argue that one energy use should be addressed in lieu of another. There is no one cause of climate change, and thus no one solution. Meanwhile, the cannabis sector is arguably decades behind the rest of the economy when it comes to energy efficiency. In any case, adequate technical fixes are unlikely to be available if the demand for extraordinary levels or artificial illumination persists.

A key starting point for establishing a context for good decision-making is quantifying the level of energy use and associated greenhouse-gas emissions, and how that compares to other activities. Until less than a decade ago, no peer-reviewed public-domain assessment of cannabis energy use had been published. Early work on this question included a national scoping estimate of the issue based on the largely pre-recreational-legalization policy environment, where virtually all large-scale cultivation was conducted outdoors and indoor cultivation was

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can include irrigation pumps, water pre-heaters or coolers, air disinfection systems, motors to operate light-deprivation curtains, and crop dryers. Transportation (during and after production) and post-cultivation product manufacturing further contributes to energy use and carbon footprint.

[3] This latter argument is not material, as outdoor growers using light-deprivation methods also achieve multiple harvests per year. Moreover, reducing labor intensity is contrary to the job-creation objectives of some cannabis policy makers.

predominantly windowless (Mills 2012). That said, small indoor operations were (and still are) numerous and generally not driven by energy efficiency considerations.

Based on best-available information at the time, a "bottom-up" model was created based on interviews with practitioners, equipment retailers, and published guidelines for growers (e.g. Rosenthal 2010) (Mills 2012). The boundary conditions (inputs and activities resulting in energy use and greenhouse-gas emissions) represented only a subset of those depicted in Figure 1. The per-facility results compared favorably to measured data available for indoor growing operations and the prevailing aggregate (e.g., state-level) energy demand estimates compared well with subsequent estimates by others, including the long-range planning authorities for the Northwest power system (Northwest Power and Conservation Council 2016).

From a national vantage point, Mills (2012) found that indoor cannabis consumed 20 billion kilowatt-hours of electricity annually, with additional amounts from direct fuel use, together corresponding to 15 million metric tonnes of CO_2 released into the atmosphere each year.[4] This in turn corresponded to an expenditure of $6 billion per year on energy, nationally, which amounted to 9% of California household electricity use, 3% of total statewide electricity use (all sectors), and 1% of electricity use nationally. Other independent estimates have found similar economy-level results. For example, indoor cultivation is estimated to require 0.6% of statewide electricity use (all sectors) in Colorado and 4% in the city of Denver (Hood 2018).[5] Washington State also reports that indoor cultivation is responsible for one percent of the state's overall electricity consumption (Jourabchi 2014), a number that has probably risen in the intervening years. As early as 2004, it was reported that indoor cannabis cultivation was responsible for 1% of electricity use in British Columbia (Easton 2004), which was long before the recreational legalization decision in Canada.

For context, the aforementioned national estimate was equivalent to the emissions of two million average U.S. homes or three million cars, and is more than four-times the aggregate U.S. pharmaceutical industry energy expenditure.[6] While part of this difference arises from the lower energy prices paid by industrial users compared to residentially-based cannabis producers of the time, it is noteworthy that the average energy intensity of pharmaceutical facilities(approximately 3,600 kBTU/sf-y) is well below that of indoor cannabis cultivation facilities (Capparella 2013) at around 5,500 kBTU/sf-y.[7]

An additional key finding was that the "energy intensity" (energy use per unit of floor area) in indoor cultivation facilities was vastly higher than that of other common building types (Figure 2).

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4 This analysis represented the typical small- to mid-scale indoor cultivation practices of the time.

5 The City of Denver reports that 45% of its total growth in electricity demand stems from cannabis (Walton 2015).

6 Note that the original study (Mills 2012) put this at six-times, but the value noted here is adjusted for approximately 25% of pharmaceuticals being consumed by Americans that are produced off-shore (Altstedter 2017).

7 This cautiously assumes that the source is reporting in "site" energy units, i.e., not including the losses due to the inefficiencies of electricity production in power plants. The source's estimate of 1,210 kBTU/sf-year translates to approximately 3,600 kBTU/sf-year when adjusting for this conversion factor.

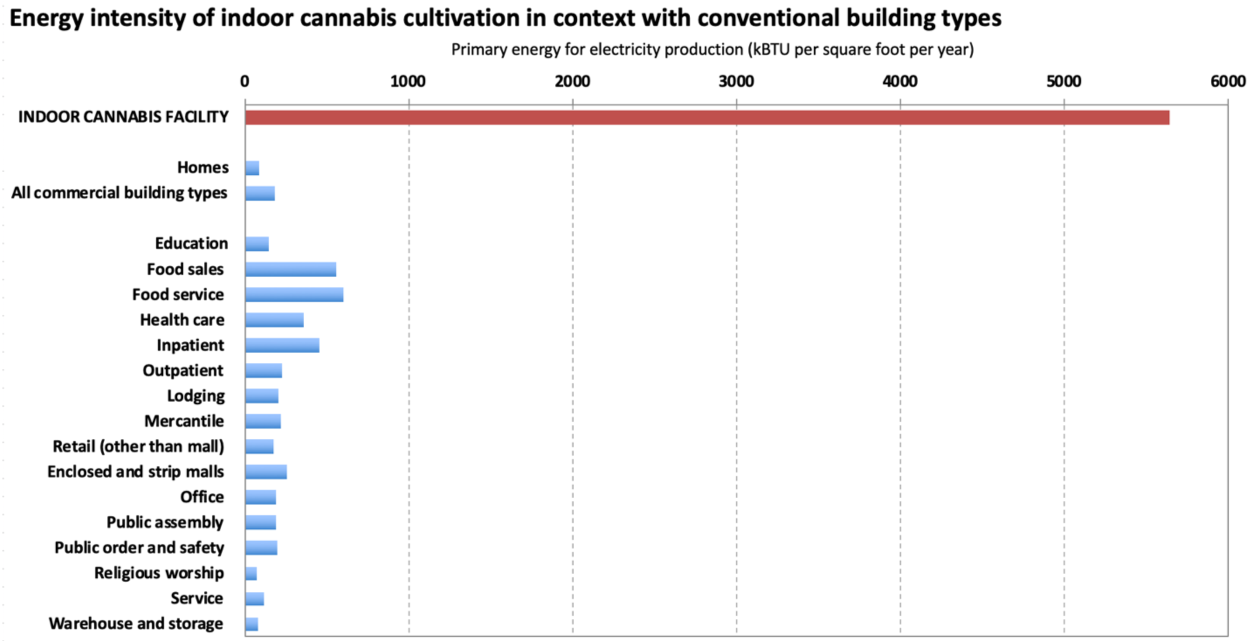

Figure 2. Cannabis energy intensity from Mills (2012). Reference data from U.S. Energy Information Administration. Homes (https://www.eia.gov/consumption/residential/). Commercial Buildings (https://www.eia.gov/consumption/commercial/)

From a regional vantage point, energy use can also be put in context by estimating how it contributes to per-person carbon emissions in economies where cannabis production is significant. While cannabis has been referred to as the largest cash crop in the U.S. in dollars (Gettman 2006), it is particularly significant in California. The implied per-person carbon footprint for the small populations in many of the producing areas is far above the averages in a state otherwise known for its energy efficiency—closer to that of the most carbon-intensive "coal" states, despite California's being known as one of the least carbon-intensive states.

From a consumer vantage point, the energy use for growing one 1-gram "joint" creates 10 pounds of carbon dioxide pollution, equivalent to running ten 10-watt LED light bulbs (or one 100-watt incandescent bulb) for 76 hours (Mills 2012). That's as much as driving 22 miles in a 44-mpg Prius. Embedded in each average indoor-grown plant is the energy equivalent of 70 gallons of oil. This means that a small "grow house" with ten grow lights consumes approximately as much electricity as ten average U.S. homes.

From a producer's vantage point, the cost of energy use varies widely depending on energy prices and efficiency, while the importance of the cost depends on the prevailing wholesale price of the finished product. Other factors such as strain choice also have a large effect as well (Arnold 2011). Circa 2012, the average energy expenditure for indoor cultivation equated to approximately one-quarter to one-half of the wholesale price. As energy prices rise and wholesale prices drop (post-legalization) this ratio will become increasingly unfavorable and could even become a factor in the solvency of some producers. Indoor producers have a far more energy-sensitive business model than outdoor producers.

Widespread cultivation in large-scale greenhouses is a relatively recent development. A subsequent analysis of industrial-scale greenhouses found that they, too, are highly energy intensive (Mills 2018), especially if poorly designed and operated. While these “hyper greenhouses” use less energy than windowless facilities per unit floor area, they still require prodigious amounts of lighting, cooling, heating, and dehumidification in most climates. As evidence of the issue, cannabis greenhouses are one reason cited for the need to update high-voltage electricity transmission lines in Canada (CBC 2019a). Data published by NFD (2018) found greenhouses in the U.S. to use half the electricity of windowless facilities on a per-square-foot basis, yet, due to their lower yields, they actually required only 25% less energy per unit weight.[8] An important caveat is that the values reported in that study do not include natural gas, which is a common heating fuel for greenhouses while heating in windowless facilities is often provided with electric heat pumps. When including natural gas, an assessment in Canada found that greenhouses used only about one-third less energy than windowless facilities (Posterity Group 2019). The data thus suggest that these greenhouses are anything but “green”, as their energy use per unit floor area still tends to be greater than that of virtually any other commercial building type.

A more recent attempt to estimate national energy consumption demonstrated many of the challenges in deepening the analysis (NFD 2018). Of note, the energy used for outdoor as well as greenhouse operations was usefully contrasted with that of windowless indoor facilities, and that of legal and black-market production estimated separately. The report admirably brought forward more measured data on specific facilities than previously available in the public domain, although the sample was small (only two dozen sites with energy and yield data), self-selected, and self-reported. Almost one third of the sites used LED lights for energy savings, likely far higher than the proportion of sites adopting this technology in the overall marketplace. The analytical scope had narrower boundary conditions (excluding energy sources other than electricity within the facility as well as transportation energy, and cultivation in perhaps more energy-intensive non-industrial settings such as homes and other informal “small-scale” facilities), did not include operations with on-site generators, and was based on a non-randomized sample weighted towards milder climates in the United States. The energy intensity of black-market operations was presumably equated with that of legal operations, embodying an assumption of equivalent efficiencies not verified with actual data. Meaningful direct comparisons to the Mills (2012) study are thus not possible given the narrower boundary conditions and non-representativeness of the sample. The study indicated that some energy-intensity metrics may be improving with the passage of time, as would be expected, although more definitive surveys are sorely needed. Of particular note, the NFD study found roughly a factor of ten variation in key energy intensity metrics (electricity per square foot and per unit of flower yield), indicating enormous non-standardization of existing practices and a correspondingly large potential for energy savings irrespective of historical trends. It is not yet known whether the energy intensity of contemporary legal production facilities is lower or higher than that of black-market operations.

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While it is encouraging to observe a variety of organizations developing environmental product labeling for cannabis, the methodologies often lack transparency and there is little or no direct

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[8] Average reported values were 0.79 grams of dried flower yield per kWh for indoor facilities and 1.07 grams/kWh for greenhouses. Values elsewhere in the NFD report suggest the greenhouses were even less favorable.

recognition of excellence or penalties for underachievement. Organizational factors create real or perceived conflicts of interest (financial dependence on the industry and users of the product being evaluated, lack of an independent watchdog, and a chronic tension between profit or market share and rigor which can result in the dilution of standards). It has been reported that growers will "shop" for certifications that put their product in the best light (Bennett 2019).

Consumers are largely unaware of the energy and environmental impacts of indoor cultivation. It is notable that the "ethical purchasing" movement (consumers seeking to vote with their dollar, e.g., to promote sustainable products) has barely emerged in the cannabis marketplace and, perhaps fearing stigmatization, environmental organizations have conspicuously sidestepped the issue (Bennett 2019). Moreover, cannabis dispensaries have been found to be unreliable sources of information on environmental issues associated with the products they sell and existing sustainability certifications for cannabis are underdeveloped, vulnerable, and lack credibility (Bennett 2017; Bennett 2020, in this volume). Consumers thus operate in an information environment that impedes good purchase decisions.

All told, the CO_2 emissions of the *average* cannabis user ranges from 16% of their total household carbon footprint in Rhode Island (the state with the nation's lowest consumption rate) where cannabis availability is highly limited to 59% in Colorado (the nation's highest consumption rate) where it is pervasive. Put differently, the per-capita emissions are equivalent to that from powering two high-efficiency refrigerators in Rhode Island and nine in Colorado.[9]

Many externalities add to the social and environmental costs of indoor cultivation

In addition to the policy community's need to better understand facility-scale energy use cannabis operations are various externalities (side effects not reflected in the prices of goods sold) that are not often considered or quantified.

These include moisture damage to buildings, nighttime light pollution, power plant emissions and other environmental impacts, power theft, and power outages and other constraints on the broader grid caused by unchecked electrical load growth. As an example of this latter issue, the city of Portland Oregon associated seven power outages over a period of five months with indoor cannabis operations (Pacific Power 2015) and Portland General Electric traced 85% of its residential transformer problems to indoor cannabis growing (Borrud 2015).

In 2010, British Columbia reported that power theft by two thirds of cannabis producers was costing the utility $100 million per year (BC Hydro 2016). At that time cannabis was legal only for medical purposes, and most of the offending facilities were serving the black market.

Unpermitted or uninspected electrical wiring has been the source of a disproportionate number of fires in some localities, and the building stock has been damaged by mold and other

[9] Per-capita cannabis consumption from *MJ Business Daily* (https://mjbizdaily.com/chart-of-the-week-average-annual-mmj-purchases-by-state-vary-widely/). State-specific household emissions from U.S. Department of Energy, Energy Information Administration. Assuming cultivation carbon footprint per Mills (2012).

consequences of raising humidity in buildings not intended for agricultural operations (Fire Chiefs Association of British Columbia 2008; Mills 2012). Massive fires have occurred even in legal facilities (Reuters 2015).

Cultivating cannabis in areas based on hydro power is often touted as an environmentally benign alternative to carbon-based power. However, attention has recently been given to the likely linkages between hydroelectric power production, reduced salmon populations, and starvation issues facing salmon-eating killer whales (*orcas*) in the Pacific Northwest (Mapes 2018; University of Massachusetts 2017). Hydroelectric power also results in more water evaporation than other forms of electricity production.

Adverse public-health considerations and waste-generation from cannabis cultivation merit more analysis

Another form of externality—public health impacts related to energy-intensive cultivation practices—merit close analysis. Cannabis has been widely demonstrated to offer medical benefits under the appropriate circumstances. However, the countervailing health-related dimensions of indoor cultivation—for workers and the general public—have not received much attention, although it is treated elsewhere (Schenker and Langer in this Handbook).

Indoor environmental conditions can be an issue for workers and consumers. For example, while mold is a common risk to product viability for indoor and outdoor cultivators alike, indoor environments can be particularly prone to mold growth that can destroy an entire crop. The risk is especially high during power outages or equipment failures when ventilation and dehumidification processes are interrupted. In another example, doubling or quadrupling of current background carbon-dioxide levels (up to 1500 ppm, to push growth) was once believed to be safe for humans but has subsequently been found to result in CO_2 levels found to significantly reduce nine distinct measures of cognitive and decision-making functioning (Fisk *et al.,* 2013; Allen *et al.,* 2015). Combustion products, such as carbon monoxide, from unvented on-site CO_2 production can also pose health hazards.

Concerns have been raised about the effect of large concentrations of plants in urban areas adversely impacting air quality through their emissions of volatile organic compounds (VOCs). A recent investigation focused on the potential that 600 cultivation facilities within the city of Denver Colorado could double the prevailing levels of VOCs, while air pollution in that city already periodically violates federal limits (Plautz 2019).

More broadly, energy production itself has well-known health consequences, and of course is the primary source of human-generated greenhouse gases which bring their own health impacts. Mills (2012) estimated national greenhouse-gas emissions of 15 metric tons of CO_2 each year from indoor cannabis cultivation across the United States. Outdoor practices can also result in greenhouse-gas emissions from land-use change and use of chemical fertilizers.

Hazardous wastes associated with indoor cultivation are also understudied. The "high-intensity discharge" lamps used for most cultivation contain significant amounts of mercury. The extent of recycling/recovery of this mercury is unknown, and broken lamps introduce mercury into the growing facility in an uncontrolled fashion. More costly LED lights do not contain mercury. However, recycling programs for LED fixtures are not yet in place.

Indoor practices involving hydroponics (or even traditional irrigation) yield contaminated wastewater that may be introduced into or circumvent wastewater systems. Moreover, non-degrading growing media, such as mineral wool that is saturated with nutrient-laden water, is typically sent to landfill after each harvest. We estimate that an operation with 100,000 square feet of canopy requires 14,000 to 34,000 cubic feet of mineral wool per cycle, which would result in the generation of approximately to 85,000 to 200,000 cubic feet of solid waste to landfill over a year with six growing cycles. This results in waste generation of 5- to 11-times the weight of the processed flowers.[10] Recycling of agricultural mineral wool is not currently available in the U.S. Indoor operations also tend not to re-use soils after each growth cycle, which is yet another large source of solid waste.

Energy efficiency and renewable energy are not enough to mitigate the problem

A key challenge intrinsic to the indoor cultivation process, and compounded by seemingly unrelated local ordinances or needs, is that these facilities tend to embody a number of counterproductive design and operational features that make energy use even higher than need be. For example, CO_2 injection requires facilities to be sealed and all air recirculated, which, in turn, boosts energy use significantly. Another example is the sometimes-mandated use of tall opaque walls in front of greenhouses in the name of security which can also block useful sunlight and thus require added electric lighting energy input. Location of these facilities in or near population centers requires high-resistance air filtration to control odor, which, in-turn requires increased ventilation energy to counteract the backpressure caused by the dense filter media. Heat is often run at the same time as air conditioning in an effort to control humidity that can otherwise lead to mold growth. Lastly, local light-pollution ordinances may require that light-deprivation covers be drawn over greenhouses at night (light may be on during that time, e.g., when the days are short or to capitalize on cheaper power rates), which can trap heat and thus require additional cooling energy. Lastly are a host of energy-using technologies to remove mold with UV, treat polluted water, recapture and purify waste water, etc., that are ironically used to improve the "sustainability" of indoor cultivation.

Despite these challenges, the industry has begun to look for efficiencies, likely driven more by the squeeze between falling wholesale prices and rising energy costs than by environmental concerns (Pols 2017). Aside from efficiencies (e.g., energy used per given weight of finished product), it is critical to maintain focus on trends in *aggregate* demand, especially for a growing industry. For example, Colorado reports a startling year-over-year increase of 23% in overall production (Hood 2018) and electricity use increased by 36% annually between 2012 and 2016 (Denver Public Health and Environment 2018). Energy efficiencies cannot improve rapidly enough to offset such growth, and the preceding numbers suggest that energy intensity has actually been increasing. The energy forecasting authority in the Pacific Northwest projects an 82% increase in energy demand despite improving energy efficiency (Jourabchi 2014). A large-

[10] See assumptions below in the discussion of mineral wool embodied energy.

scale energy savings study for the province of Ontario, Canada, found a *maximum technical* potential of only 16% for indoor facilities and 21% for greenhouses (*without* accounting for limited uptake rates or cost-effectiveness) (Posterity Group 2019).

Sleek images of energy-saving LED lights and greenhouses look "green" on the surface, but the devil is in the details. These lighting systems are still quite energy intensive.[11] One experiment found that 780 Watts of LED were needed to replace 1000-1100 watts of traditional lighting (Massoud 2014) in order to maintain yields. Peer-reviewed research dating from the time these alternative lighting sources first started being manufactured suggested that cannabis grown under LEDs may actually take longer to mature and have lower yield and/or potency (Pocock 2015), thus saving little if any energy on a per-weight basis (Nelson and Bugbee 2014). LED performance in these applications appears to be improving, although even more recent studies obtained mixed results (Leichliter *et al.,* 2018). However, product attributes (flower appearance) may be adversely affected by LEDs, which is a palpable market risk for producers. The up-front cost of LED lighting is also vastly higher than conventional lighting, the recovery of which requires a long time-horizon for the facility developer. Although the vast majority of indoor cultivation facility space has been constructed since LED fixtures have been available in the market, adoption rates are probably in the low single-digit percentage range. An in-depth analysis for Canada found that the technical potential energy savings for LED lighting (without regard for cost-effectiveness or limited adoption rates) was only 7% of entire facility-level energy use (Posterity Group 2019).

These barriers notwithstanding, it is certainly possible to construct cultivation facilities with far higher energy efficiencies than is done at present. Indications of these opportunities as applied to the facility envelope and daylighting are provided by Kinney *et al.* (2012).

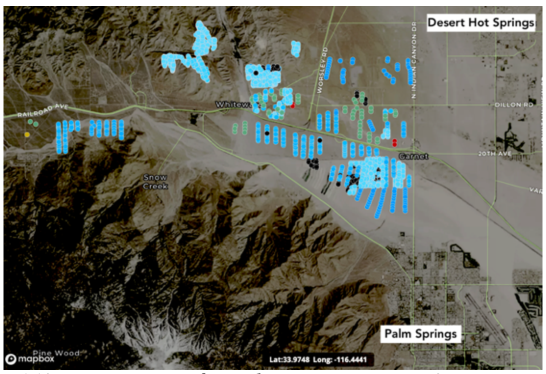
That said, there is a degree of naïve optimism and hubris that cultivators need only "go solar" to solve the problem of any remaining energy requirements after efficiencies have been captured. The feasibility of this has not been demonstrated at scale, probably because the required solar array would need to be many times larger than the roof of the facility, and could not be on the roof at all if a traditional greenhouse design is used. Even in areas with excellent solar availability, only about 5% of a facility's electricity needs could be generated on the roof (Mills 2018). This is even the case for one very large greenhouse-style facility in Southern California. One noted large-scale facility aiming to be as sustainable as possible achieved a solar contribution of about 30% (Daniels 2019), which presumably required using a very large area of land beyond the building footprint. A state-of-the-art facility in Canada is expecting to offset only 8% to 10% of its electricity use by covering its entire roof (CBC 2019b), emitting approximately 9,000 tons of CO_2 per year instead of 10,000 tons without the solar.

While it can be argued that cannabis industry as a whole can, in principle, be powered with centralized renewable energy, the amounts required are prodigious and for practical purposes (e.g., land-use constraints) often limited. Although California's Coachella Valley is one of the largest wind-energy production areas in that state, cannabis production there (assuming business-

[11] One advantage of less-efficient high-intensity discharge lamps is that the heat-producing ballasts can be remoted outside the conditioned space, thereby reducing air-conditioning needs. LED ballasts are integral to the fixture and cannot be remotely located.

as-usual energy efficiencies) will soon eclipse the entire output of all 40 wind-power projects located in the area (Figure 3). Our "bottom-up" estimate is that projects already in operation consume 13% as much as wind energy in the area produces, although other estimates (Daniels 2019) suggest cannabis facilities in the "west side" of Coachella Valley consume 235 megawatts, which is fully 35% the rated capacity of all wind projects in the area. Full build-out of existing cannabis facility entitlements would consume far more: 11-times as much electricity as can be produced by all existing wind systems in the area, and more than all the wind power generated across California. It has taken decades and the dedication of vast land areas to build up this level of wind-generation capacity. From a broader public-policy vantage point, there is an acute shortage of investment in renewable energy infrastructure to offset even existing carbon emissions, let alone emissions growth from new energy-intensive development. This comparison serves as a poignant illustration of the broader problematic tension between advances in renewable energy supply and unbridled growth in energy demand.

2,229 wind turbines in Coachella Valley, CA



663 megawatts of wind power across 40 projects

Large-scale indoor cannabis cultivation

Indoor cannabis cultivation facility, Cathedral City, CA

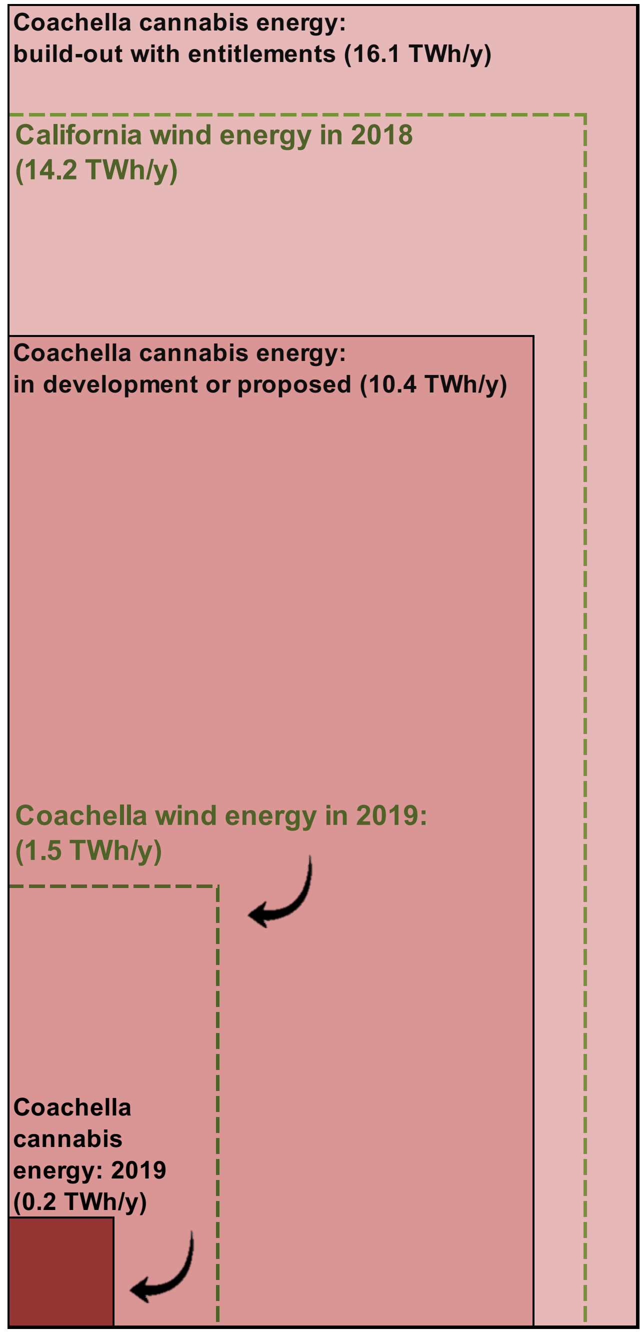


Figure 3. California's Coachella Valley is the site of 10% of the State's wind energy production. Cannabis cultivation facilities already in operation in five cities within the Coachella Valley require 13% of the entire electricity production of the 40 wind energy projects (2,229 turbines) located throughout the valley. This will grow to more than 70% of the area's total wind energy output upon completion of cannabis-facility projects proposed or under development. Full build-out per existing entitlements will consume eleven-times as much power, significantly exceeding the 14 TWh/year generated by wind power in all of California. Sources: photo of turbines from ecoflight.com, with permission; satellite view from USGS (2019); interior of cultivation facility from systemsnspace.com, with permission; Rendering of Venlo-type glasshouse by Sunniva (under construction), with permission.[12]

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[12] Calculation notes: Estimated cultivated area development status in five Coachella Valley cities, based on Simmons (2019), with 350,000 square feet of "canopy" as of April 2019, 19.4 million square feet proposed or under development, and 30 million

Market distortions bolster environmentally detrimental cannabis production practices

Among the fundamental preconditions for "perfect functioning" of markets is a vibrant information environment for all actors. Unfortunately, energy-relevant information in the cannabis industry is incomplete and often incorrect. One long-standing "myth" is that indoor-cultivated cannabis is superior to its outdoor counterpart. This is a commonly held view in the popular culture, and dispensaries are notorious for "bottom-shelfing" outdoor-grown products as inferior and otherwise favoring and steering customers towards indoor-grown products. Industry experts have argued to the contrary (*San Francisco Bay Guardian* 2011).

Economic signals can also distort markets. Energy utilities receive billions of dollars per year from cannabis cultivators. While utilities play a key role in improving energy efficiency in the economy at large (assuming that policymakers ensure that investing in new energy supply is not more profitable than investing in efficient use), utilities benefit far less from outdoor cannabis cultivation and have not been observed to encourage it.

In some areas, indoor cultivators receive the historically low, subsidized electricity prices enjoyed by traditional outdoor farmers (PG&E 2017). Many agricultural customers also receive industrial rates,[13] which are lower than those paid by occupants of other types of buildings (warehouses, data centers, offices, etc.). Subsidies of this sort to indoor growers make them more competitive against outdoor growers while reducing the profitability of making energy efficiency improvements or investment in renewable energy supply.

Conversely, in order to discourage indoor cultivation, some well-intended policymakers have sought to impose extreme electricity surcharges (*The Arcata Eye* 2012). In practice, however, the expected effect could be to merely force relocation. This may "solve" the locality's problem, but does not address global energy concerns and can even push cultivators off-grid and onto even more polluting diesel generators for power.

In other contexts, good public policy has often included financial incentives for energy efficiency (rebates, tax credits, etc.). However, in this context, the greatest possible energy savings can be obtained by shifting to outdoor cultivation. A perspective must be maintained that even super-efficient indoor facilities are highly energy intensive when compared to other building types (imagine the values in Figure 2 being reduced by, say, 75%). Outdoor producers are disadvantaged when their well-funded indoor competitors are subsidized with efficiency incentives such as rebates that are, in turn, paid by consumers through utility tariff "adders" (the traditional way of financing utility rebate programs). Such incentives arguably disrupt market forces that could otherwise lead to reduced energy use.

square feet entitled. Energy intensity is that calculated by Mills (2012). Note that while NFD (2018) cites lower average electricity intensity for some states, their value for the adjacent desert state (Nevada) in their sample is virtually identical to that used here for a California desert location. Wind energy generating capacity values are from USGS (2019) and associated energy production from California Energy Commission (2019a). Average wind energy production rates for 26 projects (475 MW) in the area (2.23 GWh/MW) are applied to the total installed 663 MW for the area to estimate total electricity production.

[13] See https://www.eia.gov/todayinenergy/detail.php?id=16231

Investor roles in indoor operations also have an impact. Enormous cash infusions following initial public offerings of stock can disincentivize efficiency, particularly if investors are unaware of best practices or unequipped to evaluate the adequacy of cultivation practices. Losses arising from inefficiency of energy use (or other inputs) can be camouflaged by lack of transparency, investor ignorance of energy engineering, and the willingness of investors to infuse more capital if there are shortfalls. An example of this is Canopy Growth Corporation, who, despite shrinking gross margins and being unable to post a profit from their primarily indoor-cultivation-based business was still able to attract a $4 billion investment from Constellation Brands (Alpert 2019). Compounding these problems, cultivation-facility investors tend not to have the time horizons needed to amortize energy efficiency or renewable energy investments.

The current policy environment increases the energy use of cannabis cultivation

Prohibition was previously blamed for the environmental impacts of cannabis cultivation, but the reality is far more complicated (Vitiello 2016). Indeed, owing to the lack of coordination between cannabis policy and environmental policy, decisions are inadvertently being made in the post-prohibition era that are compounding the energy problem.

That said, there are ample reasons to pursue regulation. For example, historically, some black-market growers have been rumored to leverage the fact of their undocumented income to take advantage of low-income electricity tariffs. This not only created an unintended cross-subsidy from other ratepayers, but the low rates also reduced their incentive to invest in energy efficiency or shift cultivation outdoors.

Local control of cannabis market regulation (e.g., at the city or county level) can lead to perverse outcomes that distort broader market conditions. For example, as noted above, the Coachella Valley in southern California has become a major hub of production due to the absence of caps on facility size, local efforts to promote the industry, and a generally permissive regulatory environment. Conversely, local ordinances set a very large minimum size for facilities at five acres (over 200,000 square feet) (Maschke 2018). As a result, very large-scale indoor cultivation is taking place in this extremely hot region, requiring far more air conditioning and ventilation than in climates more naturally suited for cultivation. An engineer working in the area is quoted as estimating that cannabis cultivation facilities use about 25-times as much energy as a “standard industrial” development (Daniels 2019).

Perversely, there are many reports of localities banning outdoor cultivation as part of their legalization process, examples of which are Nevada County, California (Riquelmy 2016) and the entire state of Illinois (Thill 2019). Regulations also require all production to occur indoors in Canada (CBC 2019b). These measures are presumably taken with security in mind. Yet, if giant internationally sanctioned opium poppy plantations for pain-management drugs can be secured outdoors (Bradsher 2014), surely cannabis farms can do so as well. Other localities stipulate equal limits to the allowable cultivation area for indoor and outdoor cultivation, thus strongly biasing choices towards energy intensive indoor operations where more crops can be produced each year.

Local officials and others have cited the odors arising from outdoor cultivation as a significant problem, and suggest the activity be restricted to indoor facilities (Johnson 2019). This of course also entails the implementation of high-resistance air filters for odor control which, as noted above, increase ventilation energy needs.

Once indoor cultivation is endorsed (or mandated), it becomes incumbent on policymakers to ensure that the resultant energy use is not excessive. Virtually all building types and the equipment in them are subject to energy codes and standards in the United States, yet comprehensive ones appropriate for cannabis cultivation facilities have not been promulgated and the supporting research essential for standards analysis has not been conducted. Massachusetts is among the early states to grapple with this. The state has determined that a single (massive) indoor cultivation facility could result in an increase in lighting demand equal to the energy saved over many years by the state's effort to convert over 130,000 streetlights from conventional high-intensity lamps to LEDs.[14] However, the state's efforts at setting energy standards have been clumsy, e.g., seeking to specify wattage limits on individual light fixtures, which could easily result in operators installing more fixtures than would otherwise be the case (Davis 2019a).

In another example of unintended energy consequences, mandatory product testing--which is certainly a potentially appropriate policy intervention—can uncover long-standing practices that yield unacceptable contamination levels in the final product. Tainted cannabis products must be destroyed, thus entailing all associated energy to be reallocated to materials that pass testing. The safety thresholds stipulated by the regulations are not necessarily based on scientific study, and nor are they consistent with standards for other consumer products. For example, there are no standards or testing for heavy metals in tobacco, despite it being known to contain them, yet testing is done at the parts-per-billion level for cannabis. Researchers have described the lack of studies on the health risks of heavy metals in tobacco (Caruso *et al.,* 2014).

Some previously black-market cultivators have found the new permitting processes under legalization to be onerous and so time-consuming that they cannot transition their businesses to the regulated market. This already appears to be having the effect of driving some legal producers back to the black market, and thus away from access to policy inducements for environmentally improved practices. As of April 16, 2019, roughly 3,000 temporary cultivation permits had expired and the California Department of Food and Agriculture (CDFA) had issued only 62 annual licenses and 564 provisional permits. Reports indicated that less cannabis was sold (legally) in the year after recreational laws went into effect than before (Fuller 2019). As an indicator of the size of the black market, the most recent official estimates of California's cannabis production, a report published in 2018 by the California Department of Food and Agriculture, showed the state producing as much as 15.5 million pounds of cannabis and consuming just 2.5 million pounds (ERA Economics LLC 2017). The balance is presumably illegal export to areas where prevailing retail prices are higher.

Even where states legalize cannabis cultivation, localities can thwart implementation, further reinforcing black-market activity. For example, there are many counties in California where a

[14] Cannabis Energy Overview and Recommendations, MA Department of Energy Resources Energy and Environmental Affairs, 2/23/18, slide 6.

public majority voted to legalize cannabis yet local government has banned most if not all cannabis-related business activities. According to Schroyer and McVey (2019) only 161 of California's 482 municipalities and 24 of the 58 counties allow commercial cannabis businesses.

A key example of the consequences of a resurgent black market are that off-grid cultivation using diesel generators results in an even higher "carbon footprint" (carbon per unit of electricity produced and consumed) than the electric grids in many areas -- e.g. 2.5-times higher in the case of California (Mills 2012).

Relevant to indoor and outdoor cultivation alike, cannabis regulatory practices also counterproductively influence transportation energy use. In the California regime, for example the product is typically transported at least four times between the point of cultivation and the point of consumption. Regulations require farmers to transport their product to processors, who then transport to distributors, who then transport to dispensaries. Retail consumers then transport the final product from the dispensary. Shipments of only 25 to 40 pounds between farmer and processor are not atypical. The amounts transported become progressively smaller along the supply chain, which multiplies the numbers of trips.

Transport energy notwithstanding, one fundamental policy barrier to reducing energy use is restrictions on interstate commerce. A comparison of electricity use per unit yield in seven states found a variation of 3.4-fold and that for greenhouse-gas emissions of 26-fold, and this did not include the full range of climate severity or power plant emissions factors seen across the whole country (NFD 2018). Were the nation's supply of cannabis grown in climatically benign locations, energy use would be vastly reduced as would pressures to grow indoors.

The case of California: A cannabis-climate train wreck driven by ill-informed policymaking

California is a beacon of progressive environmental thought and has long been an engine for innovative environmental technologies and policies. State legislators have passed some of the most far-reaching climate change policies and targets in the world, notably the California Global Warming Solutions Act of 2006 (SB-32), designed to reduce statewide greenhouse-gas emissions to a level 40% below 1990 levels by the year 2030.[15]

Yet, the regulatory structure established for the cannabis industry now works at cross-purposes to these overriding goals (Mills 2019). Seemingly prior to any rigorous analysis of energy impacts, the state dictated that indoor cultivation was integral to the broader goal of legalization, creating a preordained legal "purpose" that cannot be questioned by subsequent environmental considerations. This binding purpose led to the explicit rejection of "environmentally superior" outdoor cultivation alternatives identified in the official Environmental Impact Report (EIR), despite a recognized lack of data that precluded more than cursory quantitative environmental impact analysis.

The EIR takes several leaps of faith to conclude that the legalization program will be "beneficial" to attaining the State's greenhouse-gas emission reduction goals. They achieve this

[15] https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB32

feat by assuming, remarkably, that overall cannabis production levels will not rise materially following legalization, while the legal fraction of production will increase from approximately 5% to 10% of statewide totals (the rest remaining in the black market) and that this increment will automagically conform with the state's SB-32 emissions-reduction target thus rendering aggregate emissions slightly lower than without legalization.

The net effect of these machinations—juxtaposed with the market and policy failures outlined earlier in this chapter, particularly the forcing of indoor cultivation in many local jurisdictions—is that California has thus far failed to grasp a rapidly closing window of opportunity to manage energy use and greenhouse-gas emissions from the cannabis industry. Few localities have made efforts to manage energy use and emissions (California Department of Food and Agriculture 2017). A limited building energy standards-setting process is slowly being explored, but the earliest date for possible implementation will be 2022 – a full 25 years after the state's initial legalization of cannabis for medical use (California Energy Commission 2019b).

A large research vacuum remains

Although it has been many years since the energy issues of cannabis cultivation were first identified (Mills 2012), very little subsequent research has been conducted and thus policymaking proceeds in an information vacuum. Contributing to this problem, the cannabis industry and energy suppliers are not always forthcoming with information about current practices, and are selective about what they do release. Early work pointed out the need for open-source energy benchmarking using measured data (Mills 2012). Some studies have come forward with information of this sort, often with small samples limited to a certain region or type of cultivation (e.g., County of Boulder 2017) while other efforts are pooling and standardize the information, although based on self-selected participants and limited public access to the data.[16] Also needed are improved estimates of market-scale drivers (numbers and types of cultivation facilities, consumption trends, etc.) Much more data (and modeling) are needed to get a strong handle on trends in national energy use associated with indoor cannabis production, and to understand the potential for improved energy efficiency and greenhouse-gas reductions. More broadly, measured data alone does not help improve efficiency unless it compels the adoption of improved practices and technologies.

Among the critical technical questions remaining unanswered:

Are newer large industrial-scale facilities more or less energy efficient than traditionally smaller indoor cultivation practices?

> No definitive data have been presented in answer to this question. On the one hand, more efficient heating and cooling systems can be expected, but on the other hand higher ceilings and wider lanes for vehicles and equipment result in far greater volumes of air needing to be space-conditioned. Pressure for maximum yields, which includes six or more crops per year, may also entail greater aggregate energy inputs but less per final unit weight.

[16] See https://powerscore.resourceinnovation.org

How much energy is used in manufacturing extracts and other derivative products?

These processes can be energy intensive, involving equipment that creates high pressures and temperatures, post-processing, etc. In some cases, raw materials are frozen and stored prior to extraction, using added energy. Freezing becomes more likely when there is oversupply or inertia in bringing fresh product to market due to over-production or policy obstacles.

What is the added water burden of indoor cultivation?

Conventional wisdom is that less direct irrigation water is needed for indoor cultivation, thanks to reduced evaporation. However—and of particular relevance to the many drought-stricken parts of the country—the massive amounts of water steadily evaporated from dams and cooling towers while producing the electricity destined for indoor cultivation facilities vastly exceeds the direct agricultural water needed to grow outdoors. Based on a rule-of-thumb of one gallon of water per plant per day and the water intensity of US average electricity production at the electricity intensities of Mills (2012) and seven liters of cooling water per kilowatt-hour (per Torcellini *et al.,* 2003), indoor cultivation indirectly consumes about 18-times as much water (~1300 gallons per plant) as the amount used for direct irrigation. Amounts will vary locally depending on practices and electric generation mix in the grid. Ironically, the most water-intensive mode of electricity production is otherwise environmentally lower-impact hydroelectric power. Meanwhile, the greenhouse-gas emissions associated with the electricity used to power indoor grows are fueling future droughts.

How much energy and emissions are embodied in inputs, equipment, and facilities used for cultivation?

The energy use in making soils (or single-use growing media), soil amendments, and pesticides for cannabis production has not been quantified. Nor has that for constructing facilities and the mechanical equipment that goes into them. Soils or other growing media are typically discarded after each indoor growing cycle, making this an ongoing stream of solid waste and embodied energy. As an illustration, we estimate that the mineral wool often used as a growing media in hydroponic indoor cannabis-cultivation operations increases the overall carbon footprint of the final cannabis product by approximately 5 to 11%, depending on cultivation practices (and likely more given that it is manufactured in areas with substantially higher electricity-related greenhouse-gas emissions than those assumed here).[17] In another example, peat that is mined as a soil amendment destroys an important carbon sink in the environment. Meanwhile, agricultural activities of all kinds consume about a billion pounds of plastic, a petrochemical product, annually in the United States alone (Grossman 2015).

[17] Per Mills (2012), the grid-based electricity related emissions of CO_2 are 8.1 kg CO_2 per square foot for each indoor cannabis growth cycle. Per Bribian *et al.,* (2010), the lifecycle emissions of mineral wool are 1.511 kg CO_2 per kilogram for average European conditions. This emissions factor depends heavily on electricity generation mix. A value of 2.736 was determined by Aivazidou (2013) for conditions in Greece (where the electric system is heavily dependent on lignite coal). Much U.S. manufacturing occurs in Mississippi and West Virginia, where electricity-related CO_2 emissions are much higher than U.S. averages, which, in turn, are substantially higher than European-average emissions upon which Bribian *et al's* analysis is based. Mineral wool usage calculations are based on specific weight of 1.8 kg per cubic foot of mineral wool (per Grodan manufacturer's specs) and a range of material use in cultivation of 0.14 to 0.34 cubic feet (0.26 to 0.61kg) per square foot of growing area per growing cycle. This yields 0.38 to 0.92 kgCO_2/sf-cycle, or 5 to 11% of the energy-related emissions. This analysis generously assumes that yields are two pounds per light per cycle in industrial grow operations.

How much transportation energy is involved, and how can that be minimized?

The smaller the quantity of cannabis transported the greater the per-unit transportation emissions. In the original 2012 study (Mills 2012), transportation energy amounted to about 15% of the total carbon footprint. Vertically integrated operations (with co-located production, processing, and retail) may well reduce transportation energy requirements.

What is the ongoing role of black-market cultivation, which escapes statistical records?

There is a tendency to assume that with legalization "all" production shifts to a new footing. In practice black-market cultivation persists, and may well have a distinctly different energy and carbon profile than industrialized operations. Misdirected policy measures appear to be *enlarging* the black-market share of total production, which escapes regulation altogether. In California, for example, permitting has resulted in large amounts of paperwork and long periods of suspended operations. Fees in that state for a "medium" indoor facility (10,001-22,000 square feet) can be $80,000 per year, which can discourage participation in the regulated market. NFD (2012) estimates that black-market operations are still responsible for three-quarters of the energy used nationally. Non-uniform policy among the states is a significant driver of the black market, which fosters illegal transportation to states without legalization.

How much energy is embodied in producing cannabis products that never reach market?

The cannabis industry has been engaging in overproduction. Recent reports from Canada indicate extraordinary levels of overproduction, with only 4% of cannabis produced there reaching the market (McBride 2019). Technical problems during cultivation cycles (temperature excursions and mold outbreaks) can result in crop losses, and, for black market actors, interdiction also results in product not reaching the market. Product failing quality testing must be destroyed. The additional energy consumption associated with these factors has yet to be estimated but could be very significant.

Policy solutions

Previously, most policymakers' focus on the environmental impact of cannabis has been centered on outdoor cultivation, and even those efforts have been deemed highly inadequate by some observers (Carah *et al.,* 2015). The past California Lieutenant Governor's 2015 report on the topic doesn't once mention energy considerations (Blue Ribbon Commission on Marijuana Policy 2015).

Solutions to the problems of indoor cultivation must begin with earnest policymaker engagement. Sadly, as leading promulgators of energy R&D and policy at the national level, the U.S. Department of Energy and the U.S. Environmental Protection Agency, federal entities with decades of jurisdiction and creative work on energy efficiency through all segments of the economy, remain silent on the topic. Due to absence of legalization at the federal level, these agencies even back away from research on issues that could have significant public health and welfare implications (Plautz 2019). Moreover, vanishingly few policymakers at the state level, even in states with varying degrees of legalization, have embraced the issue. Notable exceptions are Massachusetts and Illinois, which have taken initial steps, although the quality of the outcomes is uncertain.

Following are some key research needs in the policy sphere.

Gather and publish more representative and useful energy data. A start has been made on collecting measured data for actual facilities, but it is far from being representative of the market or having the resolution necessary to evaluate specific regions, cultivation practices, or facility types. It is essential to have third-party quality control and to ensure that these data are unbiased. An acute challenge here is that energy data in this industry—as for any energy-intensive industry—is regarded as highly proprietary. Producers as well as utilities are reluctant to disclose information. Lessons may be taken from the IT sector, in which there is now ample transparency of energy use in data centers and other high-tech facilities, despite prior concerns about the sensitivity of this information. In any case, raw data on energy use doesn't in and of itself identify rates of adoption of efficient technologies, best practices, or help facilities know how to improve. Action-oriented benchmarking can achieve these latter objectives (Mills 2015).

Improve transparency. Mandatory disclosure of total energy use as well as efficiency metrics for many types of non-residential buildings is becoming widespread nationally,[18] but the cannabis industry has thus far been passed over by these initiatives. Disclosure of this information could fill information voids that currently impede sound decision-making on the part of investors, energy companies, local authorities, cultivators, and consumers. More transparency regarding the role of energy expenses in business cost structures can help identify inefficiencies that foster energy waste, as well as help to develop best practices. Cultivators are typically required to report plant counts, the number of cropping cycles and the total amount harvested from each crop. Requiring cultivators to report the facility type and equipment deployed during each cropping cycle along with the aggregate energy used as well as energy per unit crop finished weight could provide additional valuable data for policy analysts.

Create an improved consumer information environment. Policy attention should be placed on consumer education and improved credible product labeling to enable more informed consumer choice and guard against the greenwashing that is today prevalent. Prior to distribution, producers are generally required to submit their products for testing and to make some of that information available to consumers through product labels. It would be a benefit to consumers to also have information regarding the methods used to produce the products and the associated carbon footprint. Dispensaries have a key role to play in this process and can help encourage energy efficiency by educating customers and promoting products that are produced using the most environmentally benign methods.

Eliminate anti-competitive market distortions. Subsidies to indoor cultivators (grants, tax credits, energy rebates, etc.) mask price signals intended to help markets function correctly. Awarding preferential electricity tariffs or cash incentives for new equipment disadvantages outdoor growers who have a vastly lower carbon footprint. Subsidies of all forms should be eliminated when they result in added energy use. Alternatively, it has been proposed that instead

[18] See https://database.aceee.org/state/building-energy-disclosure

of utilities providing financial incentives to "efficient" indoor growers, that they incentivize outdoor cultivators, which achieves the greatest energy savings (Davis 2019b).

Allocate a portion of licensing fees to help address externalities. Licensing fees for indoor operations are often higher than those for outdoor operations. This "signal" could be further improved by incorporating some fee-proportionality to energy intensity, with an appropriate portion of resulting fees reinvested in improving energy efficiency. Note that there is a tremendous loophole in the current California license fee structure: greenhouses regardless of how many supplemental lights they incorporate, are virtually exempt from indoor cultivation fees, yet, as noted above, their energy use is prodigious.

Develop science-based product-testing standards. To minimize unnecessary destruction of energy-intensive finished products, more effort is needed to ensure that required residue levels are realistic and in line with other consumer products such as tobacco and alcohol. Rather than requiring immediate destruction of products, quarantined products should be remediated where possible. Methods such as advanced distillation and micro-filtration have been used to remove pesticides, heavy metals and mold contaminants.

Conduct market-relevant publicly funded R&D. Public-sector R&D has a long and successful track record of compensating for market failures where private industry does not independently pursue technological pathways that are in the broader public interest (Mills 1995). Where there is lack of political will to mandate that all production be conducted outdoors, R&D can inform strenuous interventions to address the damage of any compromise position. These include better engineering and design tools for designers, labeling of energy using componentry, mandatory disclosure of energy use, and mandatory efficiency standards. Other promising avenues include plant genetics to minimize energy (and water) requirements, development of large-scale energy benchmarking and disclosure initiatives, impartial technology assessments, and peer-reviewed best-practice guidelines.

Where policymakers insist on subsidizing indoor growers – to the anticompetitive disadvantage of outdoor growers – the thresholds for eligibility should be uncompromising. Arguably, only "Net Zero" facilities, i.e., those that generate all energy on-site with zero-carbon methods (typically solar photovoltaic cells) should be allowed. Hundreds of net-zero non-residential buildings have been constructed around the country (NBI 2018), but there is no evidence that this has been done for cannabis production.

Conclusions

Cannabis policy and environmental policy must be harmonized. Until then, some of the nation's hardest-earned progress towards climate change solutions is at risk as regulators continue to ignore this industry's mushrooming carbon footprint. Thanks to this inattention, producers have enjoyed a climate-change double standard (and lack of support) while being passed over by a host of policies and programs successfully improving energy efficiency and deploying renewable energy into virtually every other segment of the economy.

Those citing climate pollution as a reason not to legalize cannabis are missing the point: legalization is necessary—but not sufficient—for addressing the problem. Yet, if done poorly, legalization can make the problem worse. Indeed, history may judge today's cannabis policymakers as betraying the public trust by enabling an industry with such a large carbon footprint.

Many are eager to see an industry more forthcoming about its carbon footprint and one that signals more hands-on interest in managing it and raising consumer awareness. A key factor in this process is individual consumer choice and expectations, which sends signals back to the market that ultimately help shape production choices and processes.

The continuation of indoor cultivation does not appear to be defensible on energy and environmental grounds. It can be argued that energy use can be reduced with large investments in energy efficiency or offset with renewable energy generation. However, this is an optimization of a suboptimal activity. These resources could be used more productively in other arenas where essentially zero-energy methods (e.g., outdoor cultivation, which has met humankind's needs for thousands of years) are not available. Even with zero-net-energy indoor practices, other issues such as mercury in lighting, embodied energy in buildings and equipment, water use, and solid waste production remain concerns. Meanwhile, zero-net-energy cannabis production facilities have not been demonstrated, presumably because of the enormous area (and cost) of the required solar arrays.

Proficiency in accomplishing the unnecessary will not yield true sustainability. Myopic optimization of an activity that does not have to be conducted in the first place is not a legitimate response to the very real risks society faces from climate change. The ethical integrity of indoor cultivation—even at the greatest imaginable "stretch" levels of energy efficiency and renewable propulsion—is in question. This is a pressing issue for producers, policymakers, and consumers alike.

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