Chapter 6 Lecture - Depletable Resource Allocation: The Role of Longer Time Horizons, Substitutes, and Extraction Cost

Econ 275 – Environmental Economics

Chapter 6 Lecture - Depletable Resource Allocation: The Role of Longer Time Horizons, Substitutes, and Extraction Cost

A Resource Taxonomy

A resource taxonomy is a classification system used to distinguish various categories of resource availability.

- **Identified resources: specific bodies of mineral-bearing material whose location, quality, and quantity are known from geological evidence, supported by engineering measurements.**
- **Measured resources: material for which quantity and quality estimates are within a margin of error of less than 20 percent, from geologically well-known sample sites.**

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A Resource Taxonomy

- **Indicated resources: material for which quantity and quality have been estimated partly from sample analyses and partly from reasonable geological projections.**
- **Inferred resources: material in unexplored extensions of demonstrated resources based on geological projections.**

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A Resource Taxonomy

- **Undiscovered resources: unspecified bodies of mineral-bearing material surmised to exist on the basis of broad geological knowledge and theory.**
- **Hypothetical resources: undiscovered materials reasonably expected to exist in a known mining district under known geological conditions.**
- **Speculative resources: undiscovered materials that may occur in either known types of deposits in favorable geological settings where no discoveries have been made, or in yet unknown types of deposits that remain to be recognized.**

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A Resource Taxonomy

Classifications of the stock of depletable resources

- **Current reserves are resources that can be extracted profitably at current prices.**
- **Potential reserves are resources that are potentially available. They depend on people's willingness to pay and technology.**
- **Resource endowment represents the natural occurrence of resources in the earth.**

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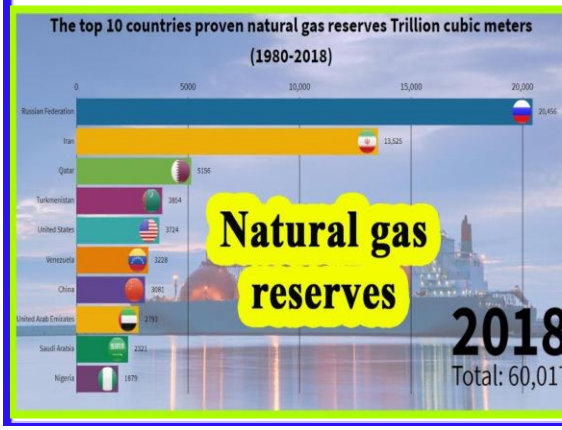
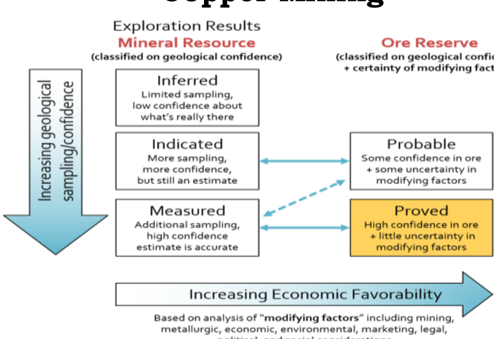


Copper Mining



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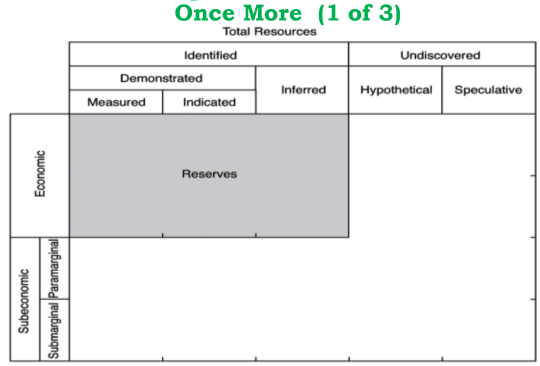
A Categorization of Resources Once More (1 of 3)



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Chapter 6 Lecture - Depletable Resource Allocation: The Role of Longer Time Horizons, Substitutes, and Extraction Cost

A Categorization of Resources Once More (2 of 3)

Terms

Identified resources: specific bodies of mineral-bearing material whose location, quality, and quantity are known from geological evidence, supported by engineering measurements.

Measured resources: material for which quantity and quality estimates are within a margin of error of less than 20 percent, from geologically well-known sample sites.

Indicated resources: material for which quantity and quality have been estimated partly from sample analyses and partly from reasonable geological projections.

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Source: U.S. Bureau of Mines and the U.S. Geological Survey. "Principle of the Mineral Resource Classification System of the U.S. Bureau of Mines and the U.S. Geological Survey," *Geological Survey Bulletin* (1976): 1450-A.

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A Categorization of Resources Once More (3 of 3)

- **Economic:** This term implies that, at the time of determination, profitable extraction or production under defined investment assumptions has been established, analytically demonstrated, or assumed with reasonable certainty (see guideline iii).
- **Subeconomic:** This term refers to those resources which do not meet the criteria of economic; subeconomic resources include paramarginal and submarginal categories.
- **Paramarginal:** That part of subeconomic resources which, at the time of determination, almost satisfies the criteria for economic. The main characteristics of this category are economic uncertainty and/or failure (albeit just) to meet the criteria which define economic. Included are resources which could be produced given postulated changes in economic or technologic factors.
- **Submarginal:** That part of subeconomic resources that would require a substantially higher commodity price or some major cost-reducing advance in technology, to render them economic.

http://www.australianminesatlas.gov.au/aimr/class.html

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A Resource Taxonomy

- **A depletable resource is not naturally replenished or is replenished at such a low rate that it can be exhausted.**
  - **The depletion rate is affected by demand, and thus by the price elasticity of demand, durability and reusability.**
- **A recyclable resource has some mass that can be recovered after use.**
  - **Copper is an example of a depletable, recyclable resource.**
- **A renewable resource is one that is naturally replenished.**
  - **Examples are water, fish, forests, and solar energy.**

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A Resource Taxonomy

- **The potential resources of depletable, recyclable resource can be exhausted.**
- **Not all depletable resources can be recycled or reused.**
- **Storage of renewable resources smoothes out the cyclical imbalance of supply and demand.**
- **Storage of depletable resources extends their economic life.**
- **The management problem for depletable resources is how to allocate dwindling stocks among generations while transitioning to a renewable alternative.**
- **The management problem for renewable resources is in maintaining an efficient and sustainable flow.**

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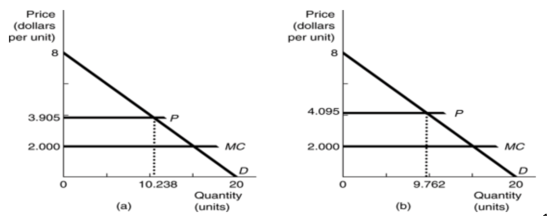
Chapter 6 Lecture - Depletable Resource Allocation: The Role of Longer Time Horizons, Substitutes, and Extraction Cost

Efficient Intertemporal Allocations

The Two-Period Model Revisited

- **Dynamic efficiency is the primary criterion when allocating resources over time.**
- **Recall the two-period model from the last chapter. This model can be generalized to longer time periods.**
- **The marginal user cost for each period in an efficient market is the difference between the price and the marginal extraction cost.**



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Efficient Intertemporal Allocations

The N-Period Constant-Cost Case

- **With constant marginal extraction cost, total marginal cost (or the sum of marginal extraction costs and marginal user cost) will rise over time.**
- **The figure on the next slide shows total marginal cost and marginal extraction cost.**
- **The vertical distance between the two equals the marginal user cost. The horizontal axis measures time.**
- **Rising marginal user cost reflects increasing scarcity and the intertemporal opportunity cost of current consumption on future consumption.**

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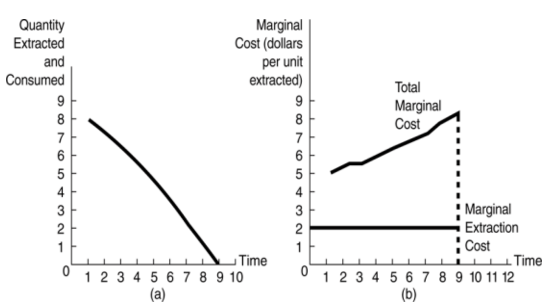
(a) Constant Marginal Extraction Cost with No Substitute Resource: Quantity Profile. (b) Constant Marginal Extraction Cost with No Substitute Resource: Marginal Cost Profile



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Efficient Intertemporal Allocations

- **Once again - The efficient marginal user cost rises steadily to reflect the scarcity and opportunity cost.**
- **As costs rise, quantity extracted falls over time.**
  - **Quantity extracted falls to zero at the point where total marginal cost reaches the maximum willingness to pay (or <u>choke price</u>) for the resource such that demand and supply simultaneously equal zero.**
  - **If $P = 8 - 0.4q$ then you can show if $MC = 8$, $q = 0$.**

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Efficient Intertemporal Allocations

Transition to a Renewable Substitute

- **An efficient allocation thus implies a smooth transition to exhaustion and/or to a renewable substitute.**
- **The transition point to the renewable substitute is called the switch point.**
- **At the switch point the total marginal cost of the depletable resource equals the marginal cost of the substitute.**

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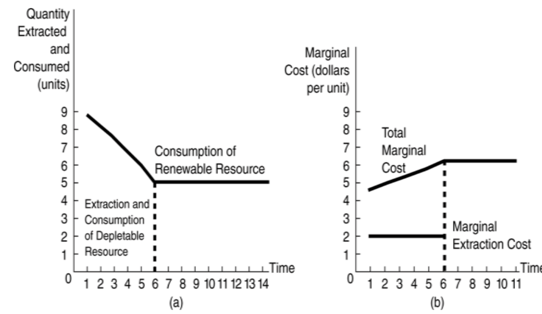
(a) Constant Marginal Extraction Cost with Substitute Resource: Quantity Profile. (b) Constant Marginal Extraction Cost with Substitute Resource: Marginal Cost Profile



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Efficient Intertemporal Allocations

Transition to a Renewable Substitute

- **The transition for two depletables with different marginal costs will also be a smooth one.**
- **The rate of increase of total marginal cost slows down after the time of transition because the marginal user cost represents a smaller portion of total marginal cost for the second, higher cost resource.**

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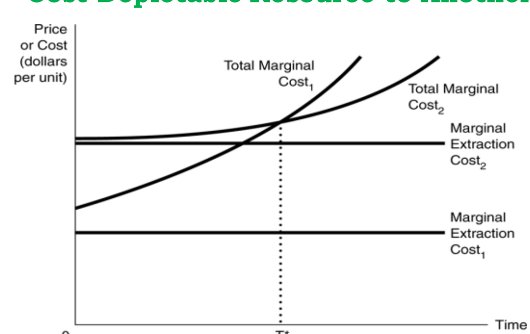
The Transition from One Constant-Cost Depletable Resource to Another



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Efficient Intertemporal Allocations

Increasing Marginal Extraction Cost

- **In this case, the marginal user cost declines over time and reaches zero at the transition point.**
- **The resource reserve is not exhausted.**
- **The marginal cost of exploration can be expected to rise over time as well.**
- **Successful exploration would cause a smaller and slower decline in consumption while dampening the rise in total marginal cost.**

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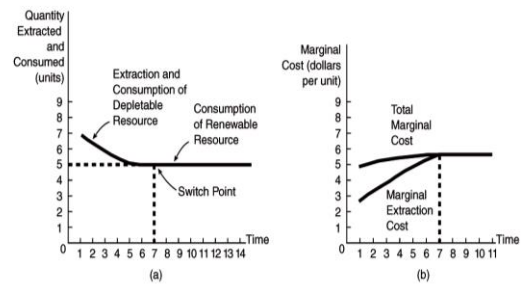
(a) Increasing Marginal Extraction Cost with Substitute Resource: Quantity Profile. (b) Increasing Marginal Extraction Cost with Substitute Resource: Marginal Cost Profile



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Efficient Intertemporal Allocations

Exploration and Technological Progress

- **Technological progress would also reduce the cost of extraction.**
  - **Lowering the future marginal cost of extraction would move the transition time further into the future.**
  - **Total marginal cost could actually fall with large advances in technology**.

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Historical Example of Technological Progress in the Iron Ore Industry

The term *technological progress* plays an important role in the economic analysis of mineral resources. Yet, at times, it can appear abstract, even mystical. It shouldn't! Far from being a blind faith detached from reality, technological progress refers to a host of ingenious ways in which people have reacted to impending shortages with sufficient imagination that the available supply of resources has been expanded by an order of magnitude and at reasonable cost. An interesting case from economic history illustrates how concrete a notion technological progress is.

In 1947, the president of Republic Steel, C. M. White, calculated the expected life of the Mesabi Range of northern Minnesota (the source of some 60 percent of iron ore consumed during World War II) as being in the range from 5 to 7 years. By 1955, only 8 years later, *U.S. News and World Report* concluded that worry over the scarcity of iron ore could be forgotten. The source of this remarkable transformation of a problem of scarcity into one of abundance was the discovery of a new technique of preparing iron ore, called *pelletization*.

Prior to pelletization, the standard ores from which iron was derived contained from 50 to more than 65 percent iron in crude form. A significant percentage of taconite ore containing less than 30 percent iron in crude form was available, but no one knew how to produce it at reasonable cost.

Pelletization, a process by which these ores are processed and concentrated at the mine site prior to shipment to the blast furnaces, allowed the profitable use of the taconite ores. While expanding the supply of iron ore, pelletization reduced its cost in spite of the inferior grade being used.

There were several sources of the cost reduction. First, substantially less energy was used; the shift in ore technology toward pelletization produced net energy savings of 17 percent in spite of the fact that the pelletization process itself required more energy. The reduction came from the discovery that the blast furnaces could be operated much more efficiently using pelletization inputs. The process also reduced labor requirements per ton by some 8.2 percent while increasing the output of the blast furnaces. A blast furnace owned by Armco Steel in Middletown, Ohio, which had a rated capacity of approximately 1500 tons of molten iron per day, was able, by 1960, to achieve production levels of 2700–2800 tons per day when fired with 90 percent pellets. Pellets nearly doubled the blast furnace productivity!

Sources: Kakela, P. J. (1978). Iron ore: Energy labor and capital changes with technology. *Science, 202*(December 15, 1978), 1151–1157; Kakela, P. J. Iron ore: From depletion to abundance. *Science, 212* (April 10, 1981), 132–136.

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Market Allocations of Depletable Resources

Appropriate Property Rights Structures

- **Markets will behave well as long as the property-rights structures governing the resources are exclusive, universal, transferable and enforceable.**
- **A resource governed by a well-defined property rights structure will then have both a use value and an asset value to its owner.**

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Market Allocations of Depletable Resources

Environmental Costs

- **The inclusion of environmental costs would result in higher prices**
  - **Which will dampen demand**
  - **From supply side effect, which causes the transition point to be sooner**
  - **Which effect dominates depends on the shape of the marginal extraction cost curve.**
- **The concept of external environmental costs ties together the fields of environmental and natural resource economics.**

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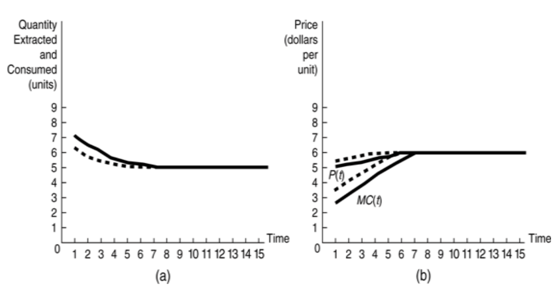
(a) Increasing Marginal Extraction Cost with Substitute Resource in the Presence of Environmental Costs: Quantity Profile. (b) Increasing Marginal Extraction Cost with Substitute Resource in the Presence of Environmental Costs: Price Profile (Solid Line—without Environmental Costs; Dashed Line—with Environmental Costs)



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The Green Paradox

Common sense indicates that when pollution taxes or subsides to promote non-polluting technology are imposed, they would lower emissions and improve welfare. In an intriguing article Sinn (2008) argues that in the case of global warming these demand-reducing policies could trigger (under certain conditions) price effects that could actually reduce welfare. Because this analysis suggests that polices designed to internalize an externality could actually result in lower economic welfare, this outcome was labeled "the green paradox."

The basic logic behind this finding is easily explained in terms of the depletable resource models developed in this chapter. The specific policy case examined by Sinn was a carbon tax rate that rises over time faster than the rate of interest. This carbon tax design changes the relative prices between current and future sales, increasing the relative profitability of earlier extraction. (Remember one reason for delaying extraction was the higher prices extractors would gain in the future. With this specific tax profile the after-tax return is falling, not rising.) This policy would not only change the profit-maximizing extraction profile so that more is extracted earlier, but the present value of net benefits could fall.

Notice that this result depends on *earlier*, not *larger* cumulative damages. In the constant MEC model cumulative extraction (and hence, cumulative damages) are fixed so these polices would affect the timing, but not the magnitude, of the cumulative emissions. In the increasing cost MEC case, however, the cumulative emissions would actually be less; the imposition of the carbon tax would ultimately result in more of the depletable resource being left in the ground.

Is the Green Paradox a serious obstacle to climate policy? The early verdict seems to be no (van der Ploeg, 2013), but the dearth of empirical evidence pointing either one way or the other leaves the door ajar.

Source: Sinn, H.-W. (2008). Public policies against global warming: A supply side approach. *International Tax and Public Finance, 15*, 360–394; van der Ploeg, F. Cumulative carbon emissions and the Green Paradox. *Oxford Centre for the Analysis of Resource Rich Economies Research Paper 110*. University of Oxford Retrieved from www.oxcarre.ox.ac.uk/files/OxCarreRP2013110(1).pdf

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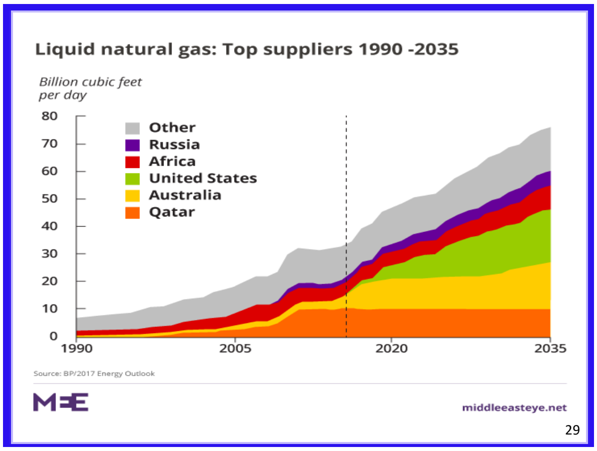
Liquid natural gas: Top suppliers 1990 -2035
Billion cubic feet per day
80
70
60
50
40
30
20
10
0
1990
2005
2020
2035
Other
Russia
Africa
United States
Australia
Qatar
Source: BP/2017 Energy Outlook
middleeasteye.net
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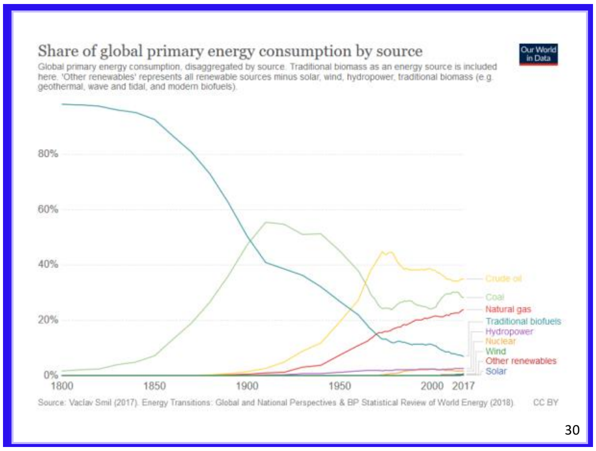
Share of global primary energy consumption by source
Our World in Data
Global primary energy consumption, disaggregated by source. Traditional biomass as an energy source is included here. 'Other renewables' represents all renewable sources minus solar, wind, hydropower, traditional biomass (e.g. geothermal, wave and tidal, and modern biofuels).
80%
60%
40%
20%
0%
1800
1850
1900
1950
2000
2017
Crude oil
Coal
Natural gas
Traditional biofuels
Hydropower
Nuclear
Wind
Other renewables
Solar
Source: Vaclav Smil (2017). Energy Transitions: Global and National Perspectives & BP Statistical Review of World Energy (2018).
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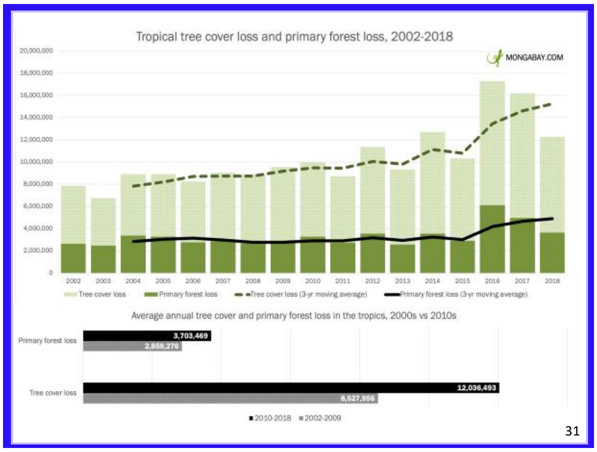
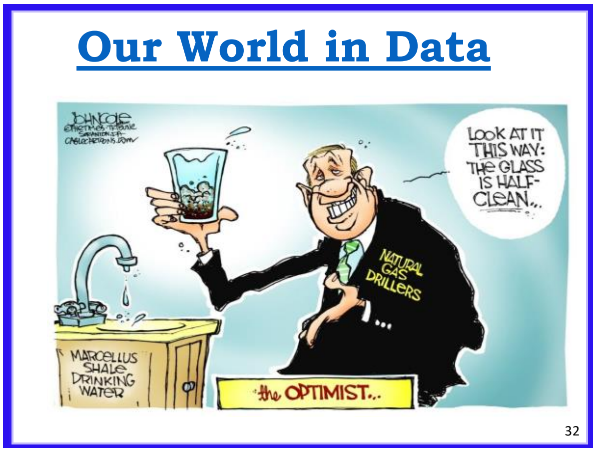

Tropical tree cover loss and primary forest loss, 2002-2018
MONGABAY.COM
20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Tree cover loss
Primary forest loss
Tree cover loss (3-yr moving average)
Primary forest loss (3-yr moving average)
Average annual tree cover and primary forest loss in the tropics, 2000s vs 2010s
Primary forest loss
3,703,469
2,859,276
Tree cover loss
12,036,493
8,527,956
2010-2018
2002-2009
31


Our World in Data
LOOK AT IT THIS WAY: THE GLASS IS HALF-CLEAN...
NATURAL GAS DRILLERS
MARCELLUS SHALE DRINKING WATER
the OPTIMIST...
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