

ENVIRONMENTAL IMPACTS AND MITIGATION STRATEGIES FOR SOLAR ENERGY PROJECTS IN INDIA

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I. INTRODUCTION

Solar energy has emerged as a significant renewable energy source in India, playing a pivotal role in the country's sustainable development. While solar projects offer numerous environmental benefits, they are not entirely devoid of ecological impacts. This chapter aims to explore the environmental effects of solar energy projects in India and propose effective mitigation strategies. The study utilizes a comprehensive review of literature, data analysis, and case studies to assess the current state of solar energy-related environmental impacts and identify viable solutions for minimizing their ecological footprints.

II. BACKGROUND AND SIGNIFICANCE OF SOLAR ENERGY PROJECTS IN INDIA

India's rapid economic growth, coupled with increasing energy demand and concerns over environmental sustainability, has led the country to explore and expand its renewable energy sector. Among various renewable sources, solar energy has gained significant attention due to its abundance and potential to meet the country's growing power requirements.

India is geographically well-suited for solar power generation, with most parts of the country receiving abundant sunlight throughout the year. The solar potential, especially in regions with high solar isolation like Rajasthan, Gujarat, and parts of South India, makes solar energy an attractive option for clean and sustainable electricity generation.

The push for solar energy in India gained momentum with the launch of the Jawaharlal Nehru National Solar Mission (NSM) in 2010. The NSM aimed to promote the development and use of solar energy to reduce dependence on fossil fuels, mitigate greenhouse gas emissions, and improve energy security. The mission set ambitious targets for the deployment of solar power capacity, both grid-connected and off-grid, with the objective of reaching 100 GW of solar capacity by 2022.¹

¹ Atul Sharma, Sanjay Kumar Kar, "Energy Sustainability Through Green Energy", Energy Sustainability Through Green Energy, Springer New Delhi, ISBN: 978-81-322-2336-8, 04 May 2015, <https://link.springer.com/book/10.1007/978-81-322-2337-5>.

Significance

The significance of solar energy projects in India stems from several critical factors:

- **Clean Energy Transition:** Solar energy is a clean and renewable source of power that helps reduce India's carbon footprint and combat climate change. As a signatory to the Paris Agreement, India has committed to reducing its carbon emissions, and solar energy plays a pivotal role in achieving this goal.
- **Energy Security:** India has traditionally relied heavily on imported fossil fuels to meet its energy needs. By harnessing solar energy, the country can enhance its energy security and reduce its dependence on costly and volatile fossil fuel imports.
- **Job Creation and Economic Growth:** The solar energy sector has the potential to create significant job opportunities across the value chain, from manufacturing solar components to project development, installation, and maintenance. This can contribute to economic growth and poverty alleviation.
- **Rural Electrification:** Solar energy is especially advantageous for providing electricity to remote and rural areas, where grid connectivity may be challenging and costly. Off-grid and decentralized solar solutions can bring power to these regions, improving the quality of life and fostering economic development.
- **Distributed Generation:** Solar power allows for distributed generation, wherein electricity can be generated closer to the point of consumption, reducing transmission losses and enhancing grid stability.²
- **Technological Advancements and Innovation:** The push for solar energy has driven technological advancements and innovation in solar panel efficiency, energy storage solutions, and grid integration techniques.
- **Global Leadership:** By aggressively promoting solar energy adoption, India has emerged as a global leader in the renewable energy sector. The country's commitment to solar power has garnered international recognition and cooperation in clean energy initiatives.
- **Meeting Rising Energy Demand:** With a growing population and increasing urbanization, India's energy demand is on the rise. Solar energy can play a crucial role in meeting this demand sustainably.³

Overall, solar energy projects in India are essential for achieving the nation's sustainable development goals, mitigating the adverse impacts of climate change, and

² Atul Sharma, Sanjay Kumar Kar, "Energy Sustainability Through Green Energy", Energy Sustainability Through Green Energy, Springer New Delhi, ISBN: 978-81-322-2336-8, 04 May 2015, <https://link.springer.com/book/10.1007/978-81-322-2337-5>

³ Abdullahi, Dahiru, "A framework for adopting solar energy governance in the Nigerian power sector", Jun-2021, University of Wolverhampton, <http://hdl.handle.net/2436/624227https://wlv.openrepository.com/>.

securing a cleaner and greener energy future. The continued focus on solar energy development aligns with India's commitment to building a resilient and low-carbon economy for the benefit of its citizens and the global community.⁴

III. PURPOSE OF SOLAR ENERGY PROJECTS IN INDIA

- 1. Renewable Energy Transition:** The primary purpose of solar energy projects in India is to facilitate a transition from fossil fuel-based energy sources to renewable and sustainable alternatives. By harnessing solar power, India aims to reduce its reliance on non-renewable resources and decrease greenhouse gas emissions, contributing to global efforts to combat climate change.
- 2. Energy Security:** India's energy security is strengthened through solar energy projects. As a country with significant energy demand, reducing dependency on imported fossil fuels enhances energy independence and stability.
- 3. Environmental Benefits:** Solar energy is a clean and green energy source that does not produce harmful emissions or pollutants during electricity generation. Utilizing solar power helps reduce air pollution, improve air quality, and mitigate the impact of conventional power generation on the environment and public health.
- 4. Rural Electrification:** One of the key purposes of solar energy projects in India is to extend electricity access to remote and rural areas where grid connectivity is limited or absent. Off-grid solar solutions, mini-grids, and decentralized solar installations play a vital role in providing electricity to underserved communities, fostering socio-economic development, and improving living standards.
- 5. Job Creation and Economic Growth:** Solar energy projects create employment opportunities across various sectors, including manufacturing, installation, operation, and maintenance. The growth of the solar industry contributes to economic development and boosts local economies.
- 6. Reducing Energy Costs:** Solar power can help mitigate the impact of rising energy costs by providing a stable and predictable source of electricity. As technology advances and economies of scale improve, solar energy becomes increasingly cost-competitive with traditional energy sources.

IV. SCOPE OF SOLAR ENERGY PROJECTS IN INDIA

- 1. Capacity Addition:** India's solar energy sector has witnessed rapid growth, and the scope for further capacity addition is immense. The government aims to achieve ambitious solar capacity targets, with a focus on both grid-connected and off-grid solar projects.
- 2. Technological Advancements:** The scope of solar energy projects in India extends to leveraging technological advancements in solar panel efficiency, energy storage, and grid

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Id at 3.

integration. Research and innovation in solar technology play a vital role in enhancing the overall efficiency and effectiveness of solar projects.

3. **Distributed Generation:** The scope includes promoting distributed generation through rooftop solar installations, enabling consumers to become prosumers by generating and consuming their solar power. This approach enhances grid resilience and reduces transmission losses.
4. **Policy Support:** The government's commitment to supporting solar energy projects is evident through favorable policies, incentives, and subsidies. The scope lies in further refining and evolving policies to create a conducive environment for the growth of solar power generation.
5. **International Collaboration:** The scope of solar energy projects in India includes collaboration with other countries and international organizations to access funding, technology transfer, and best practices for the development of the solar energy sector.
6. **Sustainable Development:** Solar energy projects align with India's sustainable development goals, ensuring access to affordable, reliable, sustainable, and modern energy for all.
7. **Hybrid Energy Solutions:** The scope extends to exploring hybrid solutions that combine solar energy with other renewable sources, such as wind and storage technologies, to enhance the overall reliability and stability of renewable energy generation.

In conclusion, the purpose and scope of solar energy projects in India encompass a wide range of objectives, from promoting renewable energy and environmental sustainability to improving energy access and driving economic growth. The concerted efforts in the solar energy sector contribute to India's journey towards a greener and more sustainable energy future.

V. ENVIRONMENTAL IMPACTS OF SOLAR ENERGY PROJECTS

Solar energy projects offer numerous environmental benefits compared to traditional fossil fuel-based power generation. However, like any form of energy production, solar energy projects do have some environmental impacts. It is essential to understand these impacts to develop effective mitigation strategies⁵. Here are some of the key environmental impacts associated with solar energy projects:

1. **Land Use and Habitat Fragmentation:** Large-scale solar installations, especially in arid regions, may require significant land area. This can lead to habitat loss and fragmentation,

⁵ Mahesh Kumar, Ch.11 "Social, Economic, and Environmental Impacts of Renewable Energy Resources", Wind Solar Hybrid Renewable Energy System, BoD – Books on Demand, 2020, 1789845904, 978178984590, https://books.google.co.in/books?id=iUP8DwAAQBAJ&dq=Environmental+Impacts+of+Solar+Energy+Projects&lr=&source=gbs_navlinks.

affecting local ecosystems and wildlife. Proper site selection and planning can help minimize the impact on sensitive habitats.

2. **Water Consumption:** Some solar technologies, such as concentrated solar power (CSP), may require water for cooling purposes. In water-scarce regions, this water consumption can strain local water resources. Implementing water-efficient cooling systems or using dry cooling technologies can reduce water usage.

Water consumption and resource depletion are the most significant environmental concerns associated with certain types of solar energy projects, particularly those that rely on water-intensive technologies for cooling and cleaning. The main types of solar technologies that can have significant water usage are Concentrated Solar Power (CSP) and some types of solar photovoltaic (PV) systems. Let's explore these issues in more detail:

- **Concentrated Solar Power (CSP):** CSP systems use mirrors or lenses to concentrate sunlight onto a receiver, producing high temperatures to generate steam and drive turbines for electricity generation.

Some CSP plants use wet cooling systems that require significant amounts of water for cooling the steam in the power generation process.

Water consumption in CSP plants can vary depending on the cooling technology used and the local climatic conditions.

In arid regions where water resources are limited, CSP's water demand can strain local water supplies and impact ecosystems.

- **Solar PV Systems:** Most standard solar PV systems do not require water during their operation, as they convert sunlight directly into electricity without the need for any cooling system.

However, some solar PV technologies, such as certain concentrated PV systems or certain types of solar thermal systems, may use water for cooling purposes, similar to CSP.

3. **Water for Cleaning Solar Panels:** Dust, dirt, and other pollutants can accumulate on the surface of solar panels, reducing their efficiency. Periodic cleaning is necessary to maintain optimal performance.

- **Chemical Use and Pollution:** The manufacturing and disposal of solar panels involve the use of certain chemicals, some of which may be hazardous if not managed properly. Improper disposal or recycling practices could lead to chemical pollution. Implementing responsible recycling and waste management practices is crucial.
- **Greenhouse Gas Emissions:** Solar energy projects themselves do not produce direct greenhouse gas emissions during operation. However, emissions may occur during the

manufacturing, transportation, and installation of solar components. Selecting energy-efficient manufacturing processes and reducing transportation distances can mitigate this impact.

Solar energy projects have relatively low greenhouse gas (GHG) emissions during their operational phase compared to conventional fossil fuel-based power generation. However, it is essential to consider the full life cycle of solar projects, including manufacturing, transportation, installation, and decommissioning, to assess their overall carbon footprint. Here are the implications of solar projects on greenhouse gas emissions and their carbon footprint⁶:

- **Operational Phase:** During the operational phase, solar energy projects generate electricity without emitting greenhouse gases. Solar panels convert sunlight into electricity through photovoltaic or concentrated solar power (CSP) technologies, and this process does not involve the combustion of fossil fuels. As a result, solar projects contribute to reducing the carbon footprint associated with electricity generation, particularly when they displace power from fossil fuel-based sources.
- **Manufacturing and Installation:** The production and transportation of solar panels and other equipment involve energy consumption and greenhouse gas emissions. Manufacturing processes, such as silicon purification and panel assembly, require energy, which, in some cases, is derived from fossil fuels. Additionally, transportation of components to the project site can lead to emissions.
- **End-of-Life Management:** Solar panels have a finite lifespan, typically ranging from 25 to 30 years. After their useful life, panels may require proper recycling or disposal. Inefficient recycling processes or improper disposal can result in additional emissions and environmental impacts.
- **Carbon Payback Time:** The "carbon payback time" refers to the period it takes for a solar project to offset the greenhouse gas emissions generated during its manufacturing, transportation, installation, and end-of-life phases. This timeframe depends on various factors, including the energy intensity of manufacturing and the solar project's electricity generation efficiency. Generally, solar projects have a relatively short carbon payback time, ranging from a few months to a few years.
- **Carbon Footprint Comparison:** Solar energy's carbon footprint is significantly lower than conventional fossil fuel-based electricity generation. When compared to coal, natural gas, or oil-fired power plants, solar projects typically have much lower lifecycle emissions per unit of electricity generated.

⁶ "Life Cycle Greenhouse Gas Emissions from Solar Photovoltaic", National renewable energy laboratory, Nov-2012 , www.nrel.gov/harmonization, nrel.gov/docs/fy13osti/56487.pdf.

- **Renewable Energy Integration:** Solar energy projects can complement other renewable energy sources, such as wind and hydropower, by diversifying the energy mix and reducing overall emissions from the power sector.⁷
- **Climate Mitigation and Adaptation:** By displacing fossil fuel-based electricity generation, solar projects play a crucial role in mitigating climate change by reducing carbon dioxide and other greenhouse gas emissions. This helps India in fulfilling its commitments under international climate agreements like the Paris Agreement.
- **Technology Advancements:** Advancements in solar technology and manufacturing processes, along with increased adoption and economies of scale, continue to improve the efficiency of solar projects and further reduce their carbon footprint.

In conclusion, while solar energy projects have some greenhouse gas emissions associated with their life cycle, their overall carbon footprint is significantly lower than conventional fossil fuel-based power generation. Solar projects contribute to mitigating climate change, reducing carbon emissions, and moving India towards a more sustainable and low-carbon energy future. However, ongoing efforts to improve manufacturing efficiency, recycling practices, and renewable energy integration can further enhance the environmental benefits of solar energy projects.

4. **Soil and Air Pollution during Construction:** Construction activities for solar projects can lead to soil erosion and air pollution due to dust and emissions from construction equipment. Proper erosion control measures and the use of cleaner construction equipment can minimize these impacts.

Solar energy projects generally have lower soil and air pollution impacts compared to conventional fossil fuel-based power generation. However, certain aspects of solar energy projects can still contribute to environmental pollution, albeit to a lesser extent. Here's an overview of the soil and air pollution implications of solar energy:

- **Soil Pollution: Manufacturing and Waste Disposal:** The production of solar panels involves the use of various chemicals and materials, some of which can be hazardous if not managed properly. Improper disposal or recycling of old or damaged panels could lead to soil contamination.⁸
- **Construction Activities:** During the construction phase of solar projects, there may be soil disturbance and erosion due to land clearing, grading, and foundation installation. Proper erosion control measures can help minimize soil pollution.

⁷“Life Cycle Greenhouse Gas Emissions from Solar Photovoltaic”, National renewable energy laboratory, Nov- 2012

www.nrel.gov/harmonization, nrel.gov/docs/fy13osti/56487.pdf.

⁸“Global assessment of soil pollution: Report. Rome”, *FAO and UNEP. 2021, Food and Agriculture Organization of the United Nations (FAO) or United Nations Environment Programme (UNEP), ISBN 978-92-5-134469-9, https://doi.org/10.4060/cb4894en*

- **Spills and Leaks:** Accidental spills of chemicals or lubricants used during maintenance or cleaning of solar panels can result in soil pollution if not promptly and adequately addressed.
- **Air Pollution:** Manufacturing Emissions: The manufacturing of solar panels and related equipment may emit greenhouse gases and air pollutants, depending on the energy sources used in the production process.
 - **Transportation Emissions:** Transportation of solar panels and components from manufacturing facilities to project sites can contribute to air pollution due to vehicle emissions.
 - **Construction Emissions:** During the construction phase, emissions from construction machinery and equipment can temporarily impact local air quality.
 - **Visual and Aesthetic Impact:** Large solar installations, particularly in scenic areas, may raise concerns about visual and aesthetic impacts. Effective landscape design and community engagement can help address these concerns.
 - **Biodiversity and Wildlife Disturbance:** Solar installations can alter local ecosystems and disturb wildlife habitats during construction and operation. Implementing measures such as wildlife corridors and habitat restoration can support biodiversity conservation.
 - **End-of-Life Management:** Solar panels have a finite lifespan, and their end-of-life management is crucial to avoid potential waste issues. Developing efficient recycling systems for solar panels can minimize waste and resource depletion.

It is important to note that many of these environmental impacts can be effectively mitigated through proper planning, technology advancements, and adherence to best practices. Additionally, compared to the environmental impacts associated with conventional fossil fuel-based power generation, solar energy remains a far cleaner and more sustainable alternative.

As the solar industry continues to grow, stakeholders must remain committed to minimizing these environmental impacts through responsible and sustainable practices. By adopting eco-friendly technologies, enhancing recycling and waste management, and integrating solar projects thoughtfully into the landscape, the environmental benefits of solar energy can be maximized while mitigating its potential adverse effects.

VI. MITIGATION STRATEGIES FOR SUSTAINABLE SOLAR ENERGY PROJECTS

Mitigation strategies play a vital role in ensuring that solar energy projects are environmentally sustainable and socially responsible. Implementing these strategies can help minimize the potential negative impacts and maximize the overall benefits of solar energy. Here are some key mitigation strategies for sustainable solar energy projects:

1. Site Selection and Planning:

- Choose project sites that have minimal environmental and social impacts, avoiding ecologically sensitive areas and habitats.
- Conduct thorough environmental assessments and consider local stakeholders' input during the site selection process.
- Engage with local communities to understand their concerns and incorporate their feedback into the project planning.

2. Energy Efficiency and Technology Advancements:

- Emphasize the use of energy-efficient solar technologies and equipment to maximize electricity generation efficiency and reduce resource consumption.
- Encourage continuous research and development to improve solar panel efficiency and reduce the carbon footprint of manufacturing.

3. Water Management:

- Adopt water-saving technologies and strategies to minimize water consumption, especially in water-intensive solar technologies like Concentrated Solar Power (CSP).
- Implement rainwater harvesting and water recycling systems to meet water needs for solar project operations.

4. Biodiversity Conservation:

- Integrate biodiversity conservation into solar project planning by preserving and restoring native vegetation and wildlife habitats.
- Create wildlife corridors and green spaces around solar installations to support local ecosystems.

5. Waste Management and Recycling:

- Develop efficient recycling and end-of-life management programs for solar panels and components to reduce waste and minimize environmental impacts.
- Promote the use of eco-friendly materials in solar panel manufacturing.

6. Community Engagement and Benefit Sharing:

- Involve local communities in the decision-making process and provide them with fair compensation and benefits for hosting solar projects.
- Invest in local capacity building and skill development to ensure community participation in the solar energy value chain.

7. Regulatory Compliance and Monitoring:

- Adhere to all environmental regulations and standards throughout the project lifecycle.
- Establish robust monitoring and reporting mechanisms to track and address any environmental impacts.

8. Renewable Energy Integration: Explore hybrid energy solutions that combine solar with other renewable energy sources, such as wind or energy storage, to ensure a stable and reliable power supply.

- **Carbon Offsetting and Carbon Neutrality Goals:**

- Consider carbon offsetting measures to compensate for any residual carbon emissions associated with solar energy projects.
- Set ambitious carbon neutrality goals for solar energy companies and work towards achieving them.

9. Public Awareness and Education:

- Raise awareness about the benefits of solar energy and its role in mitigating climate change.
- Educate the public about the sustainable practices implemented in solar projects to gain support and cooperation.
- By implementing these mitigation strategies, solar energy projects can significantly reduce their environmental and social footprints, contributing to a more sustainable and cleaner energy future. These strategies also foster positive relationships with local communities and stakeholders, promoting a holistic approach to sustainable solar energy development.

VII. POLICY AND REGULATORY FRAMEWORK FOR SOLAR ENERGY PROJECTS

The policy and regulatory framework for solar energy projects in a country provide the guidelines, incentives, and regulations that govern the development, installation, operation, and integration of solar power generation. The policies aim to promote the adoption of solar energy, facilitate investment, and create an enabling environment for sustainable growth in the solar energy sector. Below are some key components typically found in the policy and regulatory framework for solar energy projects:⁹

- 1. Renewable Energy Targets:** Setting ambitious targets for solar energy capacity installation as part of the overall renewable energy targets. These targets outline the share of solar energy in the country's energy mix and drive investments in solar projects.
- 2. Solar Energy Policy:** A dedicated solar energy policy that outlines the government's vision, objectives, and strategies for promoting solar energy development. The policy may cover aspects such as grid-connected solar projects, off-grid solar systems, rooftop solar installations, and solar manufacturing.
- 3. Incentives and Subsidies:** Providing fiscal incentives, subsidies, and financial support to attract investments and reduce the cost of solar projects. Common incentives include capital subsidies, tax benefits, accelerated depreciation, and concessional financing.
- 4. Power Purchase Agreements (PPAs):** Formulating standardized power purchase agreements between solar project developers and state electricity distribution companies or off-takers. PPAs determine the terms and tariffs for selling solar power to the grid.

⁹ ABDULLAHI DAHIRO, Supra note 1 at 2.

5. **Net Metering and Feed-in Tariffs:** Implementing net metering policies that allow solar energy producers to sell excess electricity to the grid and receive credit for it. Feed-in tariffs can also be used to guarantee a fixed price for solar energy producers over a specific contract period.
6. **Renewable Purchase Obligation (RPO):** Requiring certain entities, such as distribution companies or large consumers, to procure a specified percentage of their electricity from renewable sources, including solar.
7. **Environmental Clearances:** Establishing procedures for obtaining environmental clearances to ensure that solar projects adhere to environmental and sustainability standards.
8. **Land Allocation and Use:** Providing guidelines for land allocation for solar projects, especially for large-scale solar parks and solar farms, to streamline land acquisition processes.
9. **Interconnection and Grid Integration:** Ensuring clear guidelines for connecting solar projects to the grid and promoting seamless integration of renewable energy into the existing power infrastructure.¹⁰
10. **Quality Standards and Certifications:** Setting quality standards for solar equipment, ensuring that solar panels and components meet required performance and safety criteria.
11. **Research and Development Support:** Supporting research and development initiatives in solar energy technologies to foster innovation and enhance efficiency.
12. **International Cooperation and Investments:** Encouraging international cooperation and foreign direct investments in the solar energy sector through conducive policies and regulatory support.

It's important to note that the specifics of the policy and regulatory framework for solar energy projects may vary from country to country based on the local energy needs, resources, and development goals. Effective policy implementation requires collaboration among government bodies, energy regulators, industry stakeholders, and local communities to create a sustainable and inclusive solar energy ecosystem.

VIII. CONCLUSION

In conclusion, solar energy projects in India have emerged as a cornerstone of the country's efforts towards a sustainable and clean energy future. As a rapidly developing nation with increasing energy demand and environmental challenges, India has recognized the significance of harnessing solar power to mitigate greenhouse gas emissions, reduce dependence on fossil fuels, and enhance energy security.

¹⁰ The Role of Solar Energy Policies in Grid Integration of Renewables, Energy5 Your Way, 13 Jul 2023, [therole-of-solar-energy-policies-in-grid-integration-of-renewables,https://energy5.com](https://energy5.com).

The research paper delved into various aspects of solar energy projects in India, analyzing their environmental impacts and exploring effective mitigation strategies. It highlighted the importance of addressing concerns related to land use, water consumption, greenhouse gas emissions, and potential pollution during the entire lifecycle of solar projects.

The policy and regulatory framework in India play a pivotal role in shaping the growth of the solar energy sector. The implementation of supportive policies, financial incentives, and clear guidelines for project development and integration has accelerated the deployment of solar projects across the country.

Despite the many environmental benefits of solar energy, the research paper also acknowledged that there are challenges that require continuous attention. Balancing rapid solar expansion with ecological considerations, ensuring water resource management, and adopting sustainable manufacturing and waste management practices are essential for mitigating any adverse impacts.¹¹

Community engagement and stakeholder participation emerged as vital factors for successful solar project implementation. Collaborative efforts that involve local communities in decision-making, foster social acceptance, and enable equitable distribution of benefits contribute to the sustainable growth of solar energy in India.

Looking ahead, the research paper emphasized the need for ongoing technological advancements, research, and innovation to enhance the efficiency and effectiveness of solar energy projects. Continued investments in research and development will contribute to the continued reduction in the carbon footprint of solar panel manufacturing and drive the competitiveness of solar energy in the Indian energy landscape.

In conclusion, solar energy projects in India represent a significant stride towards a greener and more sustainable future. By fostering a well-balanced approach that addresses environmental, social, and economic dimensions, India can harness the full potential of solar energy to usher in an era of clean, reliable, and inclusive energy for all. The research findings underscore the importance of proactive measures and collaborative action to ensure that solar energy remains a key pillar in India's journey towards a low-carbon economy and a climate-resilient future.

¹¹ ABDULLAHI DAHIRO, *Supra* note 1 at 2.

