UNIVERSIDADE FEDERAL DE SANTA CATARINA
CENTRO TECNOLÓGICO
PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA CIVIL

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Community Solar in Brazil: Cooperatives in the shared distributed generation mode

Florianópolis
2020

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Dissertação submetida ao Programa de Pós-Graduação em Engenharia Civil da Universidade Federal de Santa Catarina para a obtenção do título de Mestre em Engenharia Civil.
Orientador: Prof. Ricardo Rüther, PhD.

Florianópolis
2020

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Schneider, Kathlen
Community Solar in Brazil : Cooperatives in the shared distributed generation mode / Kathlen Schneider ; orientador, Ricardo Rüther, 2020.
111 p.

Dissertação (mestrado) - Universidade Federal de Santa Catarina, , Programa de Pós-Graduação em , Florianópolis, 2020.

Inclui referências.

1. . 2. Community Solar. 3. Renewable Energy. 4. Distributed Generation. 5. Solar Cooperatives. I. Rüther, Ricardo. II. Universidade Federal de Santa Catarina. Programa de Pós-Graduação em . III. Título.

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Community Solar in Brazil: Cooperatives in the shared distributed generation mode

O presente trabalho em nível de mestrado foi avaliado e aprovado por banca examinadora composta pelos seguintes membros:

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Certificamos que esta é a **versão original e final** do trabalho de conclusão que foi julgado adequado para obtenção do título de mestre em Engenharia Civil.



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CPF: 388.223.850-04

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Florianópolis, 2020

ACKNOWLEDGMENT

Firstly, I would like to thank Prof. Ricardo Rüther for all the support and guidance given through the past years since I am part of the *Fotovoltaica-UFSC* team. I am very thankful for all the knowledge shared and for the wise advices. The dedication you take to make the solar PV energy to develop in Brazil through scientific research and education is an inspiration. Thank you for making it happen.

I would also like to thank those directly involved in the development process of this thesis for the knowledge shared, for the projects developed in collaboration and for co-authoring scientific articles resulted from this thesis. They are: Camila Japp, from the Cooperative and Raiffeisen Confederation (DGRV), Marco Olívio Morato de Oliveira, from *Organização das Cooperativas Brasileiras* (OCB) and Paula Scheidt Manoel, from *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH*. The enthusiasm you all work with towards the democratization of the renewable energy generation through the cooperativism movement is also inspiring.

I am also thankful to the representatives from the shared DG solar cooperatives presented in this thesis for their kind approach to this work, and for the information they shared about their cooperatives. They are: Alan Melo from *Coober*; Alex Lang and Marco Aurélio Silva de Souza from *Cooper Sustentável*; José Otávio Carneiro Bustamante from *Enercred*; Alexandra Januário Susteras and Guilherme Susteras from *Compartsol*; Arno Kerckhoff from *Sicoob Centro-Serrano ES*, Diego Branco from *Coopercitrus* and Vitor Romero from *Ciclos* and *CleanClic*.

To the members of the evaluation board, Prof. Monica Oliphant from University of South Australia, Prof. Roberto Lamberts from *Universidade Federal de Santa Catarina* and Prof. Roberto Zilles from *Universidade de São Paulo*, my sincere gratitude for your collaboration towards the overall enhancement of this thesis.

My special gratitude to the PV Girls from *Fotovoltaica-UFSC* of whom I have learned so much, since about solar PV topics to the deepest meaning of the word ‘friendship’. All of you are very special in my life in your own way and I am truly grateful to have crossed paths with you all. I will carry you all in my heart wherever my path will lead me. Thank you Aline Kirsten Vidal de Oliveira, Amanda Mendes Ferreira Gomes, Anelise Medeiros Pires, Clarissa Debiazi Zomer, Delma Camargos, Isadora Pauli Custódio and Marília Braga.

In addition, many thanks to the PV Boys from *Fotovoltaica-UFSC* for all the learnings and knowledge shared through these years. Thank you, Alexandre de Albuquerque

Montenegro, André Luiz Prado Cechinel, Giuliano Luchetta Martins, Guilherme Hosoda, Lucas Rafael do Nascimento, Nikolas dos Santos Barbosa, Pedro Henrique Alves Veríssimo, Sylvio Luiz Mantelli Neto and Vitor Volpato Goulart. My special thanks to Gustavo Xavier de Andrade Pinto for always being that one with one hand extended and with a smile on. Another special thanks to Rafael Antunes Campos for the philosophical talks, for inspiring me and opening the way for me to the Education world and for sharing the 'head on the clouds' lifestyle that only the ones with such a big influence from Aquarius can experience.

I would like to extend my gratitude to the *Insitituto IDEAL* team for sharing the common goal towards the energy transition and democratization, and for making it happen. Thank you Mauro Passos, Fátima Martins, Maurício Frighetto, Taynara Mighelão and, once again, Prof. Ricardo Rüther.

To my sisters from another mister, my special gratitude for sharing life with me and walking by my side no matter where in the World we are. Thank you so much for all the support and love shared Aline Rusch, Ana Carolina Adsuara de Sousa, Bruna Caroline Glasenapp, Helena Stürmer and Tainah Maria Lunge.

Finally, my eternal and deepest gratitude to my mom and dad, Arlene de Souza and Wilson Schneider, for all support, opportunities and love given through my entire life.

This study was financed in part by the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES)* - Finance Code 001.

“The meaning of my existence is that life has addressed a question to me. Or, conversely, I myself am a question which is addressed to the world, and I must communicate my answer, for otherwise I am dependent upon the world’s answer.”

(Carl Gustav Jung)

RESUMO

Principalmente em regiões urbanas, a maior parte da população aluga as suas casas ou vive em apartamentos, onde não é economicamente viável investir em um telhado solar fotovoltaico (FV), ou onde os telhados não são adequados para integração FV. Neste contexto, comunidades de energia solar têm o potencial de ultrapassar essa barreira, promovendo uma alternativa para que todas as pessoas consumidoras de energia possam ter acesso a energia solar FV. No Brasil, comunidades de energia solar só se tornaram possíveis por meio da revisão da Resolução Normativa (REN) 482/2012 através da REN 687/2015, em 2016, a qual regulou a geração distribuída (GD) compartilhada como as cooperativas, consórcios e os empreendimentos com múltiplas unidades consumidoras. Esta dissertação foca no contexto das cooperativas solares FV de GD compartilhada com o objetivo de contribuir com o fomento e desenvolvimento deste modelo descentralizado e democrático de geração de energia. O método foi dividido em três partes: (1) a primeira parte se refere ao desenvolvimento de um simulador online de cooperativas de energia solar FV; (2) a segunda parte se refere ao mapeamento e investigação das cooperativas de energia solar atualmente em operação no Brasil; (3) a parte três consiste no desenvolvimento de uma estrutura que organiza possíveis combinações de modelos de negócios que as cooperativas de energia solar FV de GD compartilhada podem se organizar, conforme o que foi observado na segunda parte do trabalho. Para a primeira parte, um simulador online foi desenvolvido como uma ferramenta complementar ao Guia de Cooperativas de Energia Solar publicado pela Organização das Cooperativas do Brasil (OCB), em parceria com a *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH* e a Confederação Alemã das Cooperativas (DGRV) em 2018. O simulador e o PDF da Guia de Cooperativas de Energia Solar estão disponíveis na plataforma da América do Sol do Instituto para o Desenvolvimento de Energias Alternativas na América Latina (IDEAL) e pode ser acessado neste link: www.americadosol.org/simulador-cooperativas/. Na segunda etapa, seis cooperativas foram mapeadas e os seus contextos e modelos de negócios foram apresentados. Baseado nas cooperativas investigadas, na terceira parte deste trabalho, foi desenvolvida uma estrutura sistêmica para apresentar as possíveis combinações de modelos de negócios em que as cooperativas de GD compartilhada solar FV podem se organizar. Essa dissertação apresenta um resumo histórico do início do desenvolvimento de cooperativas de energia solar FV no Brasil, quebrando assim a falta de informação na literatura sobre este tópico e, ao mesmo tempo, contribuindo para a discussão nacional e internacional sobre o tema.

Palavras-chave: Fotovoltaica; Energia Solar; Energia Renovável; Geração Distribuída; Comunidades de Energia Solar; Cooperativas de Energia Solar; Simulador

RESUMO EXPANDIDO

Introdução

Apesar de a tecnologia fotovoltaica (FV) ser hoje uma realidade para um número crescente de brasileiros e se tornar uma fonte competitiva em custo de geração de energia renovável, ainda existem algumas barreiras para o desenvolvimento mais difundido dessa tecnologia. Por exemplo, principalmente em áreas urbanas, para indivíduos moram de aluguel ou para aqueles que moram em um edifício multifamiliar, a opção de instalar um sistema fotovoltaico no local é limitada. Além disso, mesmo para os indivíduos que possuem sua própria casa, eles podem ter um recurso solar limitado devido a árvores ou outras sombras de edifícios no telhado, ou mesmo uma orientação ou inclinação fora do ideal.

Nesse contexto, os projetos solares compartilhados (ou ainda, comunidades solares) tem o potencial de superar essa barreira. Os projetos solares compartilhados são o conceito de múltiplos participantes que compartilham os custos e os benefícios de um sistema único e maior de GD FV, ao invés de cada indivíduo buscar sistemas fotovoltaicos em seus telhados individuais e de menor escala.

Projetos compartilhados podem ser estruturados de diversas formas. Eles podem ser de propriedade de uma concessionária, de um terceiro, de uma entidade com finalidade específica ou de uma organização sem fins lucrativos (AUGUSTINE; MCGAVISK, 2016). Essas configurações ainda podem incluir muitos modelos legais e de financiamento, como cooperativas, instituições de desenvolvimento que representam os interesses das comunidades e ações pertencentes a organizações comunitárias (SOARES et al., 2018). Este trabalho enfoca a investigação da modalidade cooperativa de um projeto compartilhado. Por sua definição, uma cooperativa é uma associação autônoma de pessoas unidas voluntariamente para atender às suas necessidades e aspirações econômicas, sociais e culturais comuns, através de uma sociedade de propriedade conjunta e uma empresa democraticamente controlada (ICA, 1995).

No Brasil, os projetos compartilhados tornaram-se possíveis com a revisão da REN 482/2012 através da REN 687/2015, criada pela Agência Nacional de Regulação Energética da ANEEL em novembro de 2015, que entrou em vigor em março de 2016. A REN 687/2015 regulamentou a modalidade de geração distribuídas (GD) compartilhada, que podem ser organizados como condomínios, consórcios ou cooperativas por meio do esquema virtual de medição de rede individual (ANEEL, 2015). Portanto, as cooperativas de GD compartilhada são um modelo de GD relativamente novo no Brasil, e há uma literatura muito limitada disponível sobre esse tópico. Por outro lado, há muito interesse em entender melhor esse modelo para transformá-lo em realidade no país. Nesse contexto, esta dissertação visa apresentar o contexto atual das cooperativas de GD compartilhada no Brasil, com o objetivo de esclarecer o desenvolvimento desse modelo de geração de energia descentralizada e democrática e contribuir para a discussão nacional e internacional sobre o tema.

Obejtivos

Esta dissertação tem o objetivo principal de contribuir com a análise, promoção e desenvolvimento dos projetos compartilhados de energia solar fotovoltaica no Brasil com foco no modelo cooperativo.

Objetivos específicos:

- Desenvolver uma ferramenta da web que visa fornecer orientação aos cidadãos para que eles aprendam mais sobre cooperativas de GD compartilhada e possam investigar por si mesmos, nos estágios iniciais de um processo de tomada de decisão, a viabilidade tecno-econômica cooperativa solar compartilhada em seu contexto;

- Mapear as cooperativas solares compartilhadas existentes em operação no Brasil até a presente data (final de 2019);
- Investigar o contexto e o modelo de negócios das cooperativas mapeadas;
- Elaborar uma estrutura que compila todos os arranjos de modelo de negócios das cooperativas existentes investigadas, que podem ser usados como base para fornecer um entendimento mais amplo sobre possíveis estruturas de modelo de negócios sob a regulamentação atual no Brasil.

Metodologia

O método desta dissertação foi dividido em três partes: (1) a primeira parte refere-se ao desenvolvimento de uma ferramenta online de simulação de cooperativas de GD compartilhada de energia solar; (2) a segunda parte refere-se ao mapeamento e investigação das cooperativas atualmente em operação no Brasil; (3) a terceira parte consiste no desenvolvimento de uma estrutura que organiza os possíveis arranjos do modelo de negócios em que as cooperativas de GD compartilhada de energia solar podem ser estruturadas, conforme as cooperativas investigadas na segunda parte deste trabalho.

1 - Primeira parte: Simulador de cooperativas de GD compartilhada de energia solar

A ideia de desenvolver um simuladore cooperativas solares surgiu paralelamente ao lançamento do Guia das Cooperativas Solares (Lima, 2018) e ao desenvolvimento do trabalho que levou a esta dissertação. O Guia traz ao leitor três exemplos de grupos de indivíduos com diferentes perfis de consumo de energia, localizados em uma determinada cidade e inseridos em um determinado contexto. Esses exemplos mostram qual seria o investimento inicial que cada indivíduo teria que fazer, de acordo com seu perfil de consumo de energia, para participar da cooperativa. Além disso, os exemplos dão uma noção de quanto dinheiro esses indivíduos gastariam mensalmente para manter a cooperativa e quais seriam suas economias na conta de eletricidade ao se tornar um membro da cooperativa. No entanto, esses exemplos logo se tornam obsoletos, pois os preços do sistema fotovoltaico estão mudando e caindo a cada ano. Além disso, embora os exemplos sejam muito simples e fáceis de seguir, eles não abrangem outros contextos de localização (e, portanto, disponibilidade de recursos solares), perfil de consumo de energia ou tarifa de eletricidade que o candidato a cooperativa em potencial paga.

O simulador foi projetado para se tornar uma ferramenta complementar ao Guia de Cooperativas Solares, tornando-se ao mesmo tempo uma contribuição da Fotovoltaica-UFSC e do Instituto IDEAL para facilitar a adoção do modelo de cooperativas solares e um componente integral da presente dissertação. Como uma maneira fácil de treinar o uso do simulador pelo(a) candidato(a) à cooperativa em potencial, o leitor do Guia pode acessar do simulador e preenchê-lo com entradas apenas lendo os exemplos do Guia da Cooperativa Solar e, se preenchendo as entradas corretamente, ele/ela deve receber as mesmas saídas apresentadas nos exemplos do Guia. Este procedimento pode, portanto, ser usado para verificar o entendimento do usuário sobre o processo. Uma vez compreendidos corretamente os passos, o usuário pode simular seu próprio contexto, verificando a viabilidade tecno-econômica de iniciar uma cooperativa solar de acordo com sua realidade.

2 - Segunda parte: Mapeamento das cooperativas de GD compartilhada de energia solar em operação

A segunda parte deste trabalho visa mapear e investigar as cooperativas solares compartilhadas existentes em operação no Brasil até o presente momento. As informações

foram coletadas através de diferentes abordagens. Primeiramente, os dados das DG Cooperativas Compartilhadas foram mapeados através do banco de dados de modalidades da DG no site da ANEEL. Para tanto, a busca foi realizada apenas nos registros da modalidade de DG compartilhada. No entanto, percebeu-se que esses registros, muitas vezes, não são realizados corretamente pela concessionária. Em consequência, o banco de dados da ANEEL não poderia ser o único recurso.

A segunda parte desta investigação foi a realização de entrevistas pessoais por meio de telefonemas e e-mails com um representante das cooperativas encontradas na base de dados da ANEEL para entender com mais detalhes seu modelo, contexto e detalhes técnicos. Esses contatos foram fornecidos por profissionais da OCB, DGRV e GIZ. Esses profissionais também forneceram contatos de outras cooperativas de GD compartilhada que ainda não estavam registradas na ANEEL ou estavam erroneamente registradas em uma modalidade diferente. Como o foco desta pesquisa são as cooperativas de energia solar FV, apenas as cooperativas que usam a fonte de energia solar foram investigadas com mais detalhes.

Em terceiro lugar, em junho de 2019, foi organizado um webinar pelo Fotovoltaica-UFSC e Instituto IDEAL, em parceria com OCB, DGRV e GIZ. Este webinar e workshop foram realizados com os representantes das cooperativas mapeadas. O evento aconteceu em Florianópolis-SC, no Fotovoltaica-UFSC. O webinar foi aberto ao público, gravado e está disponível no canal Fotovoltaica-UFSC no YouTube. No webinar, os representantes das cooperativas tiveram a oportunidade de apresentar suas cooperativas, compartilhar suas experiências e as principais barreiras que encontraram para estruturar e manter seu modelo de negócios.

Posteriormente, foi realizado um workshop com os organizadores do evento e apenas os representantes da cooperativa. No workshop, os representantes tiveram a oportunidade de se conhecer melhor e também compartilhar suas experiências, desafios, barreiras e soluções encontradas, com mais detalhes. Considerando que um dos princípios do cooperativismo é a 'Cooperação entre cooperativas', este workshop também teve o objetivo de conectar as cooperativas da modalidade de DG compartilhada para que encontrassem maneiras de cooperar umas com as outras e fortalecer essa modalidade de geração de energia no país. Durante o webinar e o workshop, informações adicionais sobre essas cooperativas também foram coletadas para esta tese.

As principais informações coletadas foram referentes ao modelo de negócio cooperativo, propriedade e instalação do sistema fotovoltaico, capacidade de energia do sistema fotovoltaico, número de membros, número de unidades consumidoras que recebem o crédito de energia, principais barreiras e planos para o futuro. Também é importante ressaltar que apenas foram consideradas cooperativas de GD compartilhada as cooperativas que geram energia através de um sistema fotovoltaico e compensam o crédito de energia em unidades consumidoras de seus membros. As cooperativas que geram energia apenas para as unidades consumidoras pertencentes à própria cooperativa foram consideradas enquadradas no modelo remoto de DG, embora seu registro na ANEEL esteja na modalidade de DG compartilhada.

3-Terceira parte: Estrutura sistemática para as cooperativas de GD compartilhada

Para organizar e apresentar os diferentes modelos das cooperativas observadas neste trabalho, foi escolhida uma abordagem sistemática. Esta seção tem como objetivo introduzir a estrutura de um modelo sistêmico e a estrutura de modelagem adotada.

O primeiro passo para estruturar o sistema é identificar seu objetivo e seu observador. O objetivo deste sistema foi definido levando em consideração o fato de que as cooperativas de energia solar baseadas na modalidade de GD compartilhada são uma possibilidade recente no Brasil e, consequentemente, existem muitas questões sobre como estruturar um modelo de

negócios de cooperativas solares compartilhadas. Portanto, o objetivo deste sistema é delinear os possíveis arranjos em que uma cooperativa de GD compartilhada de energia solar pode ser estruturada considerando a regulação atual em vigor. O observador aqui considerado é qualquer pessoa interessada em investigar e avaliar as possibilidades de como estruturar um modelo de cooperativa de GD compartilhada de energia solar.

O segundo passo é identificar os elementos e suas relações. No contexto desta dissertaçãp, os elementos e suas relações foram identificados com base nas cooperativas solares compartilhadas existentes investigadas e são observadas conforme explicado na seção '*3.2 PART TWO: MAPPING THE EXISTING SHARED SOLAR COOPS*'. Uma vez que o sistema esteja estruturado, o modelo das cooperativas mapeadas será aplicado nessa estrutura desenvolvida para exemplificar a aplicação do sistema.

Resultados e Discussão

Os resultados desta dissertação foram apresentados separadamente para cada parte conforme explicado no método.

1 – Resultados: Parte um

A ferramenta web é uma ferramenta on-line de código aberto, hospedada na plataforma América do Sol do Instituto IDEAL, e pode ser acessada no link: www.americadosol.org/simulador-cooperativas/. A Figura 23 apresenta uma captura de tela da interface atual da ferramenta da web. O Guia de Cooperativas Solares pode ser baixado no canto superior direito da página. A ferramenta web foi lançada oficialmente na Conferência e Feira da Intersolar South America durante o painel 'Cooperativas Solares / Comunidade Solar para o Brasil', em 29 de agosto de 2018, em São Paulo. Desde o seu lançamento até 31 de agosto de 2019, a ferramenta da web possuía 5436 'Sessões' e 4292 'Usuários' de 30 países diferentes, de acordo com dados do Google Analytics.

2 – Resultados: Parte dois

Foram identificadas 10 cooperativas de GD compartilhada em operação. Essas cooperativas estão localizadas no mapa, conforme a Figura 24, e alguns detalhes sobre elas, como localização, capacidade de energia de cada usina em operação e o ano em que essas usinas foram conectadas à rede, são apresentadas na Tabela 6. A partir destas cooperativas, seis usam geradores fotovoltaicos, dois usam energia hidrelétrica e dois usam biomassa. As cooperativas que usam fonte solar somam 1,6 MW de capacidade instalada de energia, enquanto as hidrelétricas compartilhadas somam 6,5 MW e as bio-cooperativas têm 6,9 MW instalados. Juntas, elas somam cerca de 15 MW de capacidade de energia, representando apenas 0,8% da capacidade total de energia da DG instalada até hoje (2 GW). Outras cooperativas em desenvolvimento também foram identificadas. No entanto, elas ainda não estavam em operação e, portanto, não foram consideradas nesta dissertação.

As cooperativas de fonte solar FV em capacidade instalada, são menos representativas quando comparadas às cooperativas hidrelétricas e de biomassa compartilhadas. As cooperativas solares compartilhadas representam apenas 11% da capacidade total de energia instalada nas cooperativas de DG compartilhadas, enquanto as hidrelétricas compartilhadas representam 43% e as cooperativas de biomassa 46%. No entanto, em quantidade de cooperativas espalhadas por todo o país, as cooperativas solares compartilhadas são mais representativas, respondendo por seis (das 10) cooperativas em operação atualizadas, conforme apresentado na Figura 24 e Tabela 6.

3 – Resultados: Parte três

A estrutura sistemática aqui apresentada é uma "captura de tela" do contexto das cooperativas solares compartilhadas existentes mapeadas nesta tese. Todos os elementos aqui identificados são baseados no que foi observado.

Com base nas seis cooperativas solares compartilhadas mapeadas neste trabalho, foram observados os seguintes elementos: a própria 'Cooperativa', o 'Membro' da cooperativa, o 'Sistema fotovoltaico', o local onde o sistema fotovoltaico está instalado, o local e Sistema fotovoltaico 'Propriedade' e 'Investimento'. Todos esses elementos foram resolvidos dentro do sistema e qualquer elemento foi identificado como estando no ambiente. A Figura 36 apresenta os elementos identificados e suas relações. Para cada elemento, existem diferentes conjuntos de possibilidades que podem ser escolhidos para formar a cooperativa.

Muitas das cooperativas mapeadas foram fundadas do zero como uma cooperativa de GD compartilhada. No entanto, também foi observado que as cooperativas existentes de outro ramo estão adotando o serviço de geração de energia compartilhada e adaptando-o ao seu modelo de negócios, como foi o caso da Sicoob Centro-Serrano e Ciclos, por exemplo. Portanto, o elemento Cooperativa pode ser estabelecido em uma configuração de uma 'cooperativa criada do zero' ou uma 'cooperativa existente de outro ramo'.

A cooperativa está relacionada ao sistema fotovoltaico e ao local em que esse sistema fotovoltaico está instalado. Como observado, o local em que o sistema fotovoltaico pode ser montado pode estar em um 'telhado' ou no 'solo'.

Observou-se que é importante considerar no sistema a propriedade do sistema fotovoltaico e do local onde está montado. Não necessariamente o proprietário do sistema fotovoltaico é o mesmo proprietário do local. Portanto, um elemento independente de propriedade foi considerado no sistema fotovoltaico e outro no local. Essa propriedade pode ser dos 'membros' da cooperativa, da própria 'cooperativa', de um 'parceiro' (neste caso, outra cooperativa, o município, algum membro específico da cooperativa e assim por diante) ou também de um 'investidor terceiro'.

O sistema fotovoltaico e a propriedade do site levam a outro elemento: como essa propriedade é financiada. Aqui, esse elemento é chamado de 'Investimento' e há um elemento independente para cada propriedade. O investimento do sistema fotovoltaico e do local pode ser feito através do "capital próprio" do proprietário ou ainda através de uma "doação" do proprietário. A estrutura de "doação" geralmente aparece apenas na propriedade do site.

O Membro está relacionado ao Sistema FV como o "proprietário" do sistema FV ou apenas como um "assinante" do sistema FV, dependendo da propriedade selecionada para o Sistema FV.

Considerações Finais

Por fim, este trabalho apresenta um resumo histórico do início do desenvolvimento de cooperativas de GD compartilhada de energia solar no Brasil e quebra a falta de literatura sobre esse tema, esclarecendo-o e contribuindo para a discussão nacional e internacional sobre o tema e, portanto, alcançando seu principal objetivo de contribuir com a análise, promoção e desenvolvimento de projetos solares compartilhados no Brasil com base no modelo cooperativo.

Palavras-chave: Fotovoltaica; Energia Solar; Energia Renovável; Geração Distribuída; Comunidades de Energia Solar; Cooperativas de Energia Solar; Simulador

ABSTRACT

Mainly in urban areas, a good portion of the population rent their houses or live in multi-family households, where it is not economically feasible to invest in a rooftop solar photovoltaic (PV) system, or where roofs are not adequate for PV integration. In this context, community solar has the potential to overcome those barriers by providing a way for all energy consumers to access solar photovoltaics. In Brazil, community solar became possible by the revision of REN 482/2012 by REN 687/2015, in 2016, which regulated shared distributed generation (DG) such as cooperatives, consortia and shared condominia. This thesis focuses on the Brazilian context of shared solar cooperatives, aiming to contribute with the promotion and development of this decentralized and democratic energy generation model. The method was divided into three parts: (1) part one refers to the development of a shared solar cooperatives web tool; (2) part two refers to mapping and investigating the existing shared solar cooperatives under operation in Brazil; (3) part three consists in the development of a framework that organizes the possible business model arrangements shared solar coops can be organized in, according to the findings investigated in the second part of this work. For the first part, a web tool was developed as a complementary tool to the Solar Cooperatives Guide published by the Brazilian Cooperatives Organization (OCB) in partnership with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and German Cooperative and Raiffeisen Confederation (DGRV) in 2018. The web tool and the PDF of the Solar Cooperative Guide are currently available at the *Instituto IDEAL's América do Sol* platform, which can be accessed through the link: www.americadosol.org/simulador-cooperativas/. For the second part, six shared solar coops were mapped and their context and business model were presented. Based on the cooperatives investigated, in the third part of this work, a systematic framework to present the possible model arrangements shared solar coops can be organized in was structured. This work presents an historical summary of the early days of the development of shared solar cooperatives in Brazil, and breaks the lack of literature about this topic, while shedding light on it and contributing to the national and international discussion.

Keywords: Photovoltaics; Solar Generation; Renewable Energy; Distributed Generation,; Community Solar; Shared Solar Cooperatives; Web Tool.

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ABREVIATIONS LIST

A_C Accounting cost

ANEEL Brazilian Electricity Regulating Agency

Avb_c Availability surcharge cost

Coop Cooperative

CONFAZ National Finance Policy Council

CS Community Solar

DG Distributed Generation

DGRV German Cooperative and Raiffeisen Confederation

E_c Energy consumption

ES *Espírito Santo* state

F_c Fixed costs

FN_A Financing amount

FN_C Financing cost

FU Fraction Use

GIZ Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

I_c Initial cost

ICMS Brazilian goods and service tax

IDEAL Institute for the Development of Alternative Energies in Latin America

I_{ref} Reference irradiance

I_{til} Solar irradiance on the plane tilted

L_C Leasing costs

OCB Brazilian Cooperatives Organization

O&M Operation and Maintenance

OM_C Operation and Maintenance costs

PD_C Power Demand cost

P_{PV} PV system nominal power

PR Performance Ratio

PV Photovoltaics

RE Renewable Energy

R$ *Reais* (Brazilian currency)

UFSC *Universidade Federal de Santa Catarina*

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1 INTRODUCTION

Climate change is causing impacts in regions all around the world. According to IPCC (2018), two thirds of greenhouse gas (GHG) emissions originate from the energy sector. Together with reducing global energy demand through energy efficiency and increasing the electrification pathway for all end-use sectors, increasing the share of renewables in the energy mix is the heart of reducing energy-related CO_2 emissions (IRENA, 2019a). In this context, the renewable energy (RE) field has developed remarkably over the past decades, including wind, solar, small hydropower, biomass and geothermal energy sources. These sources have been increasingly promoted in the context of climate policies aiming at mitigating climate change by reducing the dependency on fossil fuel energy sources. However, technological advances should not be considered as the single main actor in a low-carbon energy future. Human behavior must also be addressed towards an energy transition movement (SOVACOOL, 2014).

Therefore, to an impactful energy transition, a global approach engaging all levels of society – from communities, governments to private sectors – are required. In this context, distributed generation (DG) can play a major role into the transition movement. DG are small scale and decentralized RE energy generation systems located close to customers and distributed around the grid, such as solar PV rooftops for example. Consequently, DG energy resources provide several opportunities to increase the resilience of energy systems, improve energy security, empower communities, and reduce local and regional CO_2 emissions (IRENA, 2019a).

In 2018 a total of 181 GW of RE was globally added, highlighting the power sector in which RE became increasingly cost-competitive in comparison to conventional thermal generation. Renewables provided around 26% of global electricity generation by the end of 2018 (REN21, 2019). In addition, the widespread adoption of RE technologies generates economy growth and employment opportunities. The RE sector employed (directly and indirectly) around 11 million people worldwide in 2018 (IRENA, 2019b).

In this context, solar photovoltaics (PV) is the fastest growing RE field in the current decade summing 505 GW total capacity installed worldwide by the end of 2018 (REN21, 2019). According to the latest Global Status Report (GSR) from REN21 (2019), by the end of 2018 China had alone a cumulative PV capacity of 176 GW, followed by United States (62 GW), Japan (56 GW), Germany (45 GW) and India (33 GW).

In Brazil the PV cumulative capacity summed 4 GW by the end of 2019 (considering centralized and distributed generation) (ANEEL, 2019a; BIG, 2019), representing nearly two times the cumulative capacity (2.2 GW) registered by the end of the previous year (ANEEL, 2019a; ONS, 2019). By the end of 2018, at least 32 countries had a cumulative capacity of 1GW or more (REN21, 2019). These numbers express the important role Brazil has started to play in the PV technology market in the recent past years. PV power capacity grew exponentially in the country since DG was regulated.

In Brazil, DG systems (up to 5 MW) became a reality in 2013 when the Brazilian Electricity Regulating Agency ANEEL issued REN 482/2012, which was later revised by REN 687/2015 in 2016. This regulatory framework allowed individuals and legal entities to generate their own energy at the consumer unit location through a one-to-one net-metering scheme (each one kWh exported to the grid generates a one kWh credit, and there is a further monthly and fixed connection fee to account for the distribution grid availability to the consumer unit) (ANEEL, 2012). Currently this national regulation is under revision and its changes will be enforced in 2020.

By the end of 2019, there were around 160 thousand registrations of DG systems at the ANEEL registry, amounting to nearly 2GW of cumulative capacity installed and growing exponentially since late 2017. From these, solar PV source accounts with nearly 1.8 GW installed, representing some 90% of the total (ANEEL, 2019a). Following the Brazilian PV market increase, the prices of PV systems equipment and installation have dropped significantly up to the date (IDEAL; AHK-RJ, 2019). This fact made PV systems more attractive to the population.

Despite PV technology being today a reality to a growing number of Brazilians and becoming a cost-competitive source of renewable energy generation, there are still some barriers to the more widespread development of this technology. For example, mainly in urban areas, for individuals who do not own the house they live in, or for those who live in a multi-family building, the option of installing an on site PV system is limited. In addition, even for those individuals who own their own house, they may have a limited solar resource due to either trees or other buildings shadings on the roof, or even a sub-optimal roof orientation or tilt.

In this context, community solar (CS) has the potential to overcome this barrier. CS is the concept of multiple participants sharing both costs and benefits of a single and larger DG PV system, rather than each individual pursuing DG PV systems on their individual and smaller scale rooftops. In other words, in contrast to traditional models, CS allows multiple electricity

consumer units to collectively own an offsite and centralized PV system through the purchase or lease of shares or subscriptions of the energy generated (CHAN *et al.*, 2017).

CS projects offer many attractive benefits for subscribers. Besides enabling solar energy generation for individuals that cannot install a rooftop solar PV, there is also the cost issue. A CS project can lower the PV system cost by capturing economies of scale. Chan *et al.* (2017) also state that shared projects provide opportunities at the community level to adopt RE technology as part of a larger-scale energy transition revolution.

Besides addressing climate change through reducing carbon emissions, as well as saving money on energy bills, there are also other reasons why community led actions are beneficial: they can build strong communities and develop new skills for their members. In addition, they have the potential to overcome barriers more effectively than the government alone through involving local people towards developing solutions to meet local needs (UK DEPARTMENT OF ENERGY & CLIMATE CHANGE, 2014). On the other hand, there are also barriers that are faced by CS projects. According to Augustine (2015), there are a number of issues that need to be evaluated and addressed before developing a new CS project:

- Poor economic feasibility projects. For example, in regions with low electricity rates or low solar radiation resources, a CS project may not be feasible without additional incentives;
- Software systems barriers. In order to adapt to CS projects, utilities might have to provide system changes in order to enable on-bill crediting for subscribers, real-time tracking of the PV system generation and management systems for subscriber contracts;
- Policy barriers. Key policy parameters should be accessed prior to developing a 20-30 years CS project.

CS projects may present different ownership model designs. They can be either owned by a utility, a third party, a special-purpose entity or a charitable non-profit (AUGUSTINE; MCGAVISK, 2016). Such configurations can still include many legal and financing models such as cooperatives, development institutions representing communities' interests and shares owned by community based organizations (SOARES *et al.*, 2018). This work focuses on investigating the cooperative modality of a CS project. By its definition, a cooperative is an autonomous association of persons united voluntarily to meet their common economic, social and cultural needs and aspirations through a jointly owned and democratically controlled

enterprise (ICA, 1995). Therefore, cooperative businesses are run by and for their members, whether they are consumers, workers, residents, employees, farmers, the community, or any combination of those. What they have in common is that they are not about profit maximization, but about bonding for reaching their goals. Thus, in economic terms, cooperatives are a distinct form of business organization because they have a different model of ownership (HANSMANN, 1996). Another distinction is that decision-making in cooperatives follows the one-member-one-vote principle.

Since cooperatives are very flexible organizations, they have been proved as a good option of practice responding to current social and environmental challenges. These challenges include access to housing (e.g. grouped housing) and respect for the environment (organic farming and consumption, renewable energy, etc.). Renewable energy cooperatives (RE Coops) fit into the DG context, where energy is generated in a decentralized manner near to the consumer units. Therefore, in many cases, energy cooperatives have the potential to provide an important boost for the decentralized energy transition. Consequently, RE Coops provide the institutional framework to involve citizens with political, social and financial aspects of renewable energy deployment, thus "democratizing" the energy sector (SOARES *et al.*, 2018).

According to Chan *et al.* (2017), in several states in the USA, electricity cooperatives were the first adopters of CS projects, offering a combination of up-front and pay-as-you-go payment options. This first experience in some states apparently had influenced the wider adoption of CS projects, including through legislation. Augustine (2015) observed that electricity cooperatives, besides municipal utilities, might have been pioneers in shared solar projects because of their flexibility to create programs voluntarily.

In Brazil, CS projects became possible by the revision of REN 482/2012 through REN 687/2015, established by the National Energy Regulatory Agency ANEEL in November 2015, which came into force in March 2016. REN 687/2015 regulated the shared DG modality, which can be organized as a condominia, consortia or cooperatives through the virtual net-metering one-to-one scheme (ANEEL, 2015). According to (ANEEL, 2019b), shared DG accounted with 466 registrations summing nearly 32 MW installed by the end of the year of 2019.

Therefore, shared DG cooperatives is a relatively new DG model in Brazil, and there is very limited literature available on this topic. On the other hand, there is a lot of interest to better understand this model in order to turn it into a reality in the country. According to the UK Department of Energy & Climate Change (2014), partnerships with local authorities, commercial organizations and local networks are crucial to support and develop community led actions. In addition to partnerships, the access to the right information, advice and expertise are

also important towards communities actions to achieve scale. Therefore, empowering groups to learn from each other and share information about what works plays a major role on the development of this collaborative energy generation modality.

In this context, this thesis aims to present the current context of shared solar cooperatives in Brazil, intending to shed some light on the development of this decentralized and democratic energy generation model and to contribute to the national and international discussion. To this end, an open source web tool to simulate the techno-economic viability in the early stages of shared solar cooperatives in Brazil was developed. In addition, regulation information, data and information around the business models adopted by the existing shared solar cooperatives in Brazil are investigated and described in a review format.

1.1 OBJECTIVES

1.1.1 Main objectives

This work aims to contribute with the assessment, promotion and development of community solar projects in Brazil based on the cooperative model.

1.1.2 Specific objectives

- Develop an open source web tool that aims to provide guidance to citizens for them to learn more about shared solar cooperatives and to be able to investigate by themselves, in the early stages of a decision-making process, the techno-economic viability of a shared solar cooperative at his/her context;
- Map the existing shared solar cooperatives under operation in Brazil up to the present date (late 2019);
- Investigate the context and business model from the cooperatives mapped;
- Elaborate a framework that compiles all the existing cooperatives business model arrangements investigated, which can be used as a base to provide a wider understanding about possible business model structures under the current regulation in Brazil.

2 LITERATURE REVIEW

2.1 RENEWABLE ENERGY COOPERATIVES (RE Coops)

The International Co-operative Alliance (ICA) adopted the Statement on the Co-operative Identity at the General Assembly of the International Co-operative Alliance held in Manchester in 1995, which states the following definition for cooperatives:

> A Co-operative (sic) is an autonomous association of persons united voluntarily to meet their common economic, social and cultural needs and aspirations through a jointly owned and democratically controlled enterprise. (ICA, 1995)

Still according to ICA (1995), there are seven principles that cooperatives follow as guidelines to put their values into practice. These principles are:

1. **Voluntary and Open Membership:** cooperatives are voluntary organizations open to all persons without gender, social, racial, political or religious discrimination;
2. **Democratic Member Control:** cooperatives are democratic organizations controlled by their members, who actively participate in setting their policies and making decisions thorough equal voting rights following the principle one-member-one-vote;
3. **Member Economic Participation:** members contribute equitably to, and democratically control, the capital of their cooperative;
4. **Autonomy and Independence:** Cooperatives are autonomous, self-help organizations controlled by their members;
5. **Education, Training and Information:** Cooperatives provide education and training for their members, elected representatives, managers, and employees so they can contribute effectively to the development of their cooperatives;
6. **Cooperation among Cooperatives:** Cooperatives serve their members most effectively and strengthen the cooperative movement by cooperating with other cooperatives into the local, national, regional and international level;
7. **Concern for Community:** Cooperatives work for the sustainable development of their communities.

Cooperative business are run by and for their members. What they have in common is that they are not about profit maximization, but about bonding for reaching their goals. Therefore, in economic terms, cooperatives are a distinct form of business organization because they have a different model of ownership (HANSMANN, 1996).

It is very usual in a cooperative that members offer their professional skills as a volunteer work or by a very low remuneration. For example, if there is a member who happens to be an engineer, he/she can become responsible for monitoring the PV system installation and maintenance; another member who is an accountant can take the cooperative accounting and administration as a responsibility. It is important to highlight that if any member gets involved with the cooperative through a volunteer work, it must have a volunteering terms signed between the parties.

Cooperatives can be organized in many different ways through distinct legal structures depending on what works for the members (WILLIS; WILLIS, 2012). Cooperatives are active and very traditional in many sectors of the global economy, such as credit, agriculture, housing, education, energy and so on. Renewable energy cooperatives (RE Coops) refers to a business model in which citizens gather to jointly own and/or share a renewable energy project. Therefore, RE Coops, as defined in this work, fit into the DG context, where energy is generated in a decentralized manner near to the consumer units (but not necessarily on the same site).

In consequence, RE Coops have the potential to provide an important boost for the decentralized energy transition through providing institutional framework to involve the population with political, social and financial aspects of renewable energy development and, therefore, democratizing the energy sector (DGRV, 2015; YILDIZ *et al.*, 2015). There are those who believe that small-scale democratic practices collaborates for people to become more aware of their role and agency at the energy transition process (COOPERATIVES EUROPE, 2019).

In addition, RE Coops can contribute to the climate crisis through reducing energy consumption by improving both energy awareness and energy efficiency, since energy is produced locally, avoiding transmission and distribution losses associated with the traditional and centralized energy scenario. Many RE Coops bring concrete illustrations of implemented methods and devoted people to helping members reduce their consumption. As a result, these cooperatives seemed able to substantially reduce energy consumption (from 20 to 30% decrease) (HUYBRECHTS; MERTENS, 2014).

Finally, RE Coops have been demonstrating many other benefits to society such as a great potential for contributing to development and energy poverty alleviation. According to Soares *et al.* (2018), by making energy accessible and affordable, renewable energy improves productivity, living conditions and creates jobs, particularly in rural areas.

However, the development of RE Coops can also face some barriers. According to Yildiz *et al.* (2015), cooperatives are formed by an heterogeneous group of individuals and, therefore, aspects of conflict and trust can become a major issue to the success of the energy cooperative model.

The next sub-chapters describe the context of RE Coops in Europe, where the movement is very strong and has been well established for decades, and in the Brazilian context where RE Coops is a newborn energy generation community model.

2.1.1 RE Coops into the European Context

The cooperative movement became stronger in Europe over the course of the Industrial Revolution in mid-19th century as being the answer proposed by the working class to the rise of unemployment and poor wages offered by European companies. Cooperatives were also created as a tool to resist to monopolies and, therefore, besides its economic functions, cooperatives were also a broader movement with political aims of transforming society (HUYBRECHTS; MERTENS, 2014).

RE Coops play an important role towards energy transition in Europe and their emergence can be explained by consumers dissatisfaction, desire to better control the origin of their energy and its price. Indeed, RE Coops are the only model represented by a federation, the Federation of Groups and Cooperatives of Citizens for Renewable Energy in Europe, known as REScoop.eu. REScoop.eu was founded in 2011 and since then it has been playing a very important role as an international network, creating support and contributing to the success of such initiatives across Europe (HERAS-SAIZARBITORIA *et al.*, 2018).

In terms of energy origin, own and local production by RE Coops led to more transparency to the consumer. On prices, transparency was also a major attractiveness besides simpler pricing mechanisms that were observed in many RE Coops (HUYBRECHTS; MERTENS, 2014). Aspects such as active participation, democracy and the desire to influence local energy policy decisions were defined as the main motivation for individuals joining a RE Coop according to empirical data from Germany compiled by Yildiz *et al.* (2015). Wierling *et*

al. (2018) also noted this pattern at the pioneers' RE Coops in Europe, which are often built by societal groups that intend to demonstrate alternatives to established socio-political structures.

However, the influence of RE Coops varies across Europe, being well established in some countries while remaining marginal in others. Germany and Denmark are the countries where RE Coops are the strongest and well established (BAUWENS; GOTCHEV; HOLSTENKAMP, 2016; HERAS-SAIZARBITORIA *et al.*, 2018; HUYBRECHTS; MERTENS, 2014; SOARES *et al.*, 2018; WIERLING *et al.*, 2018). According to Bauwens, Gotchev and Holstenkamp (2016), this strong development is due to the support mechanism schemes promoted in these two countries.

United Kindom (UK), Netherlands and Belgium present a lower degree of development if compared to Germany and Denmark; yet those are also relevant countries (BAUWENS; GOTCHEV; HOLSTENKAMP, 2016; WIERLING *et al.*, 2018). In the UK, most of the RE Coops were founded in the period between 2010-2015, which coincides with the introduction of a feed-in-tariff (FiT) scheme in 2010. In 2015, the number of newly founded energy cooperatives dropped drastically, coming down from 80 in 2015 to 20 in 2016. This fact can be explained by changes in the FiT policies (WIERLING *et al.*, 2018). In Belgium, electricity generation is mainly dominated by Electrabel, the former state monopoly. Since the liberalization of the energy market, new players were able to enter the market. Only offshore wind power and hydropower are regulated. There are other support mechanisms for other renewable energy resources, such as the mechanism of green certificates. Still, these certificates do not benefit the foundation of new RE Coops (BAUWENS; GOTCHEV; HOLSTENKAMP, 2016).Bauwens, Gotchev and Holstenkamp (2016) also noted that wind cooperatives in Belgium are more likely to be a 'top-down' model, while 'bottom-up' emergences are an exception. Yet, Belgium has one of the greatest pioneers in the bottom-up RE Coops model, Ecopower, which is the largest cooperative in Europe in terms of membership (RESCOOP, 2019).

On the other hand, the development of RE Coops in southern Europe has been much slower (HERAS-SAIZARBITORIA *et al.*, 2018; HUYBRECHTS; MERTENS, 2014; SOARES *et al.*, 2018). In the case of Spain, a study of Heras-Saizarbitoria *et al.* (2018) identifies the Spanish legal framework as the main restriction for the expansion of energy cooperatives in the country. According to these same authors, there is a great lack of research on the development of RE Coops in southern Europe. Therefore, according to them, the participation of these community actors in energy generation is more developed than what is presented in the literature currently.

Huybrechts and Mertens (2014) identified two main barriers that seem to explain why RE Coops face an unequal and sometimes difficult development across Europe. They defined these barriers as barriers to entry (access to capital to invest and access to location for a renewable energy project); and, more generally, cognitive barriers related to poor knowledge and understanding of the cooperative model. According to the authors, access to capital and the lack of access to location for the development of the projects, especially in the start-up phase, are serious obstacles to the emergence and development of RE Coops. In addition, low knowledge and understanding of the cooperative model among politicians, bankers, potential partners, and the general public, are also important barriers. Furthermore, in some countries, especially in Eastern Europe, the issue was not so much cognitive but moral legitimacy, with the association of this model with 'old-fashioned' and 'socialist' images. Bauwens, Gotchev and Holstenkamp (2016) also pointed support mechanisms for renewable and societal norms including attitudes toward the cooperative model and culture of energy local activism as some other factors to explain such disparity.

The solar technology has been proving to be a very attractive option for RE Coops in Europe. PV is particularly attractive because of its modularity, simplicity, high reliability and low maintenance. In addition, another benefit from PV systems for RE Coops is the possibility of mounting them on roofs – such as public buildings, including nurseries or schools, which are not used by individuals (DGRV, 2015), thus avoiding the issue of land area and the associated costs. In the UK, solar PV has also been proving itself as a more straightforward option for cooperatives - Green Energy Nayland's project took seven months from start to finish, whereas Valley Wind took over five years struggling to find a suitable site (WILLIS; WILLIS, 2012). Germany follows the same path for choosing solar before other renewable energy sources when forming an energy cooperative (DGRV, 2015; WIERLING *et al.*, 2018; YILDIZ *et al.*, 2015). As mentioned, Germany and Denmark have a well established development in RE Coops summing some decades of experience. Therefore, in the next subsections we present their context in more detail intending to contextualize their experiences with the newborn Brazilian RE Coops into the shared DG modality context.

2.1.1.1 Germany

In Germany the history of cooperatives dates around 170 years back. The beginning of the cooperative movement was guided by Friedrich Wilhelm Raiffeisen and Hermann Schulze-Delitzsch and coincides with the beginning of the industrialization. Cooperatives functioned

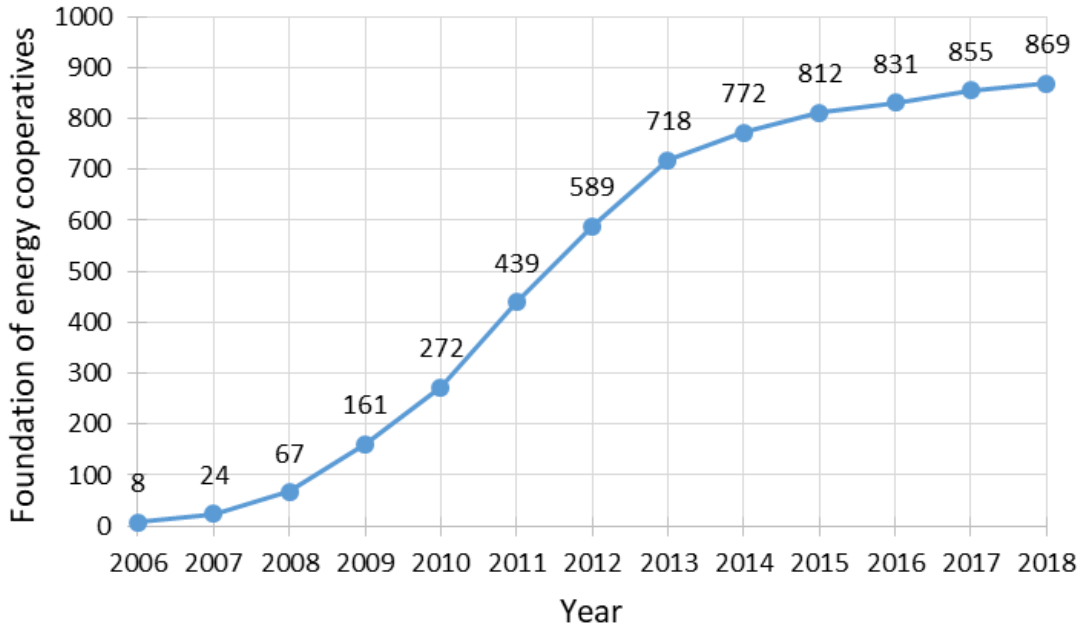
during this time as a measure to counter economic and social problems and to achieve a reduction of poverty in the long run. This led to the formation of the first credit and trade cooperatives (DGRV, 2015). Today, closely to two centuries later, the cooperative movement is very strong and solid in Germany.

The German Cooperative and Raiffeisen Confederation (Deutscher Genossenschafts- und Raiffeisenverband e.V., short: DGRV) is the confederation that organizes, promotes and develops the cooperative system in the country. According to DGRV (2015), the cooperative organization is the largest business organization in Germany in terms of membership, accounting with 19.4 million individuals members of cooperative under the roof of DGRV. This number means that nearly one in each four citizens in Germany is member of a cooperative. In the energy sector, the first boom in the development of energy cooperatives occurred between 1895 and 1932, when at least 6,000 energy cooperatives were established (HOLSTENKAMP, 2012). During this period, energy cooperatives were primarily founded in rural areas to provide electricity to smaller communities. Most of these cooperatives were later dissolved through the many regime changes that Germany experienced.

Since the end of World War II, energy cooperatives were typically founded at times of energy crisis (notably in the field of renewable energy), for example, during the first oil crisis in 1973 and in the aftermath of the nuclear incidents in Chernobyl and Fukushima. According to the DGRV (2019) survey, in 2018 there were 869 RE Coops in Germany accounting with 183,000 members registered at DGRV. Figure 1 presents the foundation of new RE Coops from 2006 to 2018. This survey also found that 75% of these energy cooperatives finance their renewable projects in cooperation with one of Germany's 1047 cooperative banks. Other findings are that the membership structure is comprised of 95% of private individuals, followed by 2% of companies and banks, 2% of farmers and 1% of local authorities/public institutions/churches. Furthermore, 78% of these cooperatives operate solar PV systems (DGRV, 2019).

As shown in Figure 1, there was a "boom" of newly founded energy cooperatives, which experienced a sharp increase up to 2014. This growth was mainly due to Germany's FiT scheme enacted in 2000 by the Renewable Sources Act (known in German as Erneuerbare-Energien-Gesetz, EEG), which granted feed-in-tariffs and priority feed-in-tariffs for electricity originated by renewables (HOLSTENKAMP, 2012; WIERLING *et al.*, 2018). Other reason for this growth, highlighted by Wierling *et al.* (2018), refers to the decision to phase out nuclear power by 2022 after the Fukushima nuclear disaster associated with the movement to accelerate the low carbon energy transition, known as "Energiewende".

Figure 1 - Accumulated growth of newly founded RE Coops in Germany from 2006-2018.



Source: Adapted from DGRV (2019) survey data.

Figure 1 also makes it clear that the number of newly founded energy cooperatives is declining since 2014. This decline is related to the recent revisions in the EEG (HERBES *et al.*, 2017; WIERLING *et al.*, 2018). In 2014 the FiT was gradually replace by a tendering system, and in 2015 an auction system was enacted. These recent changes in policy brought more difficulties to small players to enter the electricity market and therefore made the previous renewable energy cooperatives business model unprofitable. As a strategic option for RE Coops to grow under the recent German policy changes, Herbes *et al.* (2017) suggest that merging with other potentially larger RE Coops could be a good way. This movement is already a reality for some RE Coops in Germany as presented by Wierling *et al.* (2018).

According to Herbes *et al.* (2017), the shift for a tendering system may meet other policy goals, but on the other hand it can threaten the progress made in decentralizing and democratizing the energy system. These authors also point that in order to renewable energy cooperatives continue to play an important role in Germany, policy makers should consider measures to ensure their continued growth.

2.1.1.2 Denmark

Denmark was the pioneer in establishing RE Coops in Europe. However, a sharp decline on the number RE Coops in Denmark can be observed from around 2000 onward (WIERLING *et al.*, 2018).

The oil crisis from 1973 was an important factor on Denmark's shift from fossil fuel to renewable energy. The Danish government applied support mechanisms such as investment grants and tax exemptions, and from the mid-1980s, fixed FiT including guaranteed grid connection, purchase obligations and priority transmission for wind power producers (BAUWENS; GOTCHEV; HOLSTENKAMP, 2016). Due to the country's geography, wind is an abundant resource and by 2017, 49% for the electricity produced in Denmark originated from wind based energy. Before the oil crises, Denmark energy needs relied nearly 80% on imported petroleum. These numbers make clear how significant energy cooperatives initiatives were for the Danish energy transition (WIERLING *et al.*, 2018).

According to Wierling *et al.* (2018), Denmark had more than 650 energy cooperatives in 2014, down from 931 in 1999. The rapid decline in the number of cooperatives since 2002 can be explained by the abolishment of FiT by the center-right government that argued that wind energy technologies were mature enough to not need government support anymore, pushing for market liberalization (BAUWENS; GOTCHEV; HOLSTENKAMP, 2016; WIERLING *et al.*, 2018). The end of FiT was revised in 2009 intending to facilitate a further expansion of local ownership again. However, today the government support system benefits primarily large-scale projects since the government attempts to optimize wind energy generation on a national level (BAUWENS; GOTCHEV; HOLSTENKAMP, 2016).Therefore, wind cooperatives have lost space in Denmark and many of them simply disappeared from the market while others merged attempting to survive to the market into a larger scale format (WIERLING *et al.*, 2018).

2.1.2 RE Coops into the Brazilian Context

In Brazil, the cooperative movement began its history during the Portuguese settling and it was led by public workers, military workers and European immigrants. Officially, the first Brazilian cooperative was born in 1889, in Minas Gerais, and it was named as "Public Workers Economic Cooperative from Ouro Preto". Afterwards, many other cooperatives emerged in Minas Gerais and in other States such as Pernambuco, Rio de Janeiro, São Paulo and Rio

Grande do Sul (OCB, 2018). In 1969, the Brazilian Cooperatives Organization (OCB, from the Portuguese abbreviation) was stablished, which became a milestone for the Brazilian cooperatives movement. OCB is responsible for the promotion and protection of the Brazilian cooperative system in every political and institutional instance. Two years later, the "Cooperatives General Law" (Law 5764/71) was enacted – another major milestone.

Cooperatives are regulated by Brazilian Law No 5764, which states that a minimum number of 20 individuals must form a cooperative. Exceptionally, according to Art. 29, §4°, legal entities with the same goals and economic values as the individual members, can also be admitted into the cooperative ((BRASIL, 1971), as long as the minimum of 20 individuals has been reached.

Cooperatives are active in many economy sectors across the country. As a way to facilitate these cooperatives organization and representation, in 1996 OCB sub-divided cooperatives in 13 branches. Most recently, in 2019, OCB restructured these branches. Today, according to the OCB Resolution 56/2019 the cooperatives are subdivided in seven branches: (1) Agricultural; (2) Consumption; (3) Credit; (4) Infrastructure; (5) Work and production of goods and service; (6) Health and (7) Transportation (OCB, 2019a).

In 2018 there were 6828 cooperatives registered at OCB accounting with nearly 15 million members in total and generating nearly 64 thousand jobs (OCB, 2019b). Table 1 presents the quantity of cooperatives, members and jobs generated per branch. The branch that accounts with the highest number of cooperatives and the one that generates more jobs is the Agriculture. Credit cooperatives present the highest number of members. These numbers are all based on the last OCB annual report (OCB, 2019b) stating numbers from 2018 and, therefore, still based on the past 13 branches structure.

Energy cooperatives fit into the Infrastructure branch together with housing cooperatives, telecommunication, irrigation and basic sanitation. Energy cooperatives are active in distinct functions. In order to shed light on the different type and acting areas in which energy cooperatives are currently developing in the country, a general classification was prepared, as presented in Figure 2 based on the Annual Report from OCB (2019b).

Conventional Generation cooperatives are active in the production of energy for selling at the free or regulated energy market. Rural Electrification cooperatives are responsible for energy distribution mainly in rural areas. These cooperatives appeared in the 1940's in regions where there was no economic interest to take energy to and, therefore, playing a very important role in the electrification of rural areas. Rural Electrification cooperatives had their peak in the

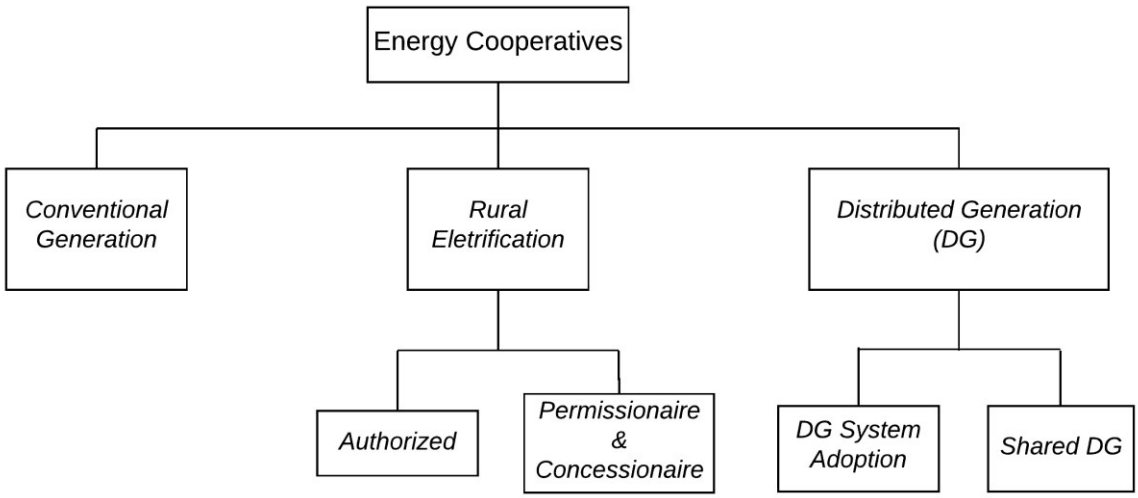
70's and 80's accounting with 280 cooperatives across the country. In the 90's, after the electricity sector was restructured, many cooperatives were incorporated by energy distribution concessionaires (CARDOSO; CAMILO, 2018; MUNARETTO, 2015; OCB, 2019b). Currently, there are 69 Rural Electrification cooperatives registered at OCB and they are classified as Authorized (16), Permissionaire (52) and Concessionaire (1) (OCB, 2019b)

Table 1 - Number of Brazilian cooperatives, members and jobs generated per branch in 2018.

#	Branch	Cooperatives	Members	Jobs
1	Agriculture	1.613	1.021.019	209.778
2	Consumption	205	1.991.152	14.272
3	Credit	909	9.840.977	67.267
4	Educational	265	60.760	3.412
5	Special	10	377	8
6	Housing	282	103.745	742
7	Infrastructure	135	1.031.260	5.824
8	Mineral	95	59.270	177
9	Production	230	5.564	1.132
10	Health	786	206.185	107.794
11	Labor	925	198.466	5.105
12	Transportation	1.351	98.190	9.792
13	Tourism and Leisure	22	1.867	15
Total		**6.828**	**14.618.832**	**425.318**

Source: OCB (2019b)

Figure 2 - Energy cooperatives classification structure



DG cooperatives fit into the DG context according to the current regulation (REN 482/2012 and REN 687/2015), which is explained in better detail in the next subsection (2.2.1 The shared DG modality). DG cooperatives are here classified in DG System Adoption and Shared DG. DG System Adoption cooperatives are existing cooperatives, from any branch, which adopt a DG system and generate RE energy to their own consumer units.

By the end of the year 2019, there were 255 cooperatives which had adopted a DG system and were registered at ANEEL[1]. Together, they add to around 11 MW of PV capacity installed. Figure 3 indicates the quantity of DG cooperatives that fit into the 'DG System Adoption' category per branch. Credit cooperatives is the branch that most adopted distributed energy generation (98 registered at ANEEL), followed by Agricultural (64) and Infrastructure (32). These data are also still based on the 13 branch structure.

Figure 3 - Number of DG cooperatives that fit into the 'DG System Adoption' category per branch

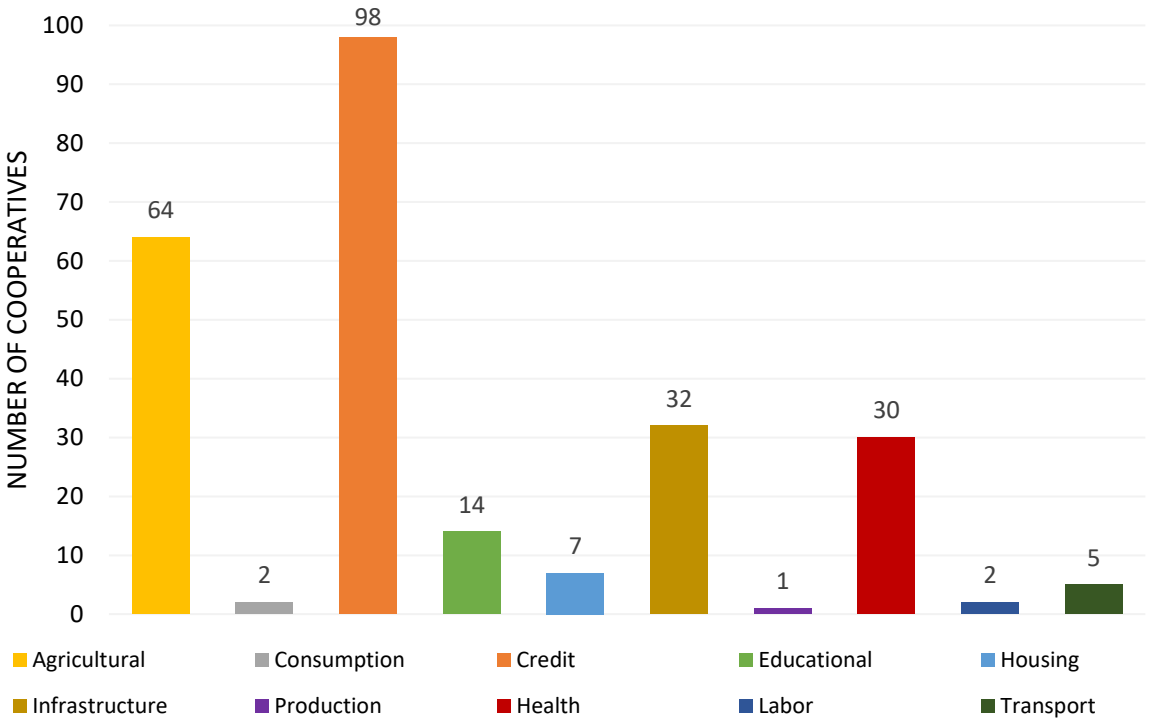
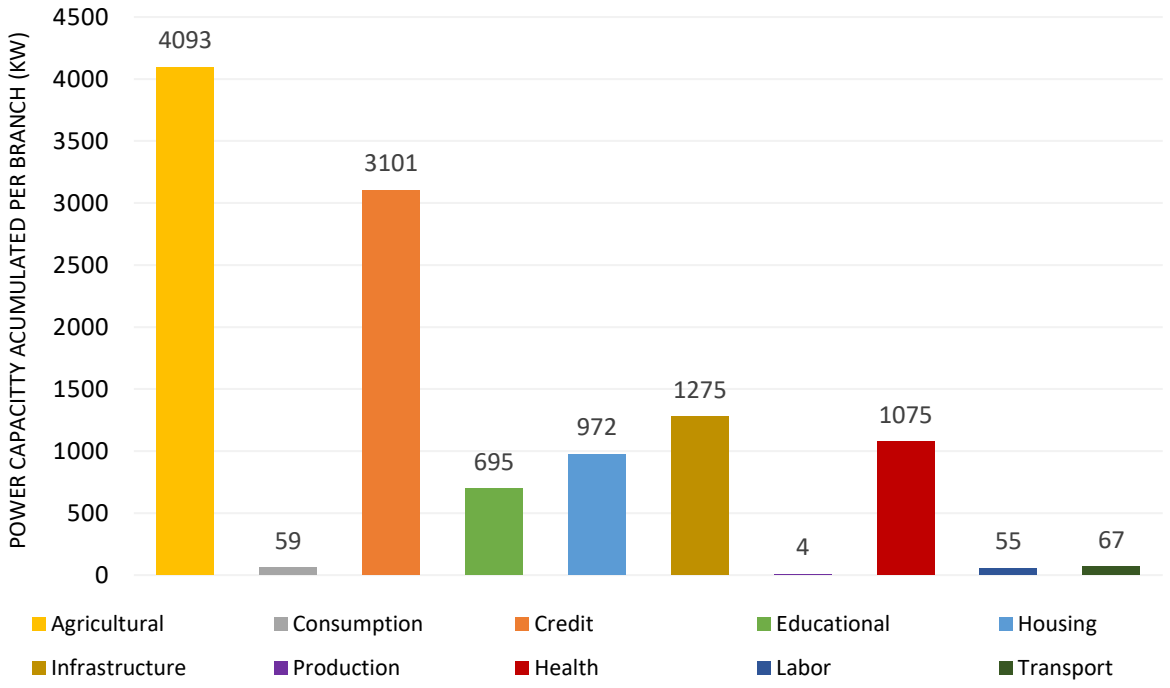


Figure 4 presents the total power capacity installed at those cooperatives. Agricultural cooperatives are the branch with the highest nominal power installed (4093 kWp), followed by Credit (3101kWp) and Infrastructure (1275kWp).

[1] Data compiled and provided by Marco Olívio Morato de Oliveira, energy and environment technical and economic analyst from OCB.

Figure 4 - Power capacity connected to the grid per branch of cooperative that fit into the 'DG System Adoption' category



Shared DG Cooperatives fit into the shared DG modality according to REN 687/2015. These generation cooperatives generate RE for their members and compensate kWh in their energy bill through the virtual one-to-one net-metering scheme. These model of energy cooperative fits into the energy community concept and at the RE Coops description according to the introduction of this work. From now on in this work, RE Coops in Brazil will be referred to as Shared DG Coops aiming to relate it with the DG model they fit in to according to the Brazilian regulation.

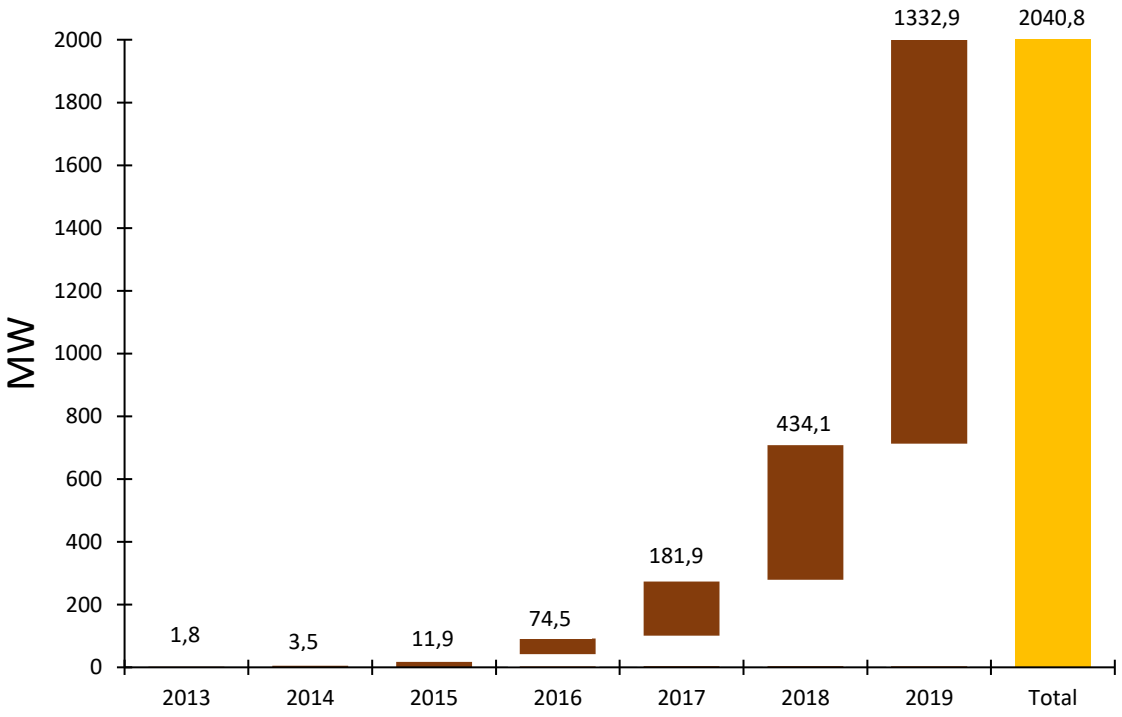
2.2 SHARED DG COOPS IN BRAZIL

In Brazil, decentralized energy generation based primarily on small-scale (up to 5MW) PV connected to the distribution grid only became a reality in early 2013, when the Brazilian Electricity Regulating Agency ANEEL issued REN 482/2012. This regulatory framework allowed individuals and legal entities to generate their own energy at the consumer unit location through a net-metering scheme.

Up to December 2019, there were around 160 thousand DG units at the ANEEL registry, amounting to nearly 2 GW of power capacity installed. From these, solar PV source accounts

with around 1.8 GW installed, representing nearly 90% of the total (ANEEL, 2019a). Figure 5 presents the power capacity of DG increase since 2013, when REN 482/2012 was issued. From 2016 up to date DG systems has experienced an impressive increase. In 2019 the DG power capacity increased 3 times more in comparison to the year before. This fact is directly related to significant drop on PV systems equipment and installation prices (IDEAL & AHK; 2019).

Figure 5 - DG power capacity growth per year since REN 482/2012 was issued



Every three years, ANEEL's regulations that causes meaningful impacts on the electricity grid must go through a revision process, which includes a public consultancy process. In 2015, REN 482/2012 went through a revision process that issued REN 687/2015, which came into force in 2016. REN 687/2015, among some other changes at REN 482/2012, enforced the Shared DG modality (see '2.2.1 The shared DG modality') and allowed decentralized RE communities.

In 2018, the DG regulation REN 482/2012 began a new revision process. The revision process was planned to be concluded by 2019-second semester with a reviewed regulation issued, which did not happened. The main topic of discussion at this current revision process is the amount of energy credit to be compensated at the prosumer energy bill. Currently, the DG regulation accounts with a one-to-one net-metering scheme (each one kWh exported to the grid generates a one kWh credit to be compensated). The energy tariff is compound of many

components (Figure 6) and ANEEL's new proposal aims to compensate only some of these components according to the alternatives presented at Figure 7.

Figure 6 - Electricity tariff components

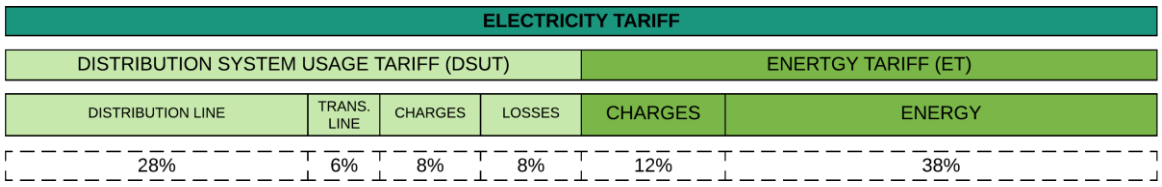
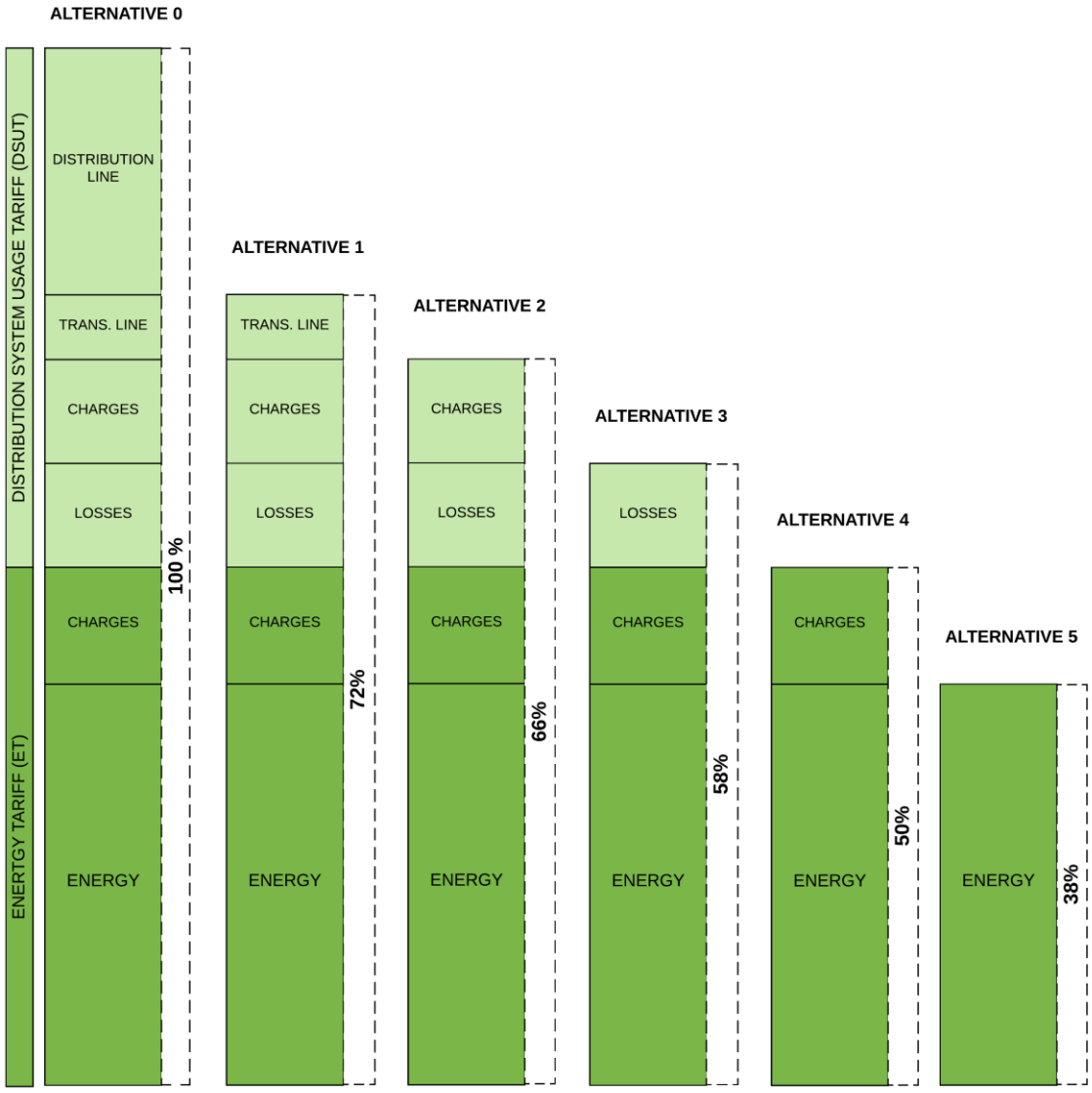


Figure 7 - ANEEL's proposal alternatives for regulation revision



Source: Adapted from ANEEL (2018)

There are two main actors in the discussion with ANEEL: the utilities and the DG sector players. From one side, the utilities stand for the argument that the one-to-one net-metering scheme encumbers the utilities once the prosumer stop contributing with some tariff components concerning the grid distribution. In consequence, electricity consumers who do not generate their own energy through a DG system will suffer with future tariff's increase "paying the bill" that the prosumers are not. The utilities are calling it as "Upside down Robin Hood", which implies taking from the poor and diving to the rich.

On the other side, the DG sector players (mainly the solar PV players due to its higher representation), stand for the argument that a drastic change in the regulation, such as the Alternative 5 for example, will kill a newborn successful market. In addition, these players argue that ANEEL is not considering the environmental and social benefits around solar DG, such as generating energy without throwing CO_2 at the atmosphere and the significant amount of employment the market is generating.

This revision process is generating a great instability in the DG sector and it is challenging to foresee the next chapters of this historical moment the sector is going through. A reviewed regulation is planned to be issued along the year of 2020.

2.2.1 The shared DG modality

In order to participate at a RE community, and to fit into the DG net-metering scheme regulated by REN 482/2012 and REN 687/2015, all members consumer units must be located at the same concession area the local distribution utility in which the RE system is connected to. From 2016 up to the end of the year of 2019, there were 471 DG units registered as shared DG at ANEEL, representing only 0.3% of the total DG units registered. For power capacity, the amount registered was 32 MW, which represents only 1.6% of the total 2 GW of DG power capacity registered up to the end of 2019.

Shared DG modality can be subdivided in three models: (1) shared condominia, (2) shared DG consortia and (3) shared DG cooperatives. Shared condominia are characterized by vertical or horizontal condos with a distributed generation system installed, and by which the energy generated is compensated among all the joint consumer units. This shared distributed generation model can be applied either to residential or to commercial condos. All consumer units must be located at the same property, or they must be neighbors and not be crossed by public roads (ANEEL, 2015).

Shared DG consortia gather enterprises that make an agreement among them through a business contract in order to take benefits from sharing a distributed generation system. The consortia must subscribe to the National Registry of Legal Entities (CNPJ, from the abbreviation in Portuguese) and own the consumer unit where the energy distributed generation system will be installed (ANEEL, 2015).

Shared DG cooperatives are characterized by individuals who wish to voluntarily gather, according to the cooperative's principles, in order to generate their own energy through a DG system. The energy generated by the DG system is compensated at the consumer units of the cooperative members through the net metering scheme (ANEEL, 2015).

This thesis focuses on investigating and presenting in deeper detail the shared DG cooperatives that use solar PV as the energy technology, which are here named as shared solar coops. The next subsection presents in more detail some barriers shared solar coops find for a larger development in the country and some business models in which they can be organized according to the literature.

2.2.2 Barriers for the larger development of shared solar coops

Even though shared solar coops are the most common model of shared DG cooperatives to date, they still face some barriers to become more popular in Brazil. Since it is a new DG modality in the country, it is noted that there is a lack of knowledge and understanding about the model. This stems from both the cooperative as well as from the utilities side. From the cooperative side, a lack of both technical knowledge about the technology and about the shared DG model through the net-metering scheme is noted, as well as of understanding about the cooperative model and its principals itself. From the utility side, it is noted a lack of experience on how to operate the DG model and properly compensate the energy generated by a shared PV system at the consumer units of a cooperative.

Another barrier found is that, for newly shared solar coops to be founded, there is a need of reaching scale in order to achieve a better economic viability. In this scenario, newly founded cooperatives have a great barrier in order to reach scale since gathering initial capital is a major difficulty. One of the reasons for that is the fact that there are currently no financing options suitable for this model.

In addition to this, there is also the need of paying the 'contracted power demand' for PV, which implies to a monthly cost required for systems greater than 75 kWp connected to the network (classified as minigenerators by REN 482/2012). In informal conversations with

people interested in establishing new shared solar coops in Brazil, they have expressed this concern as a major barrier for forming minigeneration cooperatives (with nominal power between 75kWp and 5MWp) since this fee could jeopardize the cooperative economic viability.

There are also regulation barriers to be addressed. In April 2015, the National Finance Policy Council CONFAZ published the goods and services tax (ICMS) agreement 16/2015, which allows individual States to exempt ICMS taxes from DG net-metering operations. The issue here is that the ICMS agreement 16/2015 was established during REN 482/2012 period of validity and, therefore, does not automatically apply to REN 687/2015 updates. For example, ICMS tax exemptions are only possible for distributed generation projects up to 1MW (which is the original REN 482/2012 maximum installed power for microgenerators that was increased to 5MW by REN 687/2015) and are not possible for Shared DG modalities.

The State of Minas Gerais (MG), is the only State across the country that does not follow that rule. This is because the State enacted Law No 22549/2017, adding Article 8-C to the Law No. 6763/1975, which consolidates the tax legislation. Through this Law, in the State of MG, the ICMS is exempt for distributed solar generation up to 5MW and for shared solar distributed generation as well.

The current regulation instability is also a presenting itself as a great barrier for the development of new shared solar coops, since elaborating a techno-economic analysis of a cooperative business model without certainty about the regulation context for the next 20-30 years is a very tough job and very discouraging.

2.2.3 Shared solar coops business models

Noticing the importance of spreading information about shared solar coops, in April 2018, OCB in partnership with Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and German Cooperative and Raiffeisen Confederation (DGRV, from the German abbreviation), with the support of *Instituto IDEAL*, launched a handbook about shared solar coops in Brazil. This handbook explains to the reader in an easy and very straightforward manner what a solar distributed generation cooperative is, how it works, what are the main rules, possible business models structures, what are the steps to establish a shared solar coop, etc. This handbook was written by Lima (2018) with technical revision by many professionals with knowledge in the solar PV distributed generation area and it is called “Energy Cooperatives: A Guide to Solar Distributed Generation Cooperatives”. The PDF version of the handbook is available at *Instituto IDEAL’s América do Sol* platform (www.americadosol.org)

and printed copies can be requested at *Instituto IDEAL* (www.institutoideal.org). Figure 8 shows the cover page of the guide.

Figure 8 - 'Energy Cooperatives: A Guide to Solar Distributed Generation Cooperatives' cover page



A shared solar distributed generation through a cooperative can be carried out in different business models according to the interest of the cooperative members. Lima (2018) highlighted three main possible business models for shared solar coops: (1) Own Resources; (2) External Financing; (3) PV System Leasing. A combination of these is also possible.

In the first model, Own Resources, the cooperative members take their own capital to invest in the PV system and the energy generated is used to offset their expenses with the electricity bill. Therefore, the return on invested capital is given by the savings on the electricity bill. The cooperative members have monthly expenses only with the administration activities to run the cooperative and O&M (Operation and Maintenance) services with the PV system, plus the utility connection availability (*custo de disponibilidade* in Portuguese) fee.

The second model, External Financing, fits cooperative members who do not have or do not want to invest their own capital on the PV system. Therefore, in this case, the members take external finance for the system installation. As in the first model, the return on invested capital is given by the savings on the electricity bill. The cooperative members monthly expenses are with the administration activities to run the cooperative, O&M services with the PV system and with paying back the financing, plus the utility connection availability (*custo de disponibilidade* in Portuguese) fee.

In the third model, PV System Leasing, the cooperative members lease a PV system from a third party to produce energy in order to compensate their expenses with the electricity bill. Therefore, there is a capital flow from the cooperative members to the cooperative administration to run the cooperative and to pay the PV system leasing. On the other hand, there is a capital flow from the cooperative administration to the PV system lessors whose, in turn, are responsible for O&M services and ensuring the PV system performance. The length of the leasing period varies according to the contract firmed between the third party lessor and the cooperative, but usually it takes no longer than 25-30 years (the PV modules life cycle period). Table 2 gives a brief comparison of the three business models. Here again, the utility connection availability (*custo de disponibilidade* in Portuguese) fee must be paid monthly by the cooperative member.

Table 2 – Shared solar coops business models comparison

Model	**Own Resources**	**External Financing**	**PV System Leasing**
Ideal for	Members that have and want to spend their own capital to invest with the PV system	Members that do not have or do not want to spend their own capital for pursuing the PV system	
Capital flow	Members benefit from all savings produced by the PV system generation	Initially, savings from the energy generation are used with the financing payment. Once the financing payment is completed, the cooperative members benefit from all savings produced by the PV system generation	A leasing monthly payment is given to the PV system lessor. This payment, preferably, must be lower than the energy savings on the electricity bill.

Source: Adapted from Lima (2018)

PV systems can be installed on buildings roofs, like schools, churches, sheds and so on, or either on the ground as PV power plants. The location where the PV system will be installed must be defined by a contractual agreement between the cooperative members, even if some member owns the location and intends to donate or lease it for the cooperative. Therefore, into Own Resources and External Financing models, three model possibilities about the location where the PV system will be installed were identified by Lima (2018): (1) Leasing; (2) Purchasing and (3) Cession.

In the first model, Leasing, the roof or land selected to host the PV system installation is leased from the site owner. Therefore, the cooperative members have no initial costs with the PV system location acquisition. On the other hand, cooperative members must make a monthly payment for the land/roof leasing.

In the second model, Purchasing, the location where the PV system will be installed is purchased and the cooperative members must consider these expenses into the initial costs. In the third model, Cession, the location is donated and there are no extra costs with the PV system site acquisition for the cooperative. In any situation, the site owner plays a very important role and all aspects related to the site area must be taken into account from the very beginning of the techno-economic viability analysis (LIMA, 2018).

Considering this entire context, this thesis presents an historical summary of the early days of the development of shared solar cooperatives in Brazil, and breaks the lack of literature about this topic, while shedding light on it and contributing to the national and international discussion.

3 METHOD

This thesis method was divided into three parts: (1) part one refers to the development of a shared solar cooperatives web tool; (2) part two refers to mapping and investigating the existing shared solar coop under operation in Brazil; (3) part three consists of the development of a framework that organizes the possible business model arrangements shared solar coops can be organized in, according to the findings investigated in the second part of this work.

3.1 PART ONE: SHARED SOLAR COOPERATIVES WEB TOOL

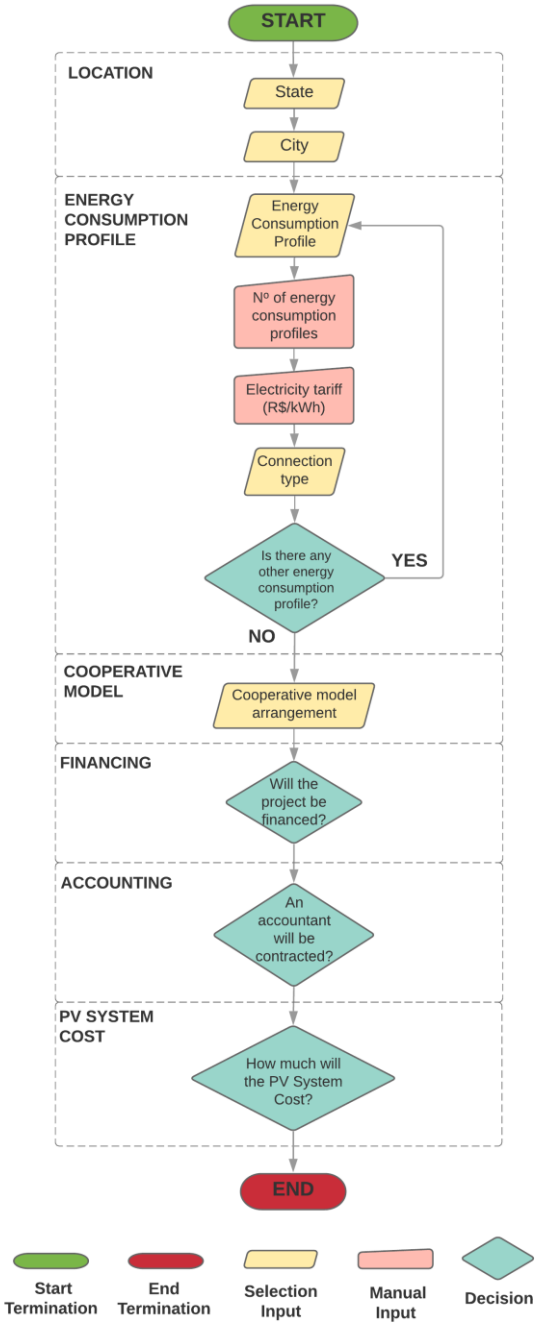
The idea of developing a solar cooperatives web tool came in parallel with the Solar Cooperatives Guide (see 2.2.3 Shared solar coops business models) launching and the development of the work leading to this thesis. The Guide brings to the reader three examples of groups of individuals with different energy consumption profiles, located in a given city and inserted in a given context. These examples show what would be the initial investment each individual would have to make, according to his/her energy consumption profile, to participate in the cooperative. Also, the examples give an idea of how much money these individuals would have to spend monthly to maintain the cooperative, and what would their savings on the electricity bill be when becoming a cooperative member. However, these examples soon become dated since PV system prices are changing and dropping every year (as shown in Figure 16 further below). In addition, even though the examples are very simple and easy to follow, they do not encompass other contexts of location (and, therefore, solar resource availability), energy consumption profile, or electricity tariff that the prospective cooperative candidate pays.

The solar cooperative web tool was thus designed to become a complementary tool to the Solar Cooperatives Guide, becoming at the same time a contribution of Fotovoltaica-UFSC and *Instituto IDEAL* to facilitating the adoption of the solar cooperatives model, and an integral component of the present thesis. As an easy way to train the prospective cooperative candidate on the web tool, the Guide reader can access the web tool and fill it in with inputs just by reading the examples from the Solar Cooperative Guide and, if filling the inputs correctly, he/she should receive the same outputs presented in the Guide examples. This procedure can thus be used to check the user's understanding of the process. Once understanding the steps properly, the user could then simulate his/her own context checking the techno-economic viability of starting a solar cooperative according to his/her reality.

3.1.1 Web tool inputs

Based on the Solar Cooperative Guide examples and in order to incorporate all possible input combinations, the web tool was divided into six sub divisions: (1) Location; (2) Energy consumption profile; (3) Cooperative model; (4) Financing; (5) Accounting and (6) PV system costs. Figure 9 shows the web tool inputs workflow. The elements and information are color- and shape-coded as indicated below.

Figure 9 - Web tool inputs workflow

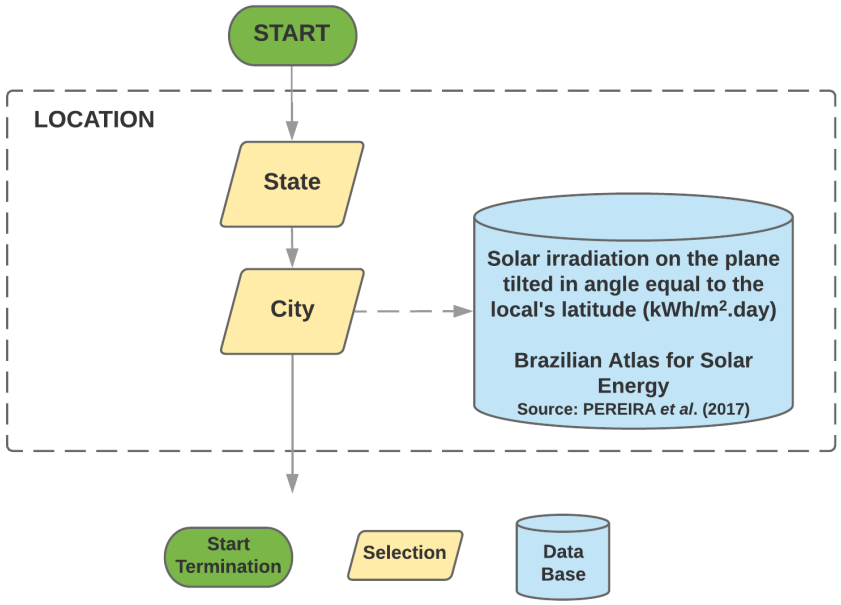


It is important to highlight that the inputs were thought to be accessible to any kind of user, from individuals who might have some knowledge and understandig about solar systems and shared solar cooperatives to individuals who know little or even nothing about the subject. Therefore, the inputs could not be very technical, neither use a very specific language. The next sub-sections explain the calculation method behind each input sub division.

3.1.1.1 Location

The first input is about the location where the user plans to install his/her shared solar coop in Brazil. He/she must choose the State and city desired. According to the city selected, the web tool will consider the solar irradiance for that location according to the Brazilian Solar Energy Atlas (PEREIRA *et al.*, 2017). The Brazilian Solar Energy Atlas provides irradiation information from collected satellite data from over 17 years, which was validated thorough solarimetric stations spread across the national territory. Figure 10 shows this input flowchart. The elements and information are color- and shape-coded as indicated below.

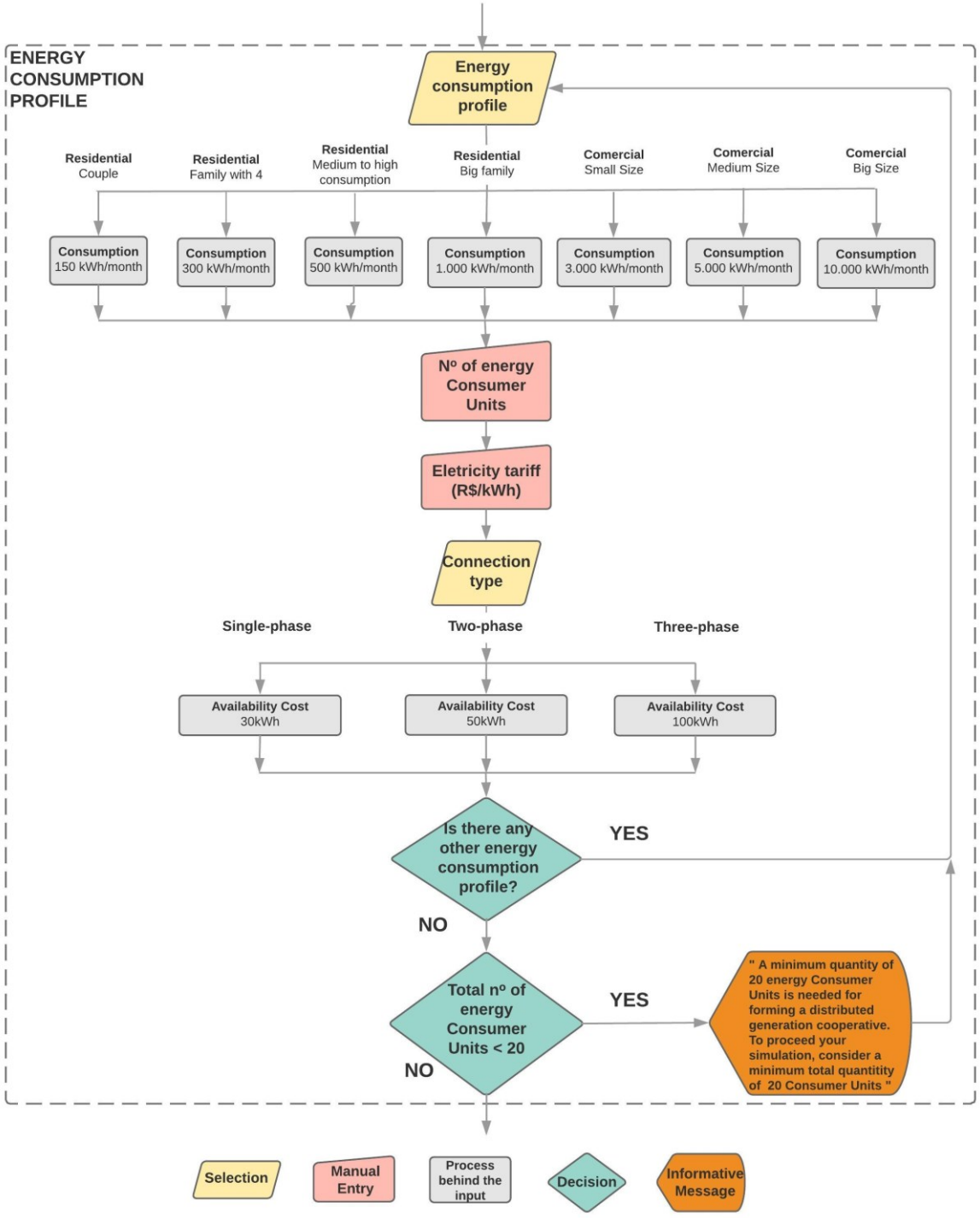
Figure 10 - Location inputs flowchart



3.1.1.2 Energy consumption profile

This input is about the energy consumption profile from the individuals who wish to start a shared solar coop. Figure 11 shows this input flowchart.

Figure 11 - Energy consumption profile inputs flowchart



Firstly, the user chooses the energy consumption profile. These profiles are pre-defined by the web tool and are divided into four consumption profile options characterized as “Residential” and three consumption profile options characterized as “Commercial”. These profile options and their respective monthly average consumption value (in kWh/month) are

shown in Figure 11. The energy consumption profile nomenclature was given according to Guide's examples, which were prepared thinking in layman users who usually do not know and understand his/her consumption in a kWh/month base.

Moving forward, the user types the number of individuals that fits the chosen energy consumption profile and its corresponding electricity tariff. Afterwards the user selects the electrical connection type that the consumption profile chosen is registered at. The options are: (1) Single-phase; (2) Two-phase and (3) Three-phase. Finally, the user can either add another energy consumption profile or continue his/her simulation. The web-tool does not allow the simulation to be completed if the number of individuals is smaller than 20. This is because according to Law 5764, the Brazilian General Cooperatives Law, a minimum number of 20 individuals is necessary to start a cooperative.

The inputs chosen in the 'Location' and 'Energy consumption profile' sub divisions are used for sizing the PV system needed for supplying the energy consumption from the cooperative members. The 'Connection type' input is directly related to the utility grid availability surcharge, which represents the electricity system availability for the consumer unit for net metering, and it is applied for Group B (low voltage) consumers. In other words, even though a consumer unit can generate the total amount of energy it consumes, the availability surcharge will be charged and it will be the equivalent, in the Brazilian currency R$, to the connection type the consumer is registered at: single-phase (30kWh), two-phase (50kWh), or three-phase (100kWh). Therefore, for sizing the PV system, the sum of the availability surcharge from each consumer unit is discounted from the total energy consumption. The equation for sizing the PV system is represented by Equation (1).

$$P_{PV} = \frac{(\sum_{i=1}^{n} E_c - \sum_{i=1}^{n} Avb_c)\ x\ I_{ref}}{I_{til}\ x\ PR} \quad (1)$$

Where P_{PV} is the nominal power the PV system must have to supply the combined energy demand from all cooperative members. E_c represents the energy consumption profile in kWh/month, Avb_c represents the availability surcharge in kWh/month, I_{ref} is the reference irradiance (=1 kW/m^2), I_{til} is the solar irradiation on the plane tilted at an angle equal to the local latitude, in kWh/m^2.month and PR is the performance ratio (typically = 75%, set as a default value).

In addition, according to the energy consumption profiles, the Fraction Use (*FU*) is calculated. The *FU* per consumer unit represents the fraction from the PV system that a

cooperative member needs to "own" in order to supply his/her energy consumption. Therefore, *FU* will determine the fraction from the initial costs the cooperative member has to invest, the amount of the energy generated from PV system which is reserved to him/her, and the amount of the cooperative monthly expenses he/she is responsible for. *FU* is calculated for each energy consumption profile chosen (E_c), and the corresponding availability surcharge (Avb_c) as represented in Equation (2).

$$FU = \frac{E_c - Avb_c}{\sum_{i=1}^{n} E_{ci} - \sum_{i=1}^{n} Avb_{ci}} \quad (2)$$

3.1.1.3 Cooperative model

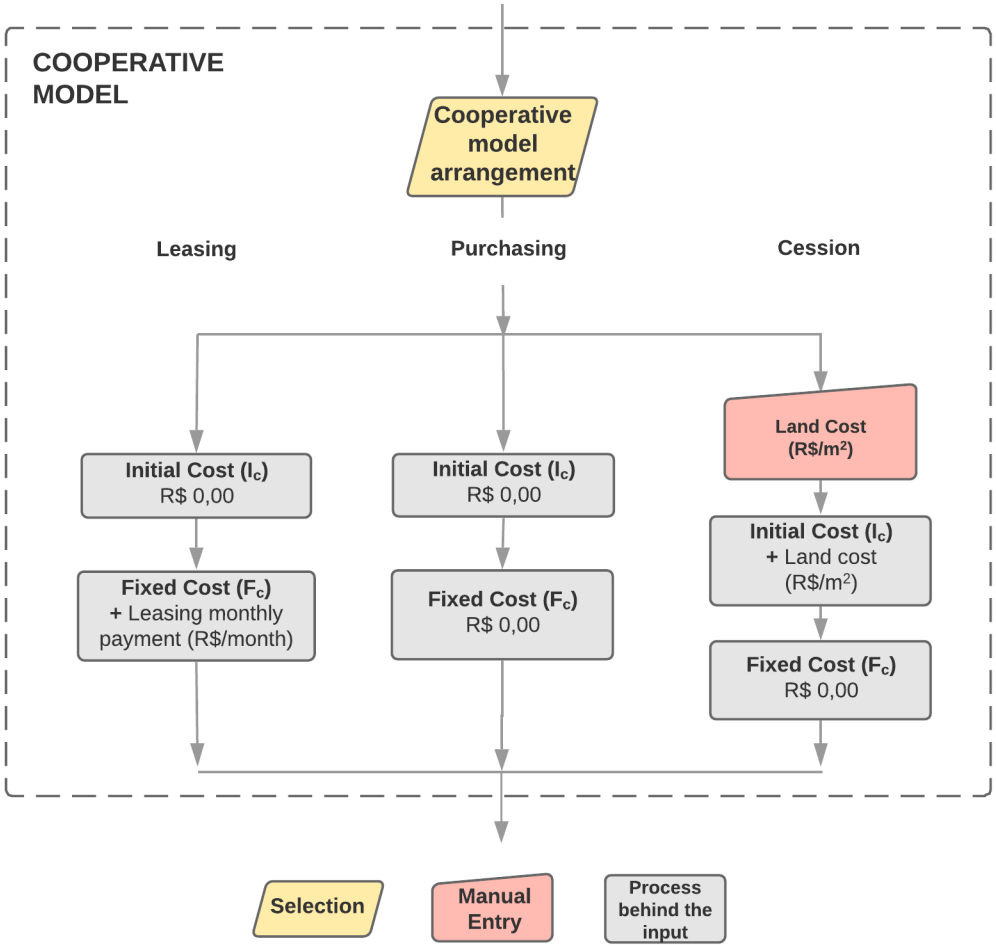
PV systems can be installed on buildings roofs, like schools, churches, sheds and so on, or either on the ground as ground-mounted PV power plants. This input refers to the location where the PV system will be installed and its impacts on the initial costs (I_c) and fixed costs (F_c) calculations. These input options are based on the three models identified by Lima (2018) as explained in section '2.2.3 Shared solar coops business models': (1) Leasing; (2) Purchasing and (3) Cession.

In the Leasing model, the roof or land used for the PV system installation is leased or rented from the site owner. Therefore, the cooperative members have no I_c with the PV system site acquisition. On the other hand, cooperative members must account for a monthly payment as F_c due the site leasing/renting[2].

In the Purchasing model, the site where the PV system will be installed is purchased and the cooperative members must consider these expenses into the I_c. The value of the land cost is an input inserted by the user in R$/m^2. In the Cession model, the location is donated and there is no I_c with the PV system site acquisition and no F_c. Figure 12 presents the cooperative model inputs workflow.

[2] If $P_{PV} \leq 75$ kWp (microgeneration), the F_c with the site leasing/renting considered is 1 R$/m^2. If 75 kWp < P_{PV} < 5MW (minigeneration), the F_c with the land/roof leasing/renting considered is 0.75 R$/m^2. These differences according to the PV system nominal power size are due to economies of scale. These values were based on information provided by the Solar Cooperatives Guide writers and technical reviewers who, based on their experiences, have defined those values as realistic for this context.

Figure 12 - Cooperative model inputs workflow

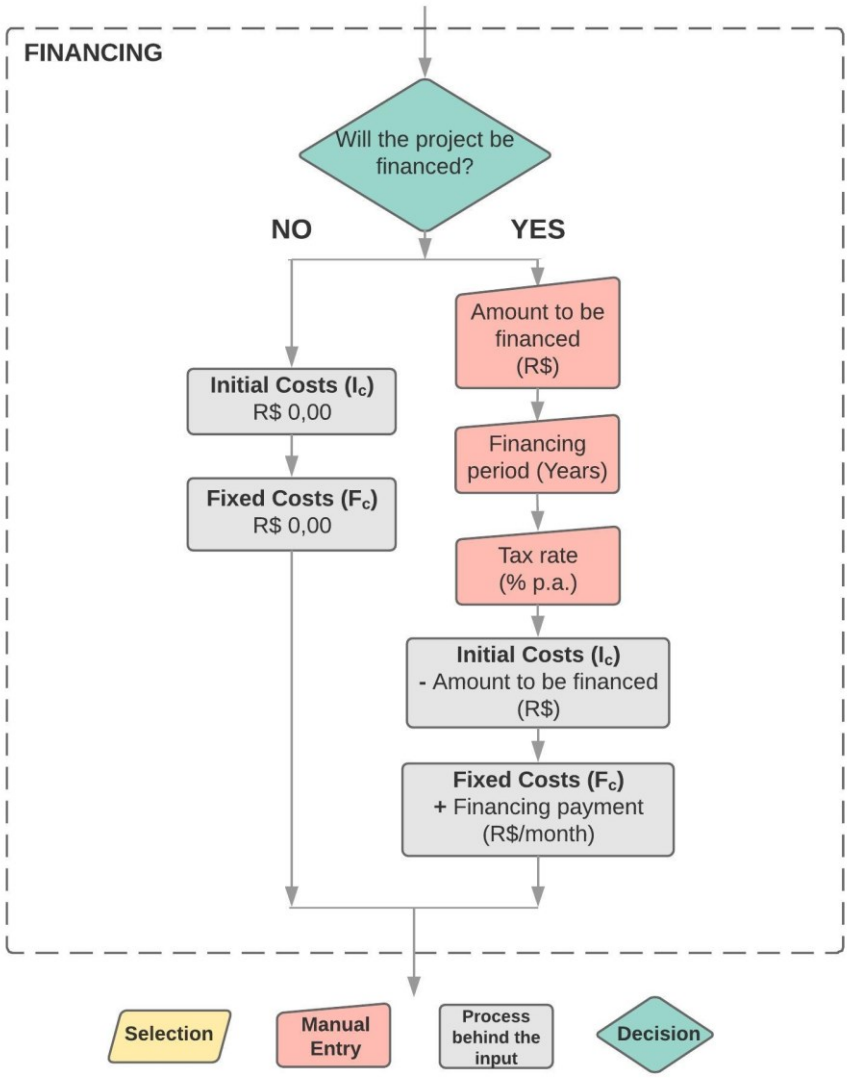


3.1.1.4 Financing

This input takes into consideration if the user wants or not to finance the PV system project. If the answer is "Yes", this option fits cooperative members who do not have or do not want to invest their own capital in the PV system. Therefore, in this case, the members take a loan for buying the PV equipment and installation. In consequence, the amount financed is discounted from the initial costs (I_c) and converted into fixed costs (F_c) through the monthly financing payment. If that is the option chosen, the user must insert the amount value he/she wants to finance (FN_A), the financing period (n) in years and the yearly finance interest rate (t). If the user choses "No" and does not want to simulate his/her shared solar coop considering financing options, there are no extra costs considered in I_c and F_c.

Figure 13 shows the financing inputs flowchart. Equation (3) represents the formula used to calculate the financing monthly payment costs (FN_c).

Figure 13 - Financing inputs flowchart



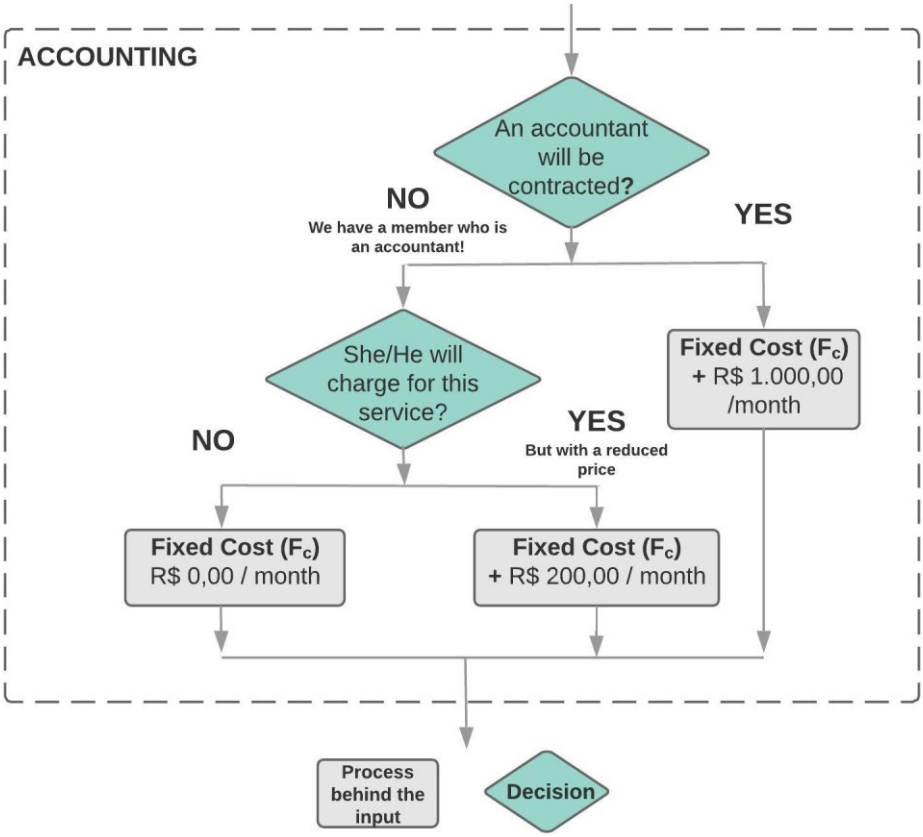
$$FN_C = \frac{FN_A\ [t(1+t)^n]}{12\ x\ [(1+t)^n - 1]} \quad (3)$$

3.1.1.5 Accounting

This input considers if the cooperative will hire an accountant to take care of the cooperative accounting and administration, or if there is any cooperative member with those

skills that will offer this service at a reduced cost or even for free. This input has direct impacts on the fixed costs (F_c). Figure 14 shows the 'Accounting' input flowchart.

Figure 14 - Accounting input flowchart



3.1.1.6 PV system cost

This input refers to the cost in R$/Wp that will be considered for calculating the PV system equipment and installation costs. Figure 15 presents the PV system costs input flowchart, where the elements and information are color- and shape-coded as indicated.

For this input, it was considered that either the user has no knowledge about PV technology/market or he/she does have knowledge about the subject and wants to simulate the cooperative with the PV prices from his/her current context. Therefore, this input asks if the user wants to consider the PV system price values taken from *Instituto IDEAL's* Brazilian PV market study[3]. If the answer is "Yes", the web tool calculates the PV system equipment and

[3] Available at www.americadosol.org/acoes-do-instituto-ideal/

installation costs according to *Instituto IDEAL's* 2018 market study, which considers PV market prices from year 2017 (IDEAL; AHK-RJ, 2018). Figure 16 shows the evolution of PV system prices in Brazil from 2013 to 2017. If the answer is "No", the user must input the value he/she wants to use for the simulation. With the current dynamics on PV system prices, market study values are quickly out of date, and the user is therefore urged to research the most recent market price conditions at her/his location.

Figure 15 - PV system cost input flowchart

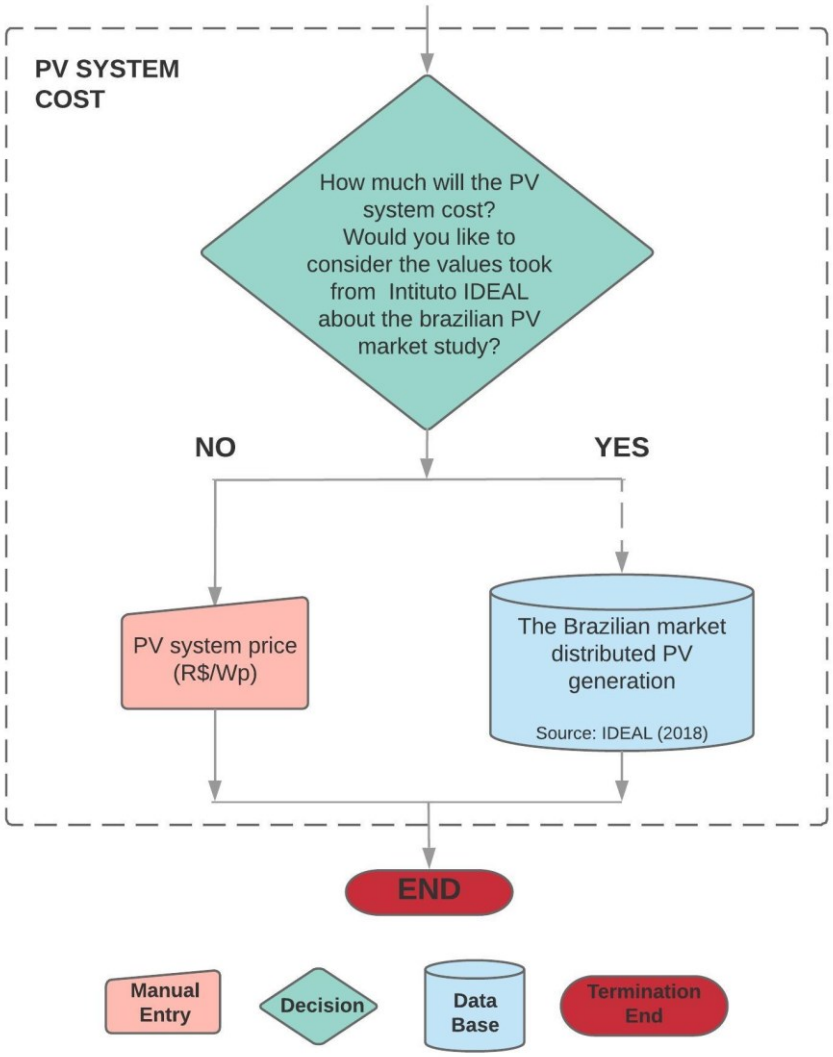
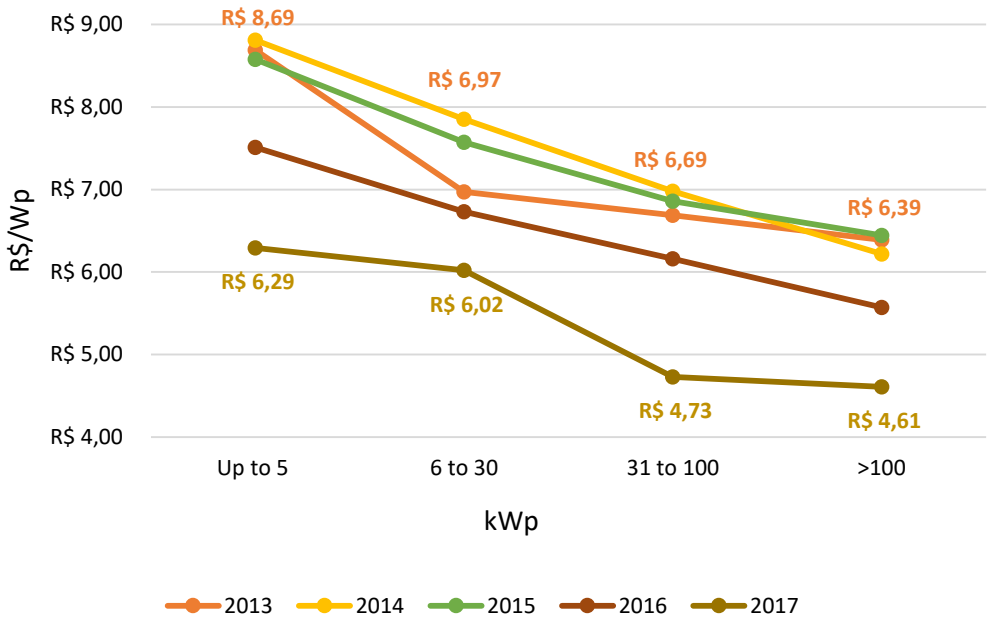


Figure 16 - PV system prices by nominal power range according to the Brazilan PV market study from *Instituto IDEAL*



Source: Adapted from IDEAL and AHK-RJ (2018)

3.1.2 Web tool outputs

The webtool outputs were also based on what is presented at the three examples from the Solar Cooperatives Guide and were divided into four sub-divisions: (1) PV System Characteristics; (2) Expected Costs; (3) Expected Savings and (4) Financing.

The output values for the 'PV System Characteristics' are presented in Figure 17. These outputs inform the PV system nominal power needed to supply the cooperative members' energy demand, the expected average monthly energy generation, the needed area for installing the PV system and, finally, the PV system equipment and installation price.

Figure 17 - PV system Characteristics outputs

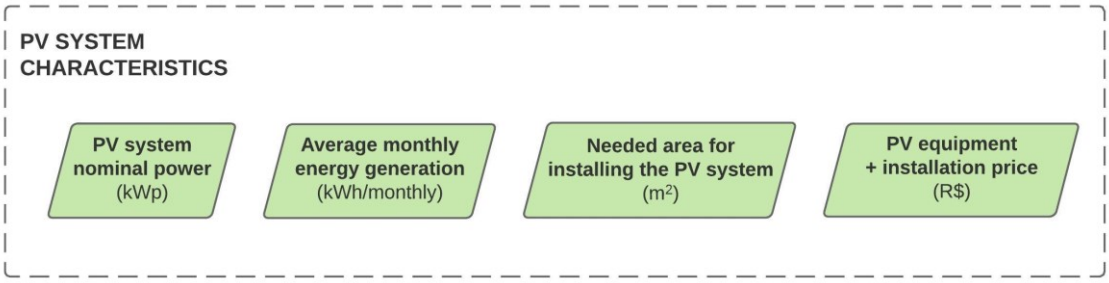


Figure 18 shows the outputs for 'Expected Costs', which are given for each energy consumption profile defined at the web tool inputs. These expected cost outputs include the initial investment costs (I_c) and the apportionment of monthly expenses each cooperative member will have to pay according to their corresponding profile for maintaining the cooperative. In the apportionment of monthly expenses output the fixed costs (F_c) of the cooperative are considered, and can be calculated using Equation (4) times the Fraction Use (FU) calculated according to the energy consumption profile explained in section '3.1.1.2 Energy consumption profile'

$$F_c = A_c + L_c + FN_c + PD_c + \mathrm{OM_C} \quad (4)$$

Fc is the composition of the costs with the cooperative accounting (Ac), site leasing costs (Lc), financing costs (FNc), contracted power demand costs (PDc) and O&M costs (OM_C). Ac represents the expenses with maintaining an accountant for the cooperative administration management and this value is selected as explained in section '3.1.1.5 Accounting'. Lc represents the annual expenses with leasing the site where the PV system is installed. This parameter only appears if the location where the PV system will be installed fits the Leasing model as explained in section '3.1.1.3 Cooperative model'. FNc represents the portion spent according to the finance conditions adopted, and it only appears if the user choses to finance the PV project as explained in '3.1.1.4 Financing'.

PDc represents the costs with the contracted power demand and it is considered only if the PV system size is above 75 kWp (minigeneration). If that is the case, PDc is calculated as the PV system nominal power times the tariff price including taxes (ICMS, PIS and COFINS) for Group A4, which are defined by each State of the Brazilian Federation. The tariff price for Group A4 of each State was defined by selecting the main utility of the State, taking the concession area it supplies as parameter[4]. The base month for the tariff prices was July 2018 and these values were taken from the distribution utilities webpages or by phone calls when the information was not available at the website. These utilities and tariff prices values for each State are shown in APPENDIX A.

OM_C represents the costs with the PV system operation and maintenance. This value was considered as a fraction of the initial investment with the PV system equipment and installation.

[4] This analysis was carried out through the Brazilian utility map available at ANEEL webpage through the link: www.aneel.gov.br/distribuicao2

If the PV system size is up to 75 kWp (microgeneration), this value represents 1.5% of the initial investment. If the PV system is larger than 75 kWp and up to 5MW (minigeneration), this value represents 0.8% of the initial investment.

Figure 18 - Expected Costs outputs

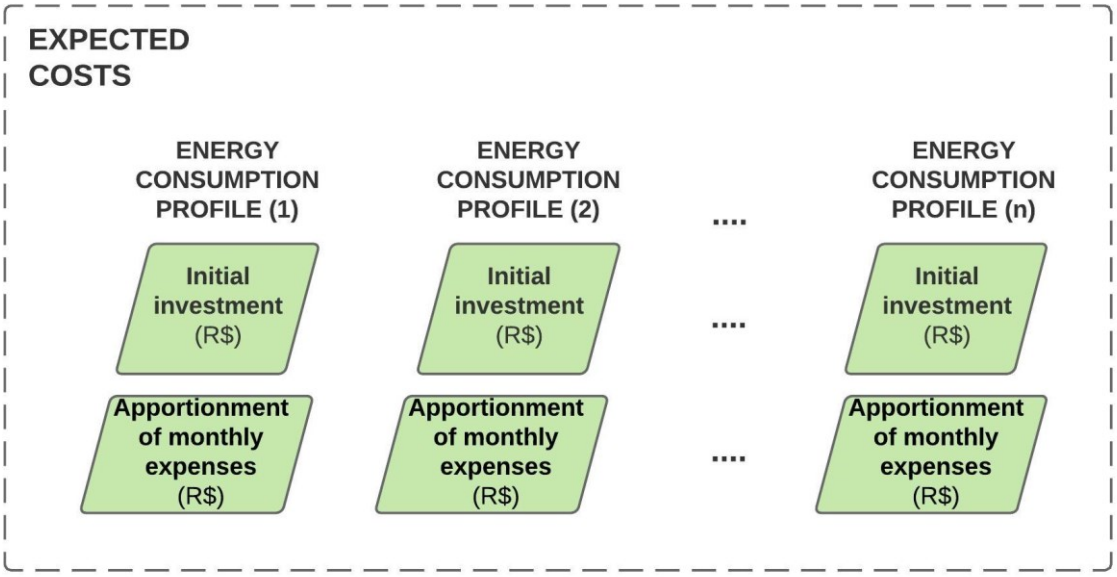


Figure 19 shows the 'Expected Savings' outputs, which are also given for each energy consumption profile defined in the inputs. These expected costs outputs include the new monthly average energy consumption and how much it represents as a reduction in % at the energy bill. These outputs also include the liquid monthly and annual savings, which includes the new average energy consumption and the apportionment of the expenses with running the cooperative. Therefore, the liquid monthly and annual savings can be negative if the expenses with the cooperative maintenance are higher than the savings on the electricity bill that the cooperative member will have with solar energy generation.

Figure 20 shows the financing characteristics output, which is the monthly financing payment required to fully write off the loan by the amount in R$ over the period, at an yearly interest rate selected by the user at the inputs. Therefore, this output only appears if the user is simulating his/her cooperative project with the financing option.

Figure 19 - Expected savings output

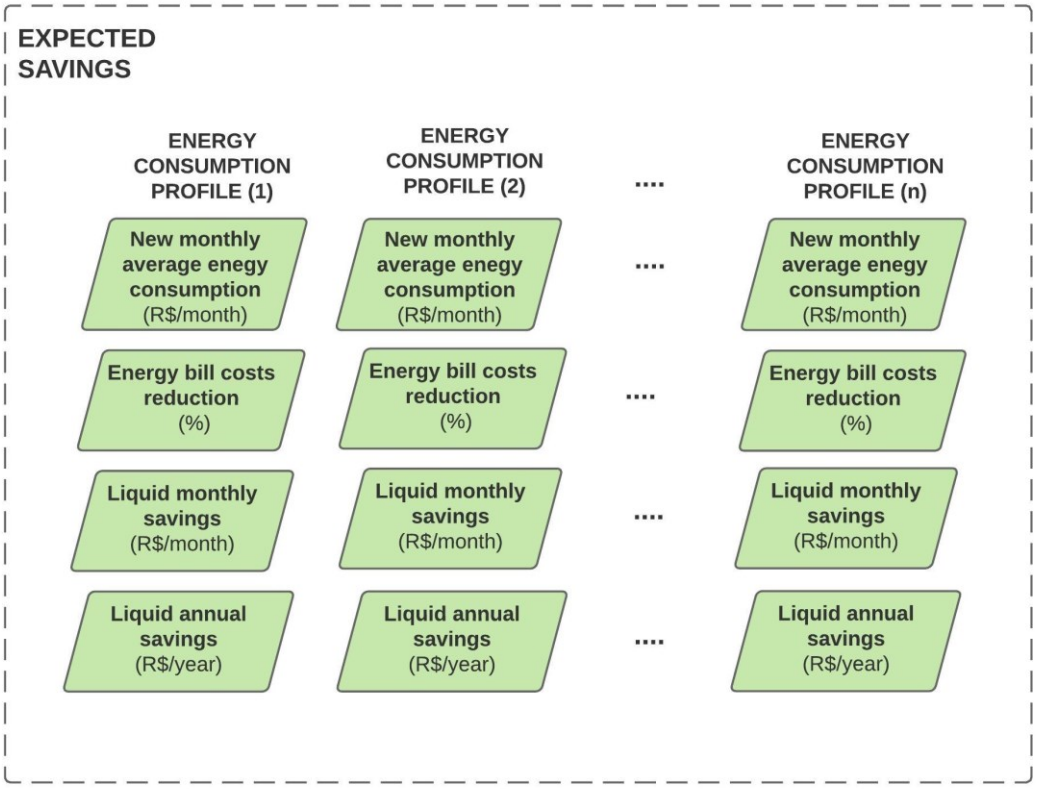
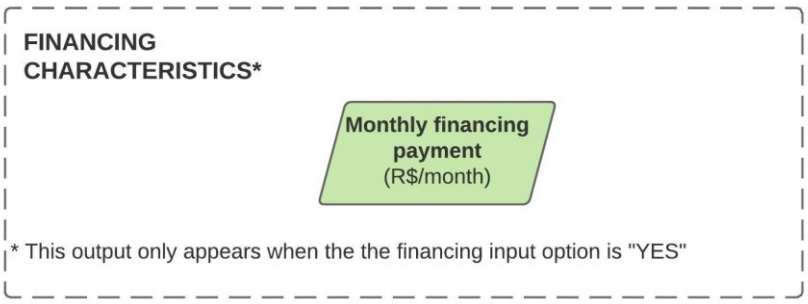


Figure 20 - Financing characteristics output



3.2 PART TWO: MAPPING THE EXISTING SHARED SOLAR COOPS

The second part of this work aims to map and investigate the existing shared solar coops under operation in Brazil up to date. The information was collected through different approaches. Firstly, data from Shared DG Coops were mapped through the database of DG

modalities from ANEEL website[5]. To that end, the search was conducted only at the registrations on the shared DG modality[6].

However, it was noticed that these registrations, many times, are not correctly carried out by the utility. For example, the first shared solar cooperative in Brazil, which is the most well-known because of its pioneering nature, is not registered at ANEEL as a shared solar DG, but as 'remote DG' modality. This mistake, despite acknowledged by ANEEL, was never corrected. In consequence, ANEEL database could not be the only resource.

The second part of this investigation was to conduct personal interviews through phone calls and emails with a representative from the cooperatives found at ANEEL database to understand in better detail their model, context and technical details. These contacts were provided by professionals from OCB, DGRV and GIZ. These professionals also provided contacts of other shared solar coops that were not yet registered at ANEEL or were mistakenly registered in a different modality. Since the focus of this research are shared solar coops, only the cooperatives using the solar energy source were investigated in better detail.

Thirdly, in June 2019, a webinar was organized by the solar laboratory Fotovoltaica-UFSC and *Instituto IDEAL*, in partnership with OCB, DGRV and GIZ. This webinar and workshop were carried out with the representatives from the cooperatives mapped. The event happened in Florianópolis-SC at the Solar Energy Center Fotovoltaica-UFSC. The webinar was open to the public, recorded and it is available at Fotovoltaica-UFSC YouTube channel[7]. At the webinar, the cooperatives representatives had the opportunity to present their cooperatives, share their experiences and the main barriers they found to structure and maintain their business model.

Afterwards, a workshop was conducted with the organizers from the event and the cooperative representatives only. At the workshop, the representatives had the opportunity to get to know each other better and, also, share their experiences, challenges, barriers and solutions found, in better detail. Considering that one of the cooperativism principles is the 'Cooperation among Cooperatives', this workshop also had the objective to connect the cooperatives of shared DG modality for them to find ways to cooperate with each other and strengthen this energy generation modality in the country. During the webinar and workshop, extra information about these cooperatives were also collected for this thesis.

[5] http://www2.aneel.gov.br/scg/gd/GD_Modalidade.asp
[6] http://www2.aneel.gov.br/scg/gd/gd_modalidade_detalhe.asp?Modalidade=C
[7] https://www.youtube.com/watch?v=bMc4bVrvn6M&t=511s

The main information collected were in regards to the cooperative business model, PV system and site ownership, PV system power capacity, number of members, number of consumer units that receive the energy credit, main barriers and plans to the future. It is also important to remark that were only considered as shared solar coops the cooperatives that generate energy through a PV system and generate energy and compensate the energy credit in consumer units from their members. Cooperatives that generate energy only to consumer units that belong to the cooperative itself were considered to fit in the remote DG model, even though their registration at ANEEL is into the shared DG modality.

3.3 PART THREE: SYSTEMATIC FRAMEWORK FOR SHARED SOLAR COOPS

In order to organize and present the different models of shared solar cooperatives observed in this work, a systematic approach was chosen. This section aims to introduce the structure of a systemic model and the modeling framework adopted.

3.2.1 The system approach

The systems approach was firstly introduced by 1950's and, since then, it has been applied in different fields, such as psychology, sociology, political sciences, biology and engineering (JACKSON; HITCHINS; EISNER, 2010). The system approach allows the designer of the system to manage, encapsulate and anticipate complex behaviors while considering the attributes of this system in order to achieve an objective (JACKSON; HITCHINS; EISNER, 2010). Although a system has been defined in many ways, all definitions agree that a system is a set of parts coordinated to accomplish a set of goals (CHURCHMAN, 1968). A system can still be classified as an open or closed system. An open system interacts with the environment and with other systems into the operational environment, while a closed system interacts with the environment only slightly. The environment of the system is what lies "outside" of the system.

Structurally speaking, according to Sagasti (1973), a system (S) can be defined as an entity of more than one element (E) and a set of relations (R) among the elements. Elements could be actions, individuals, organizations, etc, and relations could be interactions, communication, exchange of resources, information or any conceptual/physical interaction with the element. It is important to notice that the identification of the structure of the system will depend on the purposes of the observer. The set of elements (E) can be divided into two subsets:

environment (E_e) and object (E_o). The set of relations can be divided into three subsections: Object Relation (R_o), Object-Environment Relation (R_e) and Environment Relation (R_r). The definition of these subsets of elements and relations are as follows:

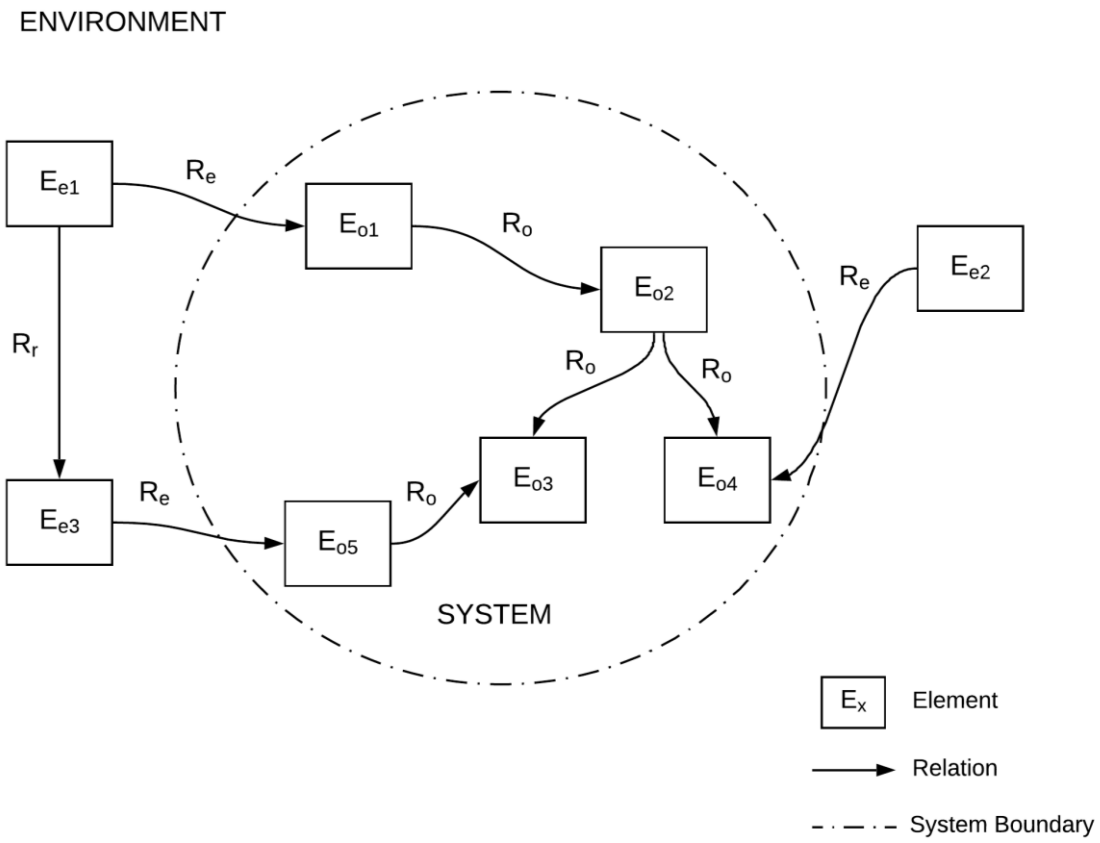
- **Environment (E_e):** elements located at the environment, outside the system (S), in which the observer has no direct concern or control about;
- **Object (E_o):** elements located inside the system (S), which are of direct and primary concern to the observer.
- **Object Relation (R_o):** relation between elements belonging to the object;
- **Object-Environment Relation (R_e):** relation between elements of the object and the environment;
- **Environment Relation (R_r):** relation between the elements of the environment.

The structure of a system can change and evolve over time (SAGASTI, 1973). Also, there is always the possibility of an element of a system to be a system by itself or a system to be an element of a larger system. In other words, as mentioned by (CHEN, 1975), “every system will be a subsystem of a larger system”.

The system and its environment are delineated by a system boundary that defines which elements lie inside and outside (environment) of the system. The components that lie inside the system require a higher level of detail. In order to identify if an element lies inside or outside of the system, two questions should be made: “Can I do anything about it?” and “Does it matter relative to my objectives?” If the answer to the first question is “No” and the second is “Yes”, then “it” is in the environment (CHURCHMAN, 1968). Figure 21 - *Structure of a system* expresses graphically the structure of a system as discussed here.

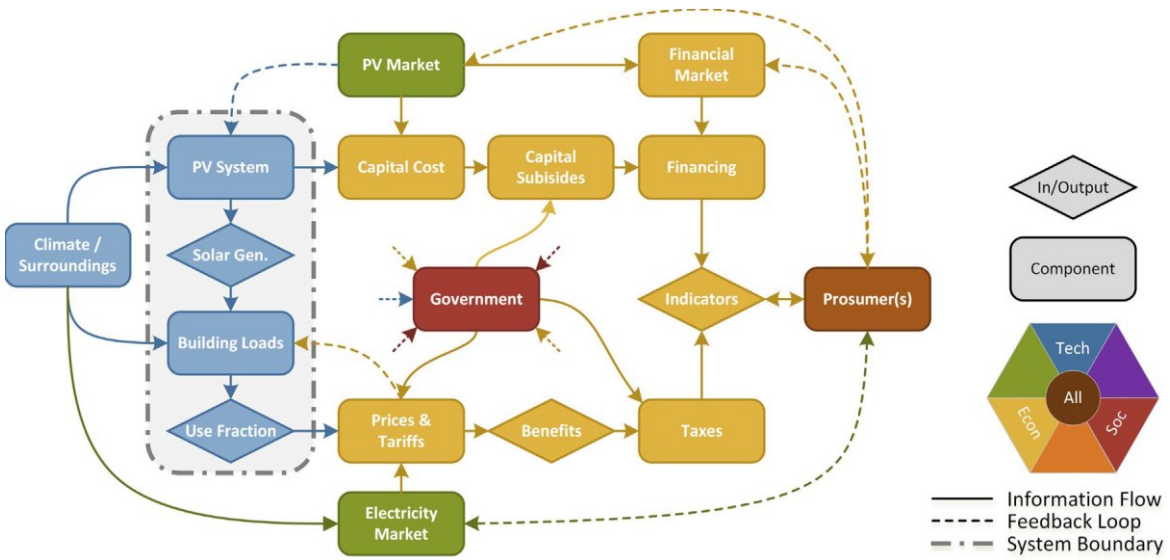
Sommerfeldt and Madani (2017) did an interesting application of these system approach principles into their work. These authors developed a system modeling framework for prosumer PV investment analysis. In their model, the observer is the prosumer and the objective is to produce PV investment information to the prosumer within the DG context, which could then be used as a component of the decision making process. Therefore, the system modeled by Sommerfeldt and Madani (2017) had an objective that led to a decision making process. The authors subdivided the elements of the system (in their work named as components) in technical, economical and social elements, and they used economic indicators to achieve the objective stated. Figure 22 presents the system modeled by Sommerfeldt and Madani (2017).

Figure 21 - Structure of a system



Source: Adapted from Churchman (1968), Sagasti (1973), Jackson *et al.* (2010)

Figure 22 - Techno-economic PV system modeling framework from the prosumer's viewpoint.



Source: Sommerfeldt and Madani (2017)

3.2.2 System's modeling framework

The first step to structure the system is to identify its objective and its observer. The objective of this system was defined taking into consideration the fact that solar cooperatives based on the shared DG modality are a recent possibility in Brazil and, in consequence, there are many questions on how to structure a shared solar coop business model. Therefore, the objective of this system is to outline the possible arrangements in which a shared solar coop can be structured considering the current regulation. The observer here considered is any person interested to investigate and evaluate the possibilities on how to structure a shared solar coop model.

The second step is to identify the elements and their relations. In the context of this thesis, the elements and their relations were identified based on the existing shared solar coops investigated, and are observed as explained in section '3.2 PART TWO: MAPPING THE EXISTING SHARED SOLAR COOPS'. Once the system is structured, the existing shared solar coops model will be applied on this structure developed in order to exemplify the application of the system. The system structure and its application on the existing shared solar coops models are presented in sections '4.3.1 System framework' and '4.3.2 Existing shared solar coops models applied to the system structure', respectively.

4 RESULTS

4.1 PART ONE: SHARED SOLAR COOPERATIVES WEB TOOL

The web tool is an online open source tool, which is hosted at the *Instituto IDEAL's América do Sol* platform, and it can be accessed at the link: www.americadosol.org/simulador-cooperativas/. Figure 23 presents a screenshot of the current interface of the web tool. The Solar Cooperatives Guide can be downloaded at the upper right corner of the page. Each blue box of the interface represents one of the six divisions as explained in '3.1.1 Web tool inputs': (1) Location; (2) Energy consumption profile; (3) Cooperative model; (4) Financing; (5) Accounting and (6) PV system costs.

Through the web tool, as indicated by (1) at Figure 23, there are some 'question mark' icons that bring information about the indicated specific blue box or question. These icons were developed with the intention to clarify any possible doubt the user might have on that point of the web tool. As indicated by (2) at Figure 23, in the beginning of each session there are also some 'open book' icons. These icons bring information about the inputs the user should insert if he/she would like to simulate the examples 01, 02 or 03 from the Solar Cooperatives Guide. If the user inserts the same values suggested in these icons, he/she must have the same output results as presented in the Guide.

The web tool was officially launched at the Intersolar South America Conference and Tradefair during the 'Solar Cooperatives/Community Solar for Brazil' panel, in August 29th 2018, in São Paulo. Since its launching up to August 31 2019, the web tool had 5436 'Sessions' and 4292 'Users' from 30 different countries according to data from Google Analytics. According to the platform, 'User' is consider the person who has initiated at least one session during the date range while a 'Session' is the period time a user is actively engaged with the website. Most users (97.5%) are located in Brazil, followed by United States, Germany and Mexico. The top 10 ranking for users and sessions per country are presented in Table 3.

In Brazil, the state that had more users and sessions is São Paulo (695 Users and 810 Sessions), followed by Minas Gerais (521 Users and 634 Sessions) and Santa Catarina (446 Users and 571 Sessions). Table 4 presents the top 10 ranking per state.

São Paulo capital is the leading city in number of Users and Sessions (303 and 355, respectively), followed by Rio de Janeiro (228/297) and Curitiba (193/227). Table 5 presents the ranking of the top 10 cities in Brazil that most accessed the web tool in the period evaluated.

Figure 23 - Screenshot from the web tool at *América do Sol* platform

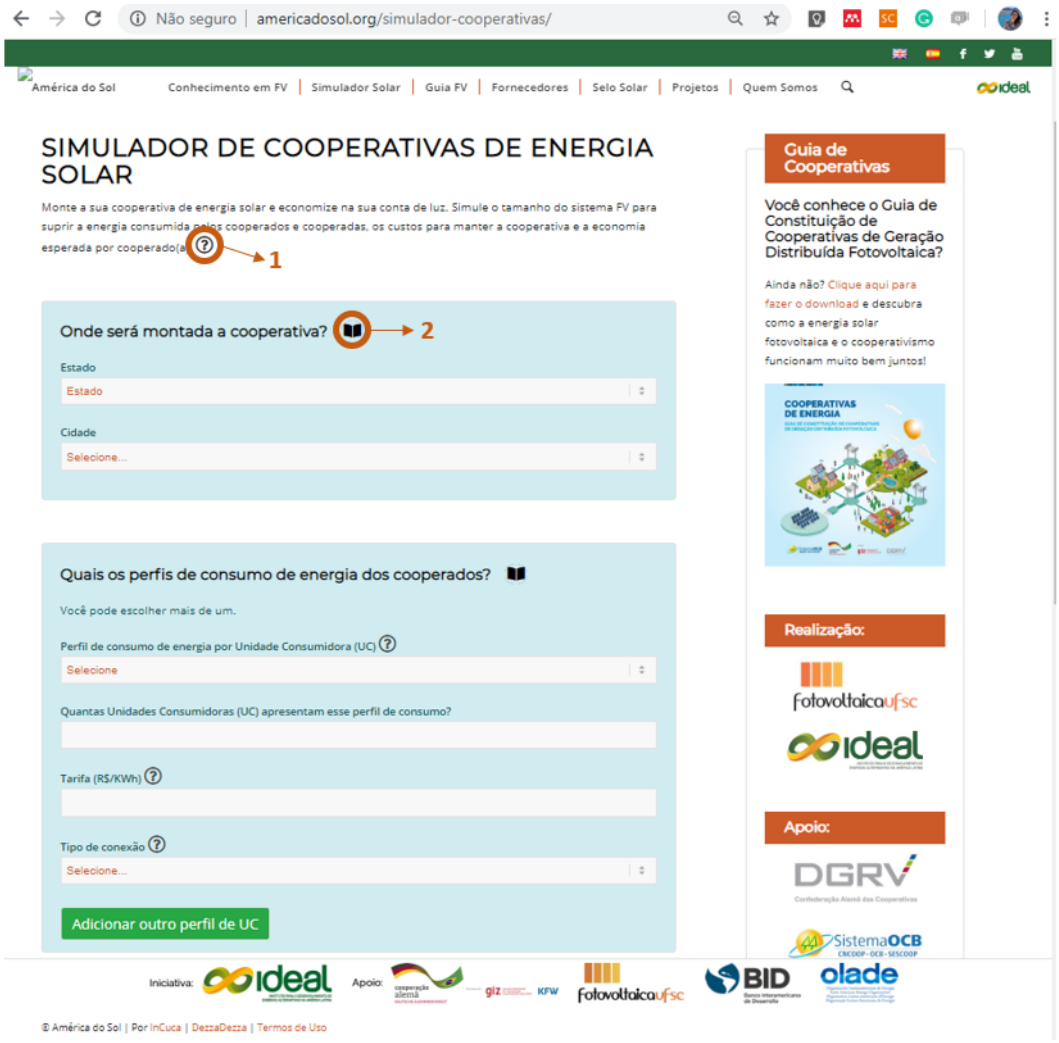


Table 3 - Web tool top 10 countries access

#	Country	Users	Sessions
1	Brazil	4185	5312
2	United States	26	27
3	Germany	11	12
4	Mexico	9	12
5	Chile	4	5
6	Japan	4	8
7	Portugal	4	4
8	Argentina	3	4
9	Switzerland	3	3
10	United Kingdom	2	3

Table 4 - Web tool top 10 Brazilian states access

#	State	Users	Sessions
1	São Paulo	695	810
2	Minas Gerais	521	634
3	Santa Catarina	446	571
4	Paraná	419	520
5	Rio de Janeiro	344	460
6	Rio Grande do Sul	286	392
7	Bahia	182	225
8	Goiás	157	197
9	Ceará	143	166
10	Federal District	136	173

Table 5 - Top 10 Brazilian cities access

#	City	Users	Sessions
1	São Paulo	303	355
2	Rio de Janeiro	228	297
3	Curitiba	193	227
4	Belo Horizonte	193	227
5	Florianópolis	136	194
6	Brasília	136	173
7	Fortaleza	116	136
8	Goiania	111	136
9	Salvador	100	122
10	Porto Alegre	82	98

4.2 PART TWO: MAPPING EXISTING SOLAR SHARED COOPS

Thorough the development of this thesis, 10 Shared DG Coops under operation were identified. These cooperatives are located on the map according to Figure 24, and some details about them, such as location, power capacity of each power plant under operation and year when these power plants were connected to the grid, are presented on Table 6. From these cooperatives, six use PV generators, two use hydropower and two use biomass. Shared solar coops together sum 1.6 MW of power capacity installed, while shared hydro coops sum 6.5 MW and shared bio coops has 6.9 MW installed. Together, they sum around 15 MW of power capacity representing only 0,8% of the total DG power capacity installed up to date (2 GW). Other cooperatives under development were also identified. However, these were not under operation yet and, therefore, were not considered in this thesis.

Shared solar coops, in installed capacity, are less representative when in comparison with shared hydro and shared biomass coops. Shared solar coops represent only 11% of the total power capacity installed in shared DG coops, while shared hydro coops represent 43% and shared biomass coops 46%. However, in quantity of cooperatives spread across the country, shared solar coops are more representative, accounting with six (out of 10) cooperatives under operation up to date as presented in Figure 24 and Table 6. The next subsections describe the share solar coops identified in more detail.

Figure 24 - Shared GD coops under operation registered at ANEEL up to December 2019.



Table 6 - Information about Shared DG Coops shown in Figure 24.

		Name	Power Plant Location	Power Capacity (kW)	Year of Grid Connection
Hydro	Hyd 1	COCCER	Parecis-RO	1664	2016
	Hyd 2a	COOGD	Colorado do Oeste-RO	1844	2017
	Hyd 2b	COOGD	Vilhena-RO	2997	2019
Biomass	Bio 1	COGECOM	Carambeí-PR	4900	2016
	Bio 2	Cooperativa de Geração de Energias Renováveis de Rondônia	Porto Velho-RO	2000	2019
Solar PV	Sol 1	COOBER	Paragominas-PA	75	2016
	Sol 2a	Cooper Sustentável	São José-SC	1	2016
	Sol 2b		Arcos-MG	0,25	2016
	Sol 3	Enercred	Pedralva-MG	15	2017
				75	2019
				75	2019
	Sol 4a	Compartsol	Araçoiaba da Serra-SP	75	2017
	Sol4a		Araçoiaba da Serra-SP	250	2018
	Sol 4b		*Porto Feliz-SP*	*1000*	*Yet to be connected*
	Sol 5	Sicoob Centro Serrana do ES	Santa Maria de Jetibá- ES	33	2017
	Sol 6	Ciclos	Ibiraçu-ES	1000	2019

4.2.1 Sol 1: Brazilian Renewable Energy Cooperative (COOBER)

The Brazilian Renewable Energy Cooperative (COOBER, from the abbreviation in Portuguese) was the first shared solar cooperative stablished in Brazil. In November 2015, REN 687/2015 regulated the Shared DG model in Brazil, which came into force only in 2016. In February 2016, Coober statute was stablished. In August, Coober PV power plant was built and in October it was officially connected to the grid. In December 2016, members from Coober had their first energy credits compensated on their energy bill.

COOBER's PV system is located at Paragominas-PA and has a nominal power of 75 kWp, being comprised of 288 multicrystalline PV modules installed on a ground mounted power plant which is connected to the utility CELPA. The energy generated by this PV system is compensated at the energy bill of 21 consumer units. Paragominas city hall donated the site where the PV system is installed.

COOBER was stablished by a group of 23 friends with the same desire of generating their own energy through a renewable energy system. COOBER's members made an initial investment in order to build the PV power plant. Their investment was according to their PV system share, which was defined according to their energy consumption average. Therefore, COOBER members are the owners from the PV system from the cooperative in which each member owns the equivalent of his/her share. COOBER is a great example of citizens uniting strengths towards a common goal.

Today, COOBER became a role model of solar energy generation in Paragominas. COOBER power plant receives many technical visits from the local community, including school tours, for example. Figure 25 shows COOBER's PV power plant and Fig. 2(b) shows COOBER's members at the power plant inauguration day.

Figure 25 - COOBER 75kWp PV power plant.



Figure 26 - Members at the PV power plant inauguration day



4.2.2 Sol 2: Renewable Energy Sustainable Cooperative (Cooper Sustentável)

The second shared solar cooperative in Brazil was Renewable Energy Sustainable Cooperative (called *Cooper Sustentável* in its short name version in Portuguese). *Cooper Sustentável* first PV system was connected to the grid in January 2017 in São José-SC, in the southern part of the country, with 1 kWp of PV sharing the solar energy among five consumer units registered to it. In October 2017, *Cooper Sustentável* connected to the grid a second branch in Arcos-MG, in the Brazil central-west, with a 0.25 kWp (just one PV module!) PV generator installed, and two consumer units registered to it. In total, *Cooper Sustentável* has 34 members and seven consumer units receiving the credits from the PV systems connected to the grid.

Cooper Sustentável strategy was to install small PV systems to learn all the technical installation and grid-connection process intending to better understand and evaluate each step of it. In parallel, the cooperative managers were seeking for investors and people interested to be part of their cooperative in order to grow their PV power plants and run the cooperative on a bigger scale. They had many issues on this process and found it hard to convince people of their idea. People did not want to join a shared solar cooperative that had no PV power plant built yet and, on the other hand, it was very hard to find investors interested on building a PV system for the cooperative business model proposed by *Cooper Sustentável*.

Cooper Sustentável remains in the small scale in which it began. Currently, the organizers of *Cooper Sustentável* are investigating the potential of biogas energy generation and

developing a new business model for their cooperative regarding biogas as the energy generation source.

4.2.3 Sol 3: Enercred

The third shared solar cooperative connected to the grid was Enercred, in April 2017, with their first 15 kWp PV power plant located at Pedralva-MG, in the southeastern Brazil (Figure 27). By that time, Enecred had 20 consumer units receiving the energy generated by the mentioned system. In March 2019, Enercred inaugurated the extension of their PV system adding an extra 90 kWp of nominal power installed and 75 kW of inverter (Figure 28) Currently, Enercred includes 96 members and 90 consumer units connected to their 90 kWp PV power plant under operation.

PV power plants used by Enercred were built and are under operation and maintenance of a third-party investor, which leases the power plant to the cooperative. Enercred, by its turn, leases shares of the PV system to its members. Therefore, Enercred members did not have to make any initial investment to build the PV system. Enercred members just have to pay a monthly fee to the cooperative according to the PV system share they subscribe for in order to receive the energy credit compensation in their energy bill. This PV system share is calculated based on the member monthly energy consumption average.

Enercred cooperative works in partnership with a TI enterprise called Enercred Web. Enercred Web developed a software in which Enercred cooperative members are able to follow their energy credits through monitoring the amount of energy their PV system share generated, their energy consumption and the amount of energy that will be compensated on their energy bill each month.

Currently, Enercred cooperative is completing another PV power plant construction also built by a third-party investor. This power plant is also located at Pedralva-MG and has 90 kWp of nominal power installed (inverter power = 75kW) (Figure 29). This power plant construction was concluded by the end of 2019. The three power plants, totaling 180 kWp, today generate energy credits to nearly 100 consumer units.

Figure 27 - Enercred first power plant (15 kWp)



Figure 28 - Enercred PV system expansion (75 kWp)

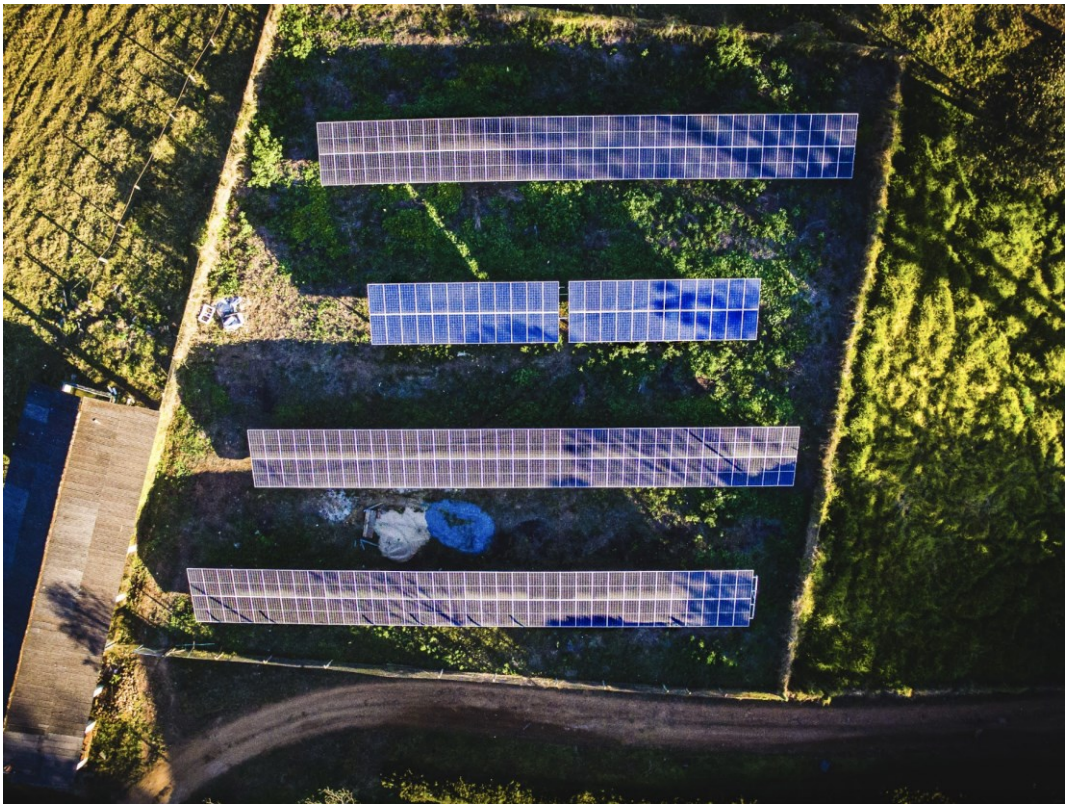


Figure 29 - Enercred third power plant constructed (90 kWp / 75 kW)



4.2.4 Sol 4: Shared Generation Cooperative (Compartsol)

In November 2017, the Shared Generation Cooperative (known as Compartsol by its short name version in Portuguese) connected to the grid their first PV power plant with a 75 kWp nominal capacity installed (and a 75 kW of inverter), located at Araçoiaba da Serra-SP. In January 2019, Compartsol connected to the grid their second PV power plant with an installed capacity of 325 kWp (250 kW inverter). Figure 30 shows Compartsol power plant currently under operation, which has a total installed capacity of 400 kWp.

Compartsol currently accounts with 63 members and 53 consumer units where the energy generated by their PV power plants is compensated. The profile of these consumer units varies from rented one-room flats where only one person lives at, to large summerhouses and commercial businesses.

The Compartsol business model concept is based not only on generating renewable energy to its members but also in providing tools that allow them to adopt energy efficiency

practices. Every Compartsol member receives a measuring device to be installed at his/her house/business that informs the instant energy consumption, in order to give insights about the consumption pattern and on the energy wasting that could be avoided. Figure 31 shows the device that is installed at Compartsol members' residences or businesses.

Also, every Compartsol member can follow his or her energy generation and consumption through a smartphone app on their mobile/computer. A monthly report is delivered to them with an overview about their energy consumption pattern, the energy generated by Compartsol PV system and the amount of credits to be compensated at their energy bill. This report also gives suggestions on how that member could lower his/her energy consumption through taking energy efficiency measures. An example of this report is shown in Figure 32.

The Compartsol PV system was built and is maintained by a startup enterprise called Sun Mobi. Therefore, in the Compartsol business model, the cooperative member does not have to invest any initial capital to build the PV system in order to become a member. Compartsol is developing their third PV power plant (also built and maintained by Sun Mobi), located at Porto Feliz-SP, to be connected to the grid by the end of January 2020 adding 1.4 MWp of nominal capacity to their portfolio and generating energy to extra 27 consumer units spread across São Paulo state (Figure 33).

Figure 30 - Compartsol PV power plant with an installed capacity of 400 kWp



Figure 31 - Measurement device installed at Compartsol members house/business



Figure 32 - Example of the monthly report delivered to Compartsol members

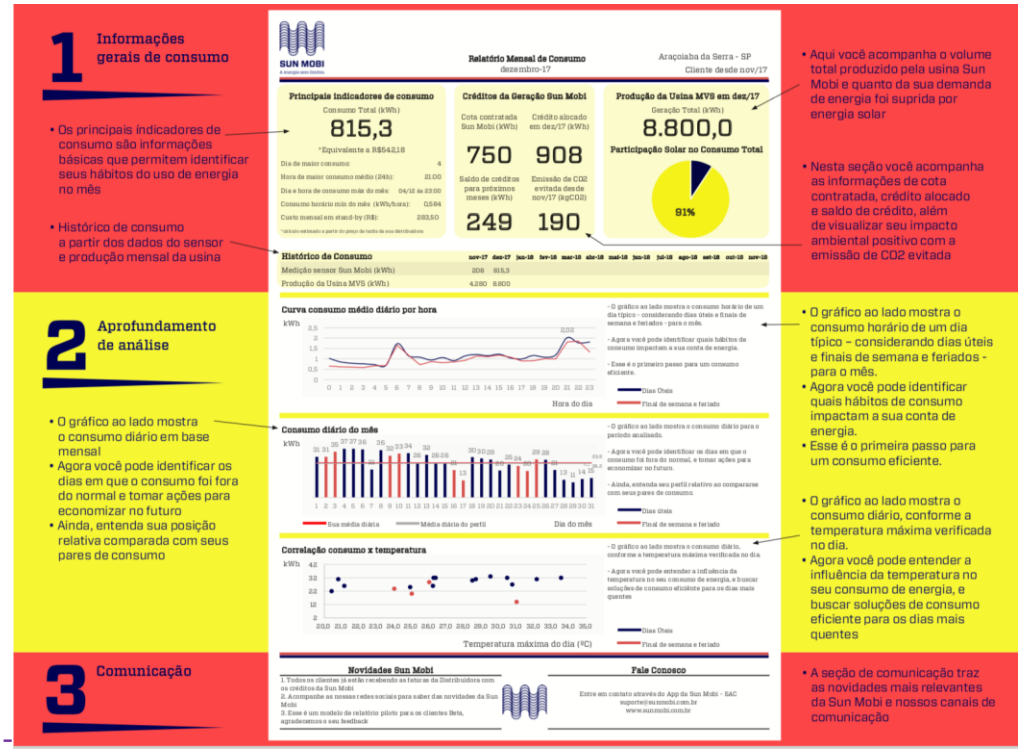


Figure 33 - Compartsol power plant of 1.4 MW at Porto Feliz-SP



4.2.5 Sol 5: Sicoob Centro-Serrano ES

Sicoob Centro-Serrano ES is a Credit cooperative from the state of Espírito Santo (ES) established in 1990. Together with others six credit cooperatives, Sicoob Centro Serrano-ES constitutes the Sistema Sicoob ES (Sicoob Credit System from Espírito Santo state). Sicoob Centro-Serrano ES accounts with 53,000 members. The entire Sistema Sicoob ES accounts with approximately 300,000.

In December 2017, Sicoob Centro-Serrano ES connected a 35 kWp (33 kW inverter) PV system installed on the roof of Sicoob Centro-Serrano ES headquarter located at Santa Maria de Jetibá-ES (Figure 34). This PV system generates energy to be compensated at six consumer units. Three of them are consumer units from Sicoob Centro-Serrano ES itself and the other three are from other partner cooperatives from ES (one Agriculture cooperative, one Educational and a Transport cooperative). This PV system was planned to be a prototype test in which Sicoob Centro-Serrano verified all the procedures of grid connection and about the

compensation DG scheme while studying a business model to offer solar energy to its members through the shared DG model.

Figure 34 - 36 kWp PV system installed at Sicoob Centro-Serrano headquarters at Santa Maria de Jetibá-ES



4.2.6 Sol 6: Ciclos

Based on the experience from Sicoob Centro-Serrano (ES), Sistema Sicoob ES developed a business model to offer solar energy to its members. To that end, a new cooperative with the main objective to generate solar energy to their members through the Shared DG modality, called Ciclos, was found. Therefore, Ciclos was stablished in partnership with Sistema Sicoob ES and another cooperative, Coopeavi, which is an Agricultural cooperative that is also a member from Sistema Sicoob ES. The condition to become a member from Ciclos is to also be a member from Sistema Sicoob ES.

In August 2019, Ciclos connected to the grid 200 kWp of 1 MWp PV system installed on the rooftop of Coopeavi, in Ibiraçu-ES, who leased the roof area for installing the PV power plant (Figure 35). The PV system was installed and is maintained by Sistema Sicoob ES.

Shared DG modality is not the only one applied at this 1 MWp power plant. The entire PV system generates energy to 86 Ciclos members and 95 consumer units from Sistma Sicoob ES (Shared DG). It also generates energy to the building from Coopeavi where the PV system is installed (DG for self-consumption) and to other consumer units owned by Coopeavi spread across the state of Espírito Santo state (Remote DG). Ciclos is currently planning to build many others PV plants spread across the state of Espírito Santo intending to reach as much of 300,000 members from Sistema Sicoob ES.

The software which manages the energy credits generated by the PV system from Ciclos and which allows the cooperative members to access the energy amount their PV system share generated monthly, the energy amount they consume and the amount that will be compensated at their energy bill, was developed by a partner TI start-up called CleanClic.

Figure 35 - 1 MWp PV system installed on the roof of a Coopeavi's building. Ciclos leases from Coopeavi 200 kWp of this system.



4.2.7 Summary

Table 7 summarizes the main topics of each one of the shared solar coops presented in the previous subsections. The first shared solar coop established in Brazil was COOBER, which connected to the grid in late 2016. In 2017, other four shared solar coops were established: Cooper Sustentável, Enercred, Compartsol and Sicoob Centro-Serrano ES. The sixth cooperative connected to the grid was Ciclos in August 2019. These shared solar coops sum together nearly 891.25 kWp nominal installed capacity currently under operation (going up to nearly 2.3 MWp with the connection of Compartsol third power plant in early 2020).

Each of these cooperatives found a business model that met their particular conditions and needs. COOBER is the reunion of 23 friends that reunite their strengths to stand a 75 kWp PV power plant to generate solar energy to their houses and families. Cooper Sustentável had plans to firstly connect small PV systems in two different states of the country in order to investigate the grid connection process and the energy compensation scheme, while reaching for investors to grow their PV power plants and aggregating new members to their cooperative. Unfortunately, Cooper Sustentável did not find means to consolidate their business model and are currently investigating a new model using biogas as energy source.

Enercred and Compartsol, both have a third party investor involved in the construction, operation and maintenance of their PV power plants. Therefore, their members do not have to make any initial capital investment to be part of the cooperative, but subscribe themselves to the cooperative in order to 'rent' a share of the PV system according to their energy consumption average. Enercred and Compartsol are expanding the capacity of their PV systems since 2017 while aggregating new members.

Sicoob Centro-Serrano ES is a Credit cooperative very well consolidated in the country and with years of experience, which saw the potential of generating solar energy to their members through the Shared DG scheme. Sicoob Centro-Serrano built a PV system to generate energy to few consumer units in order to test the shared DG model while elaborating a business model to offer energy a larger number of members. The experience from Sicoob Centro-Serrano evolved to a new cooperative: Ciclos. Ciclos is a collaboration between three cooperatives (Ciclos, Sistema Sicoob ES and Coopeavi) and a TI startup. Ciclos is a great example of one of the cooperatives principles: cooperation among cooperatives.

Table 7 - Summary of the existing shared solar coops currently under operation in Brazil

Cooperative	**Coober**	**Cooper Sustentável**	**Enercred**	**Compartsol**	**Sicoob Centro-Serrano ES**	**Ciclos**
Location	Paragominas (PA)	(1) São José (SC) (2) Arcos (MG)	Pedralva (MG)	Araçoiaba da Serra (SP)	Santa Maria de Jetibá (ES)	Ibiraçu-ES
PV system connection to the grid date	October 2016	(1) January 2017 (2) October 2017	April 2017 with expansions in 2019	November 2017 with expansion in 2019 and 2020	December 2017	August 2019
Utility	CELPA	(1) CELESC (2) Cemig	Cemig	CPFL Piratininga	EDP ES	EDP ES
Nominal Installed Capacity	75 kWp	(1) 1 kWp (2) 0.25 kWp	180 kWp	1800 kWp *(accounting with the expansion from 2020)*	35 kWp	200 kWp
The energy generated is compensated at the energy bill of:	Cooperative members consumer units	Cooperative members consumer units	Cooperative members consumer units	Cooperative members consumer units	Consumer units owned by the cooperative and consumer units from another partner cooperatives	Cooperative members and consumer units from the partner cooperatives
Ground or roof mounted system?	Ground	Ground	Ground	Ground	Roof	Roof
Nº of members	23	34	96	63	53,000	86
Nº of consumer units where the energy generated is compensated	21	(1) 5 (2) 2	90	53	6	86
Did members had to make an initial capital investment?	Yes	No	No	No	No	No

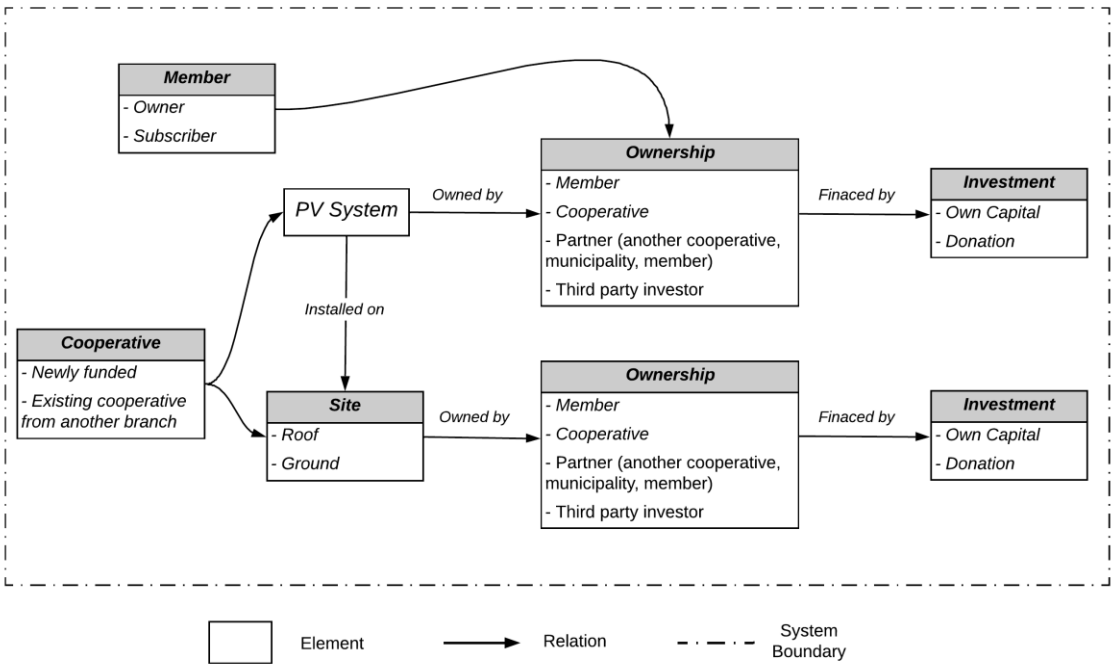
4.3 PART THREE: SYSTEMATIC FRAMEWORK FOR SHARED SOLAR COOPS

4.3.1 System framework

The system here structured is based on the existing cooperatives mapped in the second part of this thesis. Therefore, it can be said that the system framework here presented is a 'screenshot' of the context of the existing shared solar coops mapped in this thesis. All the elements here identified are based on what has been observed.

Based on the six shared solar coops mapped in this work, the following elements were observed: the '*Cooperative'* itself, the '*Member'* of the cooperative, the '*PV System'*, the *Site* where the PV system is installed, the site and PV system '*Ownership'* and '*Investment'*. All these elements were settled inside the system and any element was identified to be in the environment. Figure 36 presents the elements identified and their relations. For each element, there are different sets of possibilities that can be chosen to form the cooperative.

Figure 36 - General systematic framework for shared solar coops



This system is certainly a subsystem from a bigger system. The system here proposed can easily be applied, and be very helpful, in the development of another system that have the objective, for example, to evaluate the technical-economic viability of a shared solar coop taking the cooperative member or the cooperative itself as an observer. The business model of

the cooperative and all the parties involved in its structure play a key role to investigate the techno-economic viability of the entire project.

4.3.1.1 Elements description

Many of the cooperatives mapped were newly funded as a shared DG cooperative. However, it was also observed that existing cooperatives from another branch are embracing the share energy generation service and adapting it to their business model, which was the case of Sicoob Centro-Serrano and Ciclos, for example. Therefore, the *Cooperative* element can be settled in a configuration of a 'newly founded cooperative' or an 'existing cooperative from another branch'.

The *Cooperative* is related to the *PV System* and to the *Site* where this PV system is installed. As observed, the *Site* where the PV system can be mounted at can be on a 'roof' or on the 'ground'.

It was observed that it is important to consider in the system the ownership of the *PV System* and of the *Site* where it is mounted. Not necessarily the owner from the PV system is the same owner from the site. Therefore, an independent *Ownership* element was considered to the *PV System* and another to the *Site*. This ownership could be by the 'members' of the cooperative, by the 'cooperative' itself, by a 'partner' (in this case, another cooperative, the municipality, some specific member from the cooperative and so on) or also, from a 'third party investor'.

The PV system and site ownership leads to another element: how this ownership is financed. Here, this element is called '*Investment*' and there is one independent element for each ownership. The *Investment* of the PV system and of the site can be made through the owner's 'own capital' or still through a 'donation' from the owner. The 'donation' structure usually appears only on the site's ownership.

The *Member* is related to the PV System as the 'owner' of the PV system or as just a 'subscriber' from the PV system depending on the ownership selected for the PV System.

4.3.2 Existing shared solar coops models applied to the system structure

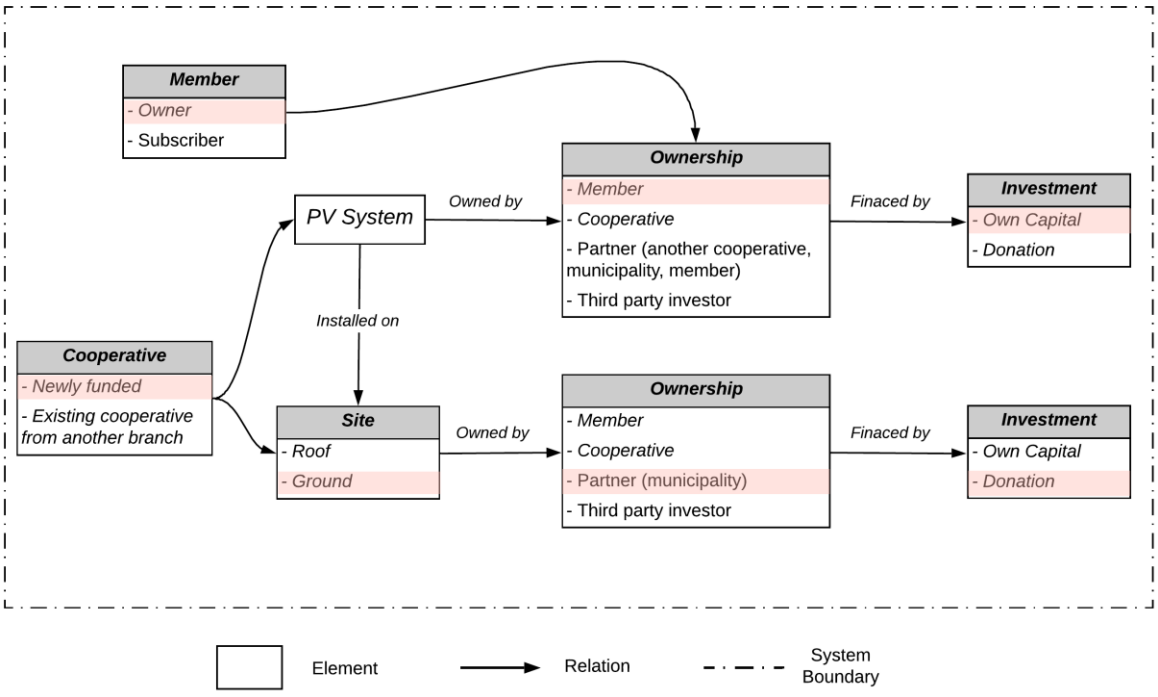
The next subsections present the existing shared solar coops investigated into this work applied to the systematic structure proposed to exemplify its application. *Cooper Sustentável*

was not considered here once this cooperative model did not developed as well as the others did.

4.3.2.1 COOBER

Figure 37 presents COOBER model arrangement applied to the systematic framework proposed. COOBER was a newly funded cooperative in which its own members had to make an initial investment with their own capital to build the PV power plant. Therefore, COOBER members are jointly the owners from the PV power plant. The PV system is ground mounted and the site was donated by Paragominas municipality.

Figure 37 - COOBER business model arrangement applied to the systematic framework

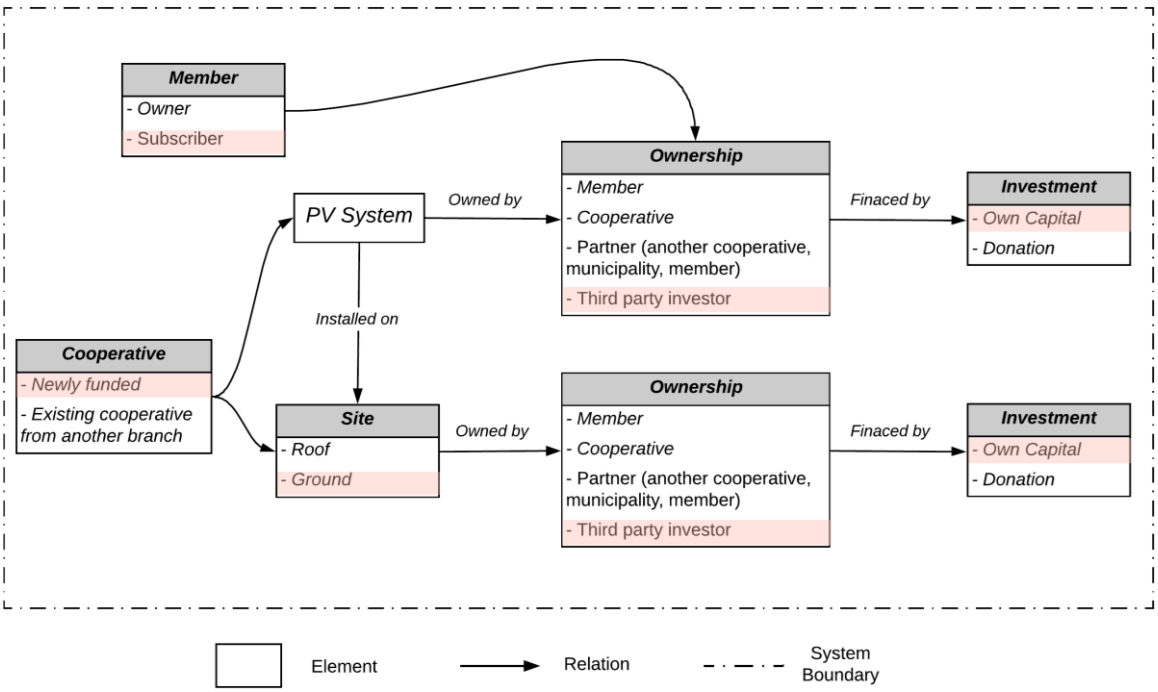


4.3.2.2 Enercred

Figure 38 presents Enercred model arrangement applied to the systematic framework proposed. Enercred was a newly funded cooperative. The PV System, ground mounted, is owned by a third party investor as well as the site where it is installed. Either the PV system and the site where it is mounted were financed by this third party investor own capital.

Therefore, the members from the cooperative are only subscribers from the cooperative and ‘rent’ from the cooperative shares of the PV System.

Figure 38 - Enercred business model arrangement applied to the systematic framework



4.3.2.3 Compartsol

Figure 39 presents Compartsol model arrangement applied to the systematic framework proposed. Compartsol model arrangement follows the same structure as Enercred. Compartsol is a newly funded cooperative. The PV System, ground mounted, is owned by a third party investor as well as the site where it is installed. Both the PV system and the site where it is mounted were financed by this third party investor’s own capital. Therefore, the cooperative members are only subscribers from the cooperative and ‘rent’ from the cooperative a number of shares of the PV system.

4.3.2.4 Sicoob Centro Serrano ES

Figure 40 presents Sicoob Centro Serrano ES model arrangement applied to the systematic framework proposed. Sicoob is a credit cooperative very well known and stablished in the country, therefore it is classified here as an ‘existing cooperative from another branch’. The PV system was installed on the roof of Sicoob Centro Serrano ES, in Santa Maria de Jetibá-

ES, and it was financed by the own capital of the cooperative itself. The cooperative members are, therefore, only subscribers and 'rent' from the cooperative shares of the PV system.

Figure 39 - Compartsol business model arrangement applied to the systematic framework

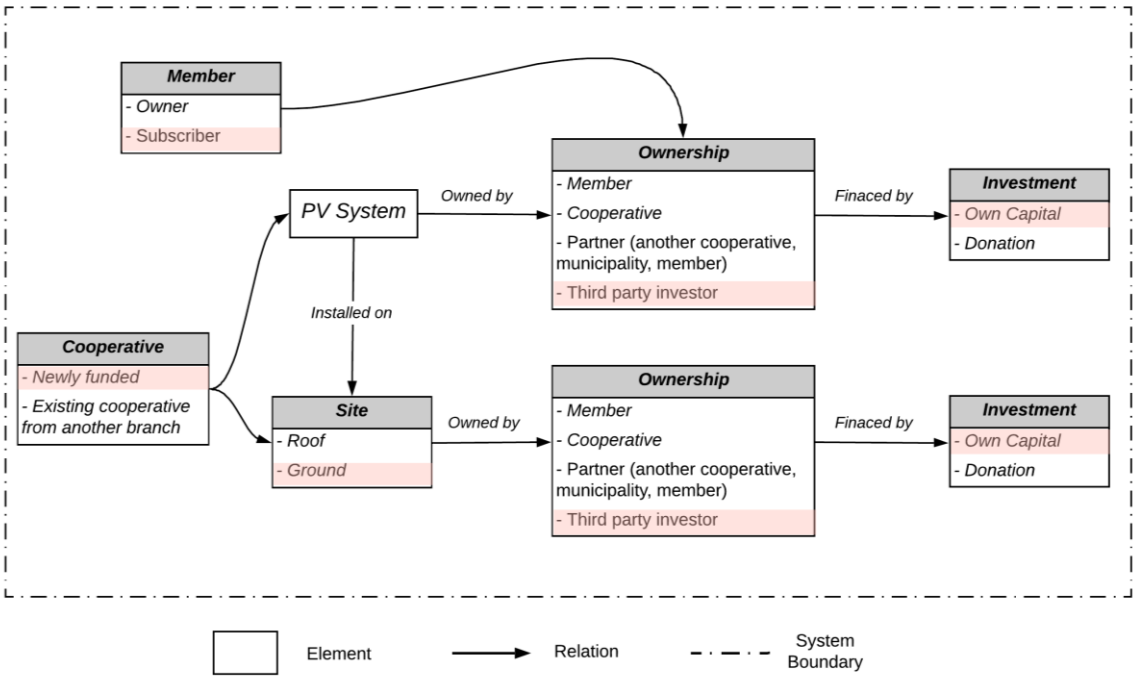
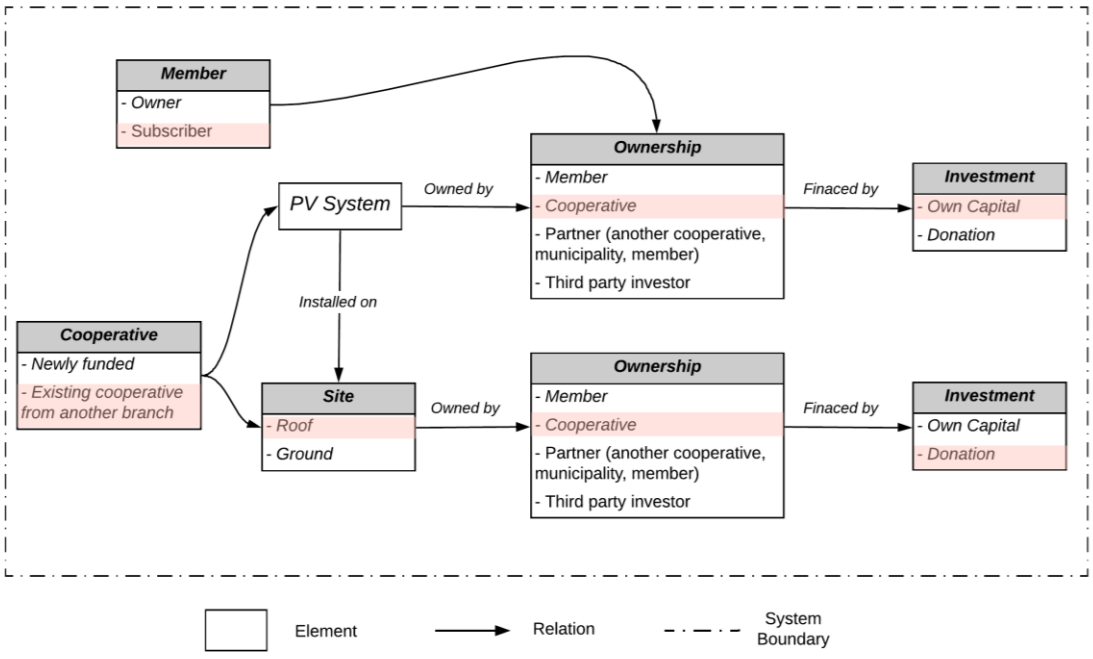


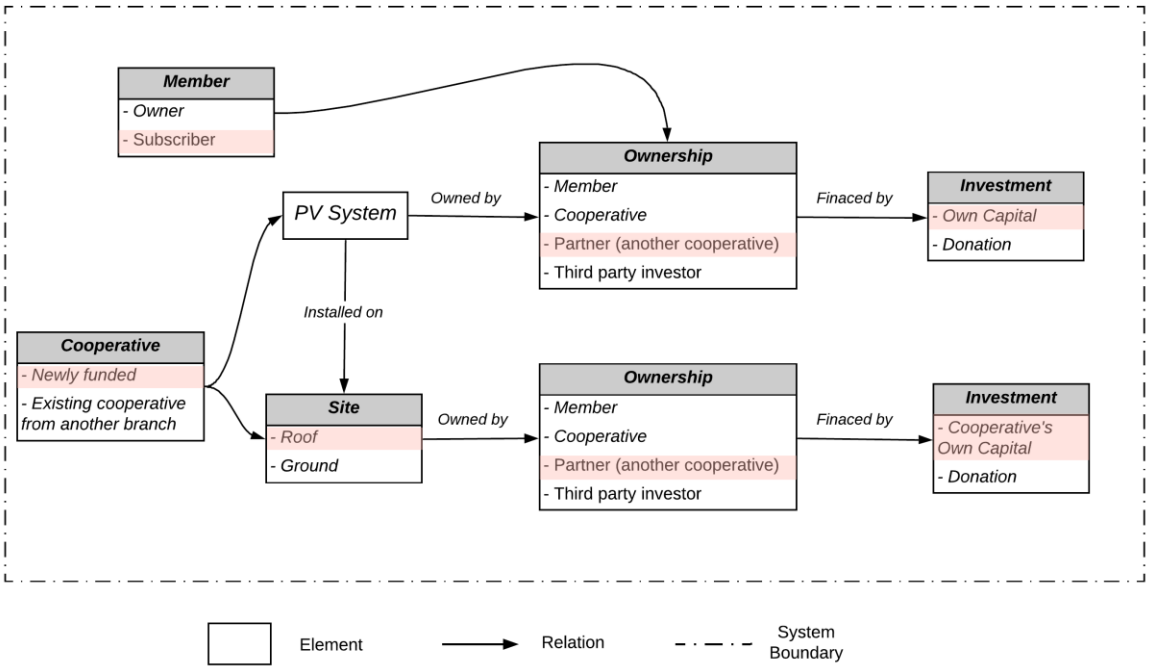
Figure 40 - Sicoob Centro Serrano ES business model arrangement applied to the systematic framework



4.3.2.5 Ciclos

Figure 41 presents Ciclos model arrangement applied to the systematic framework proposed. Despite being a newly funded cooperative, Ciclos model is structured in partnership with existing cooperatives from another branches: Sistema Sicoob ES (credit cooperative) and Coopeavi (agricultural cooperative). Members from Ciclos must be also a member from Sistema Sicoob ES. The PV System is owned by Sistema Sicoob ES who financed the PV power plant with its own capital. The PV system is installed on a roof area donated by Coopeavi at one of its buildings located at Ibiraçu-ES. The cooperative members are, therefore, only subscribers and 'rent' from the cooperative shares of the PV system.

Figure 41 - Ciclos business model arrangement applied to the systematic framework



6 DISCUSSION

Cooperatives are a very traditional business model in Europe and elsewhere. This traditional model summed with consumers' dissatisfaction and the desire to better control the origin of their energy and its price, are together the main players in the development of renewable energy in Europe. In Brazil, citizens are not yet aware that they have in their hands the power of being part of the energy transition through the cooperative movement. Therefore, the lack of knowledge and understanding about the cooperative culture is a considerable barrier this decentralized energy generation model faces in Brazil.

In addition to this, RE Coops only became possible in Brazil in 2016, when the regulation for Shared DG projects by the National Energy Agency ANEEL came into force. Thus, it is also noted that there is a lack of knowledge and understanding among the population about the possibility of energy sharing in a net-metering scheme. People are still not aware of the possibility of gathering to generate their own energy and compensate for it in their energy bill.

In Europe, on the other hand, shared renewable energy projects into the decentralized energy market are not such a new possibility. However, their development varies significantly from one country to another. In Germany and in Denmark, RE Coops are well established and played an important role to increase the share of renewable energy into these countries' energy market. In UK, Belgium and Netherlands they also have a significant participation. On the other hand, in Southern and Eastern Europe RE Coops development are much slower.

It is well documented that the rise of RE Coops in many European countries, mainly in the ones where the movement is stronger, is related to people action in times of energy crises. This is the case of Denmark and Germany. In Denmark, the oil crisis in 1973 was the main player for the shifting from fossil fuel to renewable energies. In Germany, this movement has boomed mainly after Fukushima nuclear disaster in 2011.

Another important finding is that the history of RE Coops development matches with the implementation of supportive mechanisms in most European countries presented in the literature reviewed. In particular, the FiT scheme demonstrated to be the most effective. This was clearly the trend in Denmark, Germany and UK. In these three countries, a similar pattern was also noted when the removal of the supportive schemes occurred: the funding of new RE Coops remarkably slowed down. For the existing RE Coops, many are merging in order to survive to the changes into the schemes framework. In the Germany context, the change from FiTs to Auctions that were introduced in 2017 in Germany had a noticeable impact. See Figure 1 of the thesis where between 2006 and 2012 the number of new RE cooperatives in Germany

was 581 but dropped to 280 between 2012 and 2018 which can be partly attributable to Auctions.

In Brazil, the net-metering DG scheme introduced in 2012 by the REN 482/2012 boosted the decentralized energy generation market, with particular highlight to the solar source representing currently 90% of the 2 GW of DG systems under operation. However, in 2012 Shared DG projects were not yet allowed. In 2016, ANEEL reviewed the REN 482/2012 through REN 687/2015 and allowed shared DG projects through condominia, consortia and cooperatives. Since then up to date, only 10 RE Coops were established and are currently under operation according to this work's investigation. From these, six are solar PV, two are hydro and one uses biomass as a source.

The reasons why shared solar coops are developing in more quantity than the other energy sources might be due to the fact that solar PV technology is currently the lowest cost energy generation technology, and is therefore becoming more popular in Brazil since REN 482/2012 was issued. The population is getting more in contact with the technology since more and more people are installing it in their own houses and since solar PV has opened a new employment and market niche.

Yet, the existing RE Coops under operation together sum only 0.04% of the total power capacity installed in DG projects. Therefore, despite the introduction of a regulation that allows shared DG projects in Brazil, the net-metering scheme did not have the same impact in developing RE Coops in Brazil as the FiT scheme had in countries like Denmark, Germany and the UK. Besides the lack of understanding about the cooperative model and the lack of technical knowledge about the shared net-metering scheme as already mentioned, another great barrier was also noticed: the lack of financial options for this model. In this scenario, newly founded RE Coops have a great barrier to gather initial capital and the fact that there are no suitable financing options discourages many possible initiatives.

In the Germany case, 75% of the RE Coops under the DGRV umbrella in 2018 had financed their projects with credit cooperatives. This finding can shed some light on how to foster the development of newly funded RE Coops in Brazil: through fostering the partnership of credit cooperatives with shared DG cooperatives through financing options for shared renewable energy projects into the cooperativism scope.

The shared solar coops mapped in this thesis found other strategies to turn their business model viable despite the lack of financing options for the model. Enercred and Compartsol, for example, found a solution in a third party investor. In these cooperatives models, for example, the PV system is owned by a third party investor. This investor leases the PV system to the

cooperative and the cooperative members, by its turn, ‘rent’ shares of the PV system through their membership with the cooperative. This model has been proving to be a very successful model once these two cooperatives are expanding well in size and memberships since their establishment in 2017.

Another important finding observing the Brazilian context, is the trend of existing cooperatives from different sectors to embrace the share energy generation service and adapt it to their cooperative business model, offering energy to their members through the net-metering scheme. For these cooperatives, barriers like the lack of understanding about the cooperatives model and high initial capital needed are not considerable (or non-existent) as they are for newly founded cooperatives. In their case, the main barrier is the lack of technical knowledge and understanding about the share DG regulation.

To overcome this barrier, existing cooperatives are beginning small in size and testing the shared DG model internally through compensating the energy generated in few consumer units (Sicoob Centro-Serrano ES case). Once the model and the relation with the utility is understood, these existing cooperatives are then able to design their business model to offer energy to a larger share of their members. This is the case of Ciclos, which from the learnings taken from Sicoob Centro-Serrano ES, and in partnership with Sistema Sicoob ES (of which Sicoob Centro-Serrano makes part of) and Coopeavi (an Agricultural cooperative partner), built a bigger scale PV power plant and is now offering solar energy to 86 members.

Based on the findings about the existing shared solar coops under operation, a systematic framework to present the different arrangements in which a shared solar coops model can be elaborated was developed. This systematic framework is, therefore, a ‘screenshot’ of the context of the existing shared solar coops mapped into this work. All the elements here identified and the set of options these elements can be represented as, are based on what has been observed. However, as mentioned by Sagasti (1973), a system can change and evolve over time. This system structure is a very general framework and can serve as base for future analysis and insights of all the possibility of arrangements shared solar coops can be structured. Also, this system could be a subsystem of a larger system with the objective to evaluate the techno-economical viability of a shared solar coop. Therefore, it can be very useful and helpful for further analysis in about the viability of shared solar coops in Brazil.

In addition, considering the findings about the existing shared solar coops under operation, it was observed that the web tool developed in this work only encompassed the model arrangement in which the cooperative member is the owner of the PV system. Therefore, in this case, the member has to make an initial investment to be part of a shared solar coop. COOBER

was the only cooperative, from the ones investigated in this work, which adopted this model. As already mentioned, one of the biggest barriers for the development of this type of model arrangement is the lack of financing options for newly funded shared solar coops.

It is relevant to point out that the web tool was developed based on the business models presented at the Solar Cooperatives Guide. Therefore, the web tool had the intention to empower and give guidance to citizens to learn more about shared solar coops and be able to investigate by themselves, in the early stages of a decision-making process, the viability of a shared solar coop at his/her context. Therefore, from that perspective, the web tool reached its goal. However, the findings from this work about the different business model arrangement a shared solar coop can be structured could be incorporated in future versions from the web tool.

7 CONCLUSIONS

All over the world, environmental protection and energy security are a rising concern. Therefore, energy systems are under increasing pressure and policy-makers are in search for solutions for achieving a faster adoption of renewable energy technologies. In this context, RE Coops can become a major actor in that matter providing institutional framework to involve the population with political, social and financial aspects of renewable energy development and, therefore, democratizing the energy sector.

From the international context experiences, RE Coops have been playing a major role in the energy transition movement. In Brazil, Shared DG Cooperatives were only regulated in 2016 and, therefore, are yet not well known and developed across the country. A lot of work must be done for popularizing this decentralized energy generation model, which faces barriers such as the main ones here listed: (1) lack of technical knowledge and understanding about the model; (2) lack of understanding about the cooperative culture, and (3) no financing options suitable for the modality.

In this context, this work had the objective to contribute with the understanding and development of community solar projects in Brazil based on the cooperative model. To that end, the development of this work was carried out in three parts: (1) part one refers to the development of a shared solar cooperatives web tool to assist potential adopters of the model in the early stages of the decision-making process; (2) part two refers to mapping and investigating the existing shared solar coop under operation in Brazil; (3) part three consists in the development of a framework that organizes the possible business model arrangements shared solar coops can be organized in, according to the findings investigated in the second part of this work.

In the first part of this work, a web tool for early stages of techno-economic analysis of shared solar cooperatives in the Brazilian context was elaborated. The web tool was developed as a complementary tool to the Solar Cooperatives Guide, and it was designed to be accessible to any kind of user, from individuals who might have some knowledge and understanding about solar systems and shared solar cooperatives to individuals who know little or even nothing about the subject. The web tool and the PDF of the Solar Cooperative Guide are currently available at the *Instituto IDEAL's América do Sol* platform, which can be accessed through the link: www.americadosol.org/simulador-cooperativas/.

There are many web tools available on the Internet regarding early stages PV sizing for those interested to have an idea of how many PV panels they would need to generate enough

energy to meet their energy consumption. The same is not true regarding web tools for shared solar cooperatives. To our knowledge, there is no other online simulator with that capability currently available as an open source. Therefore, the web tool presented in this thesis, on top of the Solar Cooperative Guide, can be regarded as a relevant contribution to the assessment, promotion and popularization of shared solar cooperatives in the country.

In the second part of this work, the existing shared solar cooperatives under operation were mapped and their context and business model was investigated. To that end, a webinar was organized with the representatives from the cooperatives identified. In this webinar, the cooperatives representatives had the opportunity to present their cooperatives history and context to the public. The webinar is available at Fotovoltaica-UFSC YouTube channel and up to date the video had over 1600 views. This output from this work also represents the contribution it had towards the popularization of shared solar cooperatives in Brazil.

According to the investigation, 10 Shared DG cooperatives were mapped: six shared solar coops, two shared hydro coops and two shared biomass coops. The six shared solar coops are presented in this work. Based on their context and business model, in the third part of this work, a systematic framework to present the different arrangements in which a shared solar coop model can be elaborated was developed. This systematic framework is a simple representative manner to organize all the possible business arrangements shared solar coops can be organized in, as it was observed in the second part of this thesis. This framework aimed to provide a wider understanding about the shared solar coops business model structures that are possible under the current regulation. Therefore, it can serve as base for future analysis and insights of all the possibility of arrangements shared solar coops can be structured, becoming a useful tool helpful for further analysis on the viability of shared solar coops in Brazil .

Finally, this work presents an historical summary of the early days of the development of shared solar cooperatives in Brazil, and breaks the lack of literature about this topic, while shedding light on it and contributing to the national and international discussion and, therefore, reaching its main objective to contribute with the assessment, promotion and development of community solar projects in Brazil based on the cooperative model.

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APPENDIX A

The table bellow presents the tariff prices including taxes (ICMS, PIS and COFINS) for Group A4 defined, for each State of the Brazilian Federation, used for calculating the contracted power demand parameter (PD_C) as explained in section '3.1.2 Web tool outputs'.

The tariff price for Group A4 of each State was defined by selecting the main utility of the State, taking the concession area it supplies as parameter[8]. The base month for the tariff prices was July 2018 and these values were taken from the distribution utilities webpages or by phone calls when the information was not available at the website.

State	Utility	Tariff with taxes
AC	Eletrobras AC (Eletroacre)	R$ 16.35
AL	Eletrobras AL (CEAL)	R$ 22.12
AM	Eletrobrás AM	R$ 21.92
AP	Companhia de Eletricidade do Amapá (CEA)	R$ 23.37
BA	Coelba Neoenergia	R$ 35.83
CE	Enel CE (COELCE)	R$ 21.32
DF	CEB Distribuição S.A.	R$ 15.48
ES	EDP ES	R$ 22.44
GO	ENEL GO	R$ 21.98
MA	CEMAR	R$ 22.29
MG	CEMIG	R$ 20.52
MS	Energisa MS	R$ 22.08
MT	Energisa MT	R$ 23.14
PA	Celpa	R$ 32.20
PB	Energisa PB	R$ 25.15
PE	CELPE Neoenergia	R$ 21.79
PI	Eletrobrás PI	R$ 18.30
PR	COPEL Dis.	R$ 22.23
RJ	Enel RJ	R$ 21.27
RN	Cosern Neoenergia	R$ 27.21
RO	Eletrobrás RO (Ceron)	R$ 22.29
RR	Eletrobrás RR (CERR)	R$ 12.28
RS	CEEE	R$ 30.57
SC	CELESC	R$ 18.53
SE	Sulgipe	R$ 21.00
SP	CPFL	R$ 14.08
TO	CELTINS	R$ 25.99

[8] This analysis was carried out through the Brazilian utility map available at ANEEL webpage through the link: www.aneel.gov.br/distribuicao2